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Vol. 1

Generic Environmental Impact Statement for License Renewal of Nuclear Plants

Main Report

Final Report

U.S. Nuclear Regulatory Commission

Office of Nuclear Regulatory Research

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ABSTRACT

The Nuclear Regulatory Commission (NRC) anticipates that it will receive applications for renewal of the operating licenses of a significant portion of existing nuclear power plants. This Generic Environmental Impact Statement (GEIS) examines the possible environmental impacts that could occur as a result of renewing licenses of individual nuclear power plants under 10 CFR 54. The GEIS, to the extent possible, establishes the bounds and significance of these potential impacts. The analyses in the GEIS encompass all operating light-water reactors. For each type of environmental impact the GEIS attempts to establish generic findings covering as many plants as possible. While plant and site-specific information is used in developing the generic findings, the NRC does not intend for the GEIS to be a compilation of individual plant environmental impact statements.

This GEIS has three principal objectives: (1) to provide an understanding of the types and severity of environmental impacts that may occur as a result of license renewal of nuclear power plants under 10 CFR Part 54, (2) to identify and assess those impacts that are expected to be generic to license renewal, and (3) to support a rulemaking (10 CFR Part 51) to define the number and scope of issues that need to be addressed by the applicants in plant-by-plant license renewal proceedings. To accomplish these objectives, the GEIS makes maximum use of environmental and safety documentation from original licensing proceedings and information from state and federal regulatory agencies, the nuclear utility industry, the open literature, and professional contacts.

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ACRONYMS AND ABBREVIATIONS

ADS	automatic depressurization system
AEA	Atomic Energy Act of 1954
AEC	U.S. Atomic Energy Commission
AEO	*Atomic Energy Outlook 1990*
AFUDC	allowance for funds used during construction
AGA	American Gas Association
AGR	advanced gas-cooled reactor
AIRFA	American Indian Religious Freedom Act
ALARA	as low as reasonably achievable
ALI	annual limits on intake
A/m	amps per meter
AML	acute myelogenous leukemia
ANO	Arkansas Nuclear One
ANOVA	analysis of variance
ANSI	American National Standards Institute
AP&L	Arkansas Power and Light
ASME	American Society of Mechanical Engineers
ATWS	anticipated transit without scram
BAU	business-as-usual
BEIR	Biological Effects of Ionizing Radiation
BIG/GT	biomass-gasifier/gas turbine
BRC	below regulatory concern
BSD	Burlington School District
B&W	Babcock and Wilcox
BWR	boiling-water reactor
°C	degrees centigrade (Celsius)
CAA	Clean Air Act
CAAA	Clean Air Act Amendments of 1990
CCC	California Coastal Commission
CDE	committed dose equivalent
CDF	core damage frequencies
CE	Combustion Engineering
CEDE	committed effective dose equivalent
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFC	chlorofluorocarbon
CFR	Code of Federal Regulations
Ci	curie
CML	chronic myelogenous leukemia
CMSA	consolidated metropolitan statistical area
CNS	central nervous system
CO	carbon monoxide

ConEd	Consolidated Edison
CPI	containment performance improvement
CPW	continuous polymer wire
CRAC	Consequence (of) Reactor Accident Code
CRD	control rod drive
CWA	Clean Water Act of 1977
CZMA	Coastal Zone Management Act
DAC	derived air concentrations
DAW	dry active waste
DE	dose equivalent
DECON	a nuclear plant decommissioning method
DER	Florida Department of Environmental Regulation
DFA	direct fluorescent antibody
DMBA	dimethylbenzanthracene
DNR	Florida Department of Natural Resources
DO	dissolved oxygen
DOE	U.S. Department of Energy
DOI	Department of Interior
DRBC	Delaware River Basin Commission
DREF	dose rate effectiveness factor
DRI	Data Resources Incorporated
DSC	dry shielded canister
DSM	demand-side management
E	electric field
EA	environmental assessment
EAB	exclusion area boundary
EDE	effective dose equivalent
EEC	European Economic Community
EEDB	Energy Economic Data Base
EEG	electroencephalogram
EEI	Edison Electric Institute
E-field	electric-field
EI	exposure index
EIA	Energy Information Administration
EIS	environmental impact statement
EKG	electrocardiogram
ELF	extremely low frequency
EM	electromagnetic
EMF	electromagnetic field
ENTOMB	a nuclear plant decommissioning method
EO	Executive Order
EPA	U.S. Environmental Protection Agency
EPACT	Energy Policy Act of 1992
EPCRA	Emergency Planning and and Community Right-to-Know Act

EPRI	Electric Power Research Institute
EPZ	emergency planning zone
ESA	Endangered Species Act
ESEERCO	Empire State Electric Energy Research Corporation
FDA	U.S. Food and Drug Administration
FEMA	U.S. Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FES	final environmental statement
FFCA	Federal Facilities Compliance Agreement
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FIS	federal interim storage
FONSI	finding of low significant impact
FPC	Florida Power Commission
FP&L	Florida Power & Light
FR	Federal Register
FSAR	final safety analysis report
FWCA	Fish and Wildlife Coordination Act
FWS	U.S. Fish and Wildlife Service
GBD	gas bubble disease
GCHWR	gas-cooled heavy-water-moderated reactor
GCR	gas-cooled reactor
GE	General Electric Company
GEIS	generic environmental impact statement
$g/m^2/s$	gallons per square meter per second
GNP	gross national product
GNSI	General Nuclear Systems, Inc.
GPU	General Public Utilities Corporation
GRI	Gas Research Institute
GTCC	greater-than-class-C
GW	gigawatt
GWd	gigawatt-days
HC	hydrocarbons
HL&P	Houston Lighting and Power Company
HLW	high-level radioactive waste
HP	health physics
HPOF	high-pressure oil-filled
HRS	hazard ranking system
HSM	horizontal storage module
HSWA	Hazardous and Solid Waste Amendments of 1984
HWR	heavy-water reactor
ICRP	International Commission on Radiological Protection
IGSCC	intergranular stress-cracking corrosion

IMP	intramembranous protein particle
INIRC	International Non-Ionizing Radiation Protection Association
INPO	Institute of Nuclear Power Operations
IOR	ion exchange resin
IPA	integrated plant assessment
IPE	individual plant examination
IRPA	International Radiation Protection Association
ISFSI	independent spent-fuel storage installation
ISI	in-service inspection
ISTM	inspection, surveillance, testing, and maintenance
kV	kilovolt
kV/m	kilovolts per meter
kW	kilowatt
kWh	kilowatt-hour
LD	Legionnaires' disease
LDR	land disposal restrictions
LDSD	Lower Dauphin School District
LET	linear energy transfer
LLRWPAA	Low-Level Radioactive Waste Policy Amendments Act of 1985
LLW	low-level radioactive waste
LMFBR	liquid-metal first breeder reactor
LOCA	loss-of-coolant accident
LOS	level of service
LPGS	Liquid Pathway Generic Study
LPZ	low population zone
LWR	light-water reactor
m	meter
mA	milliamperes
MACCS	MELCOR Accident Consequence Code System
MANOVA	multivariate analyses of covariance
MAP	Methodologies Applications Program
MASD	Middletown Area School District
mCi	milliCurie
MCLG	maximum contaminant goal levels
MDNR	Maryland Department of Natural Resources
MFD	magnetic flux density
mG	milligauss
mM	millimole
MMPA	Marine Mammals Protection Act
MPC	maximum permissible concentration
MPRSA	Marine Protection, Research, and Sanctuaries Act
MPOB	maximum permissible organ burden
MRC	Marine Review Committee

mrem	millirem
MRS	monitored retrievable storage
m^3/s	cubic meters per second
MSA	metropolitan statistical area
MSW	municipal solid waste
mT	millitesla
MTIHM	metric tons of initial heavy metal
MTU	metric tons of uranium
mV/m	millivolts per meter
MW	megawatt
MWd	megawatt-days
MW(e)	megawatt (electrical)
MW(t)	megawatt (thermal)
MYL	middle year of license
MYR	middle year of relicense
µg/g	micrograms per gram
µm	micron
NAA	nonattainment area
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Sciences
NBS	National Bureau of Standards (now NIST)
NCA	National Coal Association
NCRP	National Council on Radiation Protection and Measurements
NEC	normalized expected cost
NEPA	National Environmental Policy Act of 1969
NERC	North American Electric Reliability Council
NESC	National Electric Safety Code
NESHAP	National Emission Standards for Hazardous Air Pollutants
NGS	nuclear generating station
NHPA	National Historic Preservation Act of 1966
NIEHS	National Institute of Environmental Health Sciences
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NLF	normalized latent facility
NMFS	National Marine Fisheries Service
NMR	nuclear magnetic resonance
NO_x	nitrogen oxide(s)
NPA	National Planning Association
NPDES	National Pollutant Discharge Elimination System
NPP	nuclear power plant
NRC	U.S. Nuclear Regulatory Commission
NSPS	new source performance standards
NSSS	nuclear steam supply system
NTD	normalized total dose
NUHOMS	Nutech Horizontal Modular System

NUMARC	Nuclear Utilities Management and Resources Council
NUREG	an NRC reports category
NUS	NUS Corporation
NWPA	Nuclear Waste Policy Act of 1982
NYSDEC	New York State Department of Environmental Conservation
ODC	ornithine decarboxylase
OHMS	hydroxy melatonin sulfate
OL	operating license
O&M	operation and maintenance
ONS	Oconee Nuclear Station
OPEC	Organization of Petroleum Exporting Countries
OR	odds ratio
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OTA	Office of Technology Assessment
OTEC	ocean thermal energy conversion
PAME	primary amoebic meningoencephalitis
PASNY	Power Authority for the State of New York
PCB	polychlorinated biphenyl
PG&E	Pacific Gas and Electric
pH	hydrogen-ion concentration
PHWR	pressurized heavy-water reactor
PLEX	plant life extension
PM	particulate matter
PMR	proportionate mortality ratios
ppm	parts per million
PSD	prevention of significant deterioration
PRA	probabilistic risk assessment
PTH	parathyroid hormone
PURPA	Public Utility Regulatory Policies Act of 1978
PURTA	Public Utilities Realty Tax Assessment of 1970
PV	solar photovoltaic
PWR	pressurized-water reactor
QA	quality assurance
RBE	relative biological effectiveness
RCB	reactor containment building
RCRA	Resource Conservation and Recovery Act of 1976
RD&D	1. research, design, and development 2. research, development, and demonstration
RERF	Radiation Effects Research Council
RET	renewable energy technology
RF	radio frequency

RHR	residual heat removal
RIMS	Regional Industrial Multiplier System
rms	root mean square
ROW	right(s) of way
RPV	reactor pressure vessel
RRY	reference reactor year
RSD	Russellville (Ark.) School District
RSS	Reactor Safety Study
RV	recreational vehicle
RY	reactor-year
SAFSTOR	a nuclear plant decommissioning method
SAMDA	severe accident mitigation design alternative
SAND	Data Resource Incorporated's detailed electricity sector model
SAND NUPLEX	SAND generating capacity projections
SAR	safety analysis report
SARA	Superfund Amendments and Reauthorization Act
SCE	Southern California Edison
SCM	Surface Compartment Model
SDG&E	San Diego Gas & Electric Company
SDWA	Safe Drinking Water Act
SEA	Science and Engineering Associates, Inc.
SER	safety evaluation report
SERI	Solar Energy Research Institute
SEV	state equalized value
SF	spent fuel
SHPO	state historic preservation office
SI	International System
SIR	standardized incidence ratio
SLB	shallow land burial
SMR	standardized mortality ratio
SMITTR	surveillance, on-line monitoring, inspections, testing, trending, and recordkeeping
SMSA	standard metropolitan statistical area
SO_2	sulfur dioxide
SOK	San Onofre kelp bed
SONGS	San Onofre Nuclear Generating Station
SRBC	Susquehanna River Basin Commission
SSC	systems, structures, and components
t	metric tons
TDE	total dose equivalent
TDS	total dissolved solids
TEDE	total effective dose equivalent
TMI	Three Mile Island (nuclear plant)
TRU	transuranic

TSCA	Toxic Substances Control Act
TVA	Tennessee Valley Authority
UCB	upper confidence bound
UFC	uranium fuel cycle
UHV	ultra-high voltage
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USD	Unified School District
USGS	U.S. Geological Survey
USI	unresolved safety issue
VDT	video display terminal
VR	volume reduction
VRF	volume reduction factor
W	watt
WCGS	Wolf Creek Generating Station
WHO	World Health Organization
WNP-2	Washington Nuclear Project
WTE®	Whole Tree Energy®

EXECUTIVE SUMMARY

This Generic Environmental Impact Statement (GEIS) for license renewal of nuclear power plants was undertaken to (1) assess the environmental impacts that could be associated with nuclear power plant license renewal and an additional 20 years of operation of individual plants and (2) provide the technical basis for an amendment to the Nuclear Regulatory Commission's (NRC's) regulations, 10 CFR Part 51, "Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions," with regard to the renewal of nuclear power plant operating licenses. The rule amendment and this document were initiated to enhance the efficiency of the license renewal process by documenting in this GEIS and codifying in the Commission's regulations the environmental impacts that are well understood.

Under NRC's environmental protection regulations in 10 CFR Part 51, renewal of a nuclear power plant operating license is identified as a major federal action significantly affecting the quality of the human environment, and thus an environmental impact statement (EIS) is required for a plant license renewal review. The EIS requirements for a plant-specific license renewal review are specified in 10 CFR Part 51. Operating licenses may be renewed for up to 20 years beyond the 40-year term of the initial license. License renewal applicants perform evaluations and assessments of their facility to provide sufficient information for the NRC to determine whether continued operation of the facility during the renewal term will endanger public health and safety or the environment. The assessments also help to determine what activities and modifications are necessary at the time of license renewal and throughout the renewal term to ensure continued safe operation of the plant. Most utilities are expected to begin preparation for license renewal about 10 to 20 years before expiration of their original operating licenses. For the analysis in this GEIS, the staff anticipates that plant refurbishment undertaken specifically for license renewal would probably be completed during normal plant outage cycles, beginning 8 years before the original license expires, and during one longer outage, if a major refurbishment item is involved.

The Commission will act on an application for license renewal submitted by a licensee of an operating nuclear power plant. Although a licensee must have a renewed license to operate a plant beyond the term of the existing operating license, the possession of that license is just one of a number of conditions that must be met for the licensee to continue plant operation during the term of the renewed license. If the Commission grants a license renewal for a plant, state regulatory agencies and the owners of the plant would ultimately decide whether the plant will continue to operate based on factors such as need for power or other matters within the state's jurisdiction or the purview of the owners. Economic considerations will play a primary role in the decision made by state regulatory agencies and the owners of the plant. Thus, for license renewal reviews, the Commission has adopted the following definition of purpose and need:

> The purpose and need for the proposed action (renewal of an operating license) is to provide an option that allows for power generation capability beyond the term of a current nuclear power plant operating license to meet future system generating needs, as such needs may be determined by State, utility, and, where authorized, Federal (other than NRC) decisionmakers.

In Chapter 8, the Commission considers the environmental consequences of the no-action alternative (i.e., denying a license renewal application) and the environmental consequences of the various alternatives for replacing lost generating capacity that would be available to a utility and other responsible energy planners. No conclusions are made in this document about the relative environmental consequences of license renewal or the construction and operation of alternative facilities for generating electric energy. The information in the GEIS is available for use by the NRC and the licensee in performing the site-specific analysis of alternatives. This information will be updated periodically, as appropriate.

The GEIS summarizes the findings of a systematic inquiry into the potential environmental consequences of renewing the licenses of and operating individual nuclear power plants for an additional 20 years. The inquiry identifies the attributes of the nuclear power plants, such as major features and plant systems, and the ways the plants can affect the environment. The inquiry also identifies the possible refurbishment activities and modifications to maintenance and operating procedures that might be undertaken given the requirements of the safety review as provided for in the Commission's regulations in 10 CFR Part 54, or given a utility's motivation to increase economic efficiency. Two scenarios were developed to identify possible initiators of environmental impacts from the possible set of refurbishment activities and continuation of plant operation during the renewal term. One scenario was developed as a typical but somewhat conservative scenario for license renewal, intended to be representative of the type of program that many licensees seeking license renewal might implement. The other scenario is highly conservative, encompassing considerably more activities, and is intended to characterize a reasonable upper bound of impact initiators that might result from license renewal.

The general analytical approach to each environmental issue is to (1) describe the activity that affects the environment, (2) identify the population or resource that is affected, (3) assess the nature and magnitude of the impact on the affected population or resource, (4) characterize the significance of the effect for both beneficial and adverse effects, (5) determine whether the results of the analysis apply to all plants, and (6) consider whether additional mitigation measures would be warranted for impacts that would have the same significance level for all plants.

A standard of significance was established for assessing environmental issues; and, because significance and severity of an impact can vary with the setting of a proposed action, both "context" and "intensity" as defined in the Council on Environmental Quality regulations (40 CFR 1508.27) were considered. With these standards as a basis, each impact was assigned to one of three significance levels:

Small: For the issue, environmental effects are not detectable or are so minor that they will neither destabilize nor noticeably alter any important attribute of the resource. For the purposes of assessing radiological impacts, the Commission has concluded that those impacts that do not exceed permissible levels in the Commission's regulations are considered small.

Moderate: For the issue, environmental effects are sufficient to alter noticeably but not to destabilize important attributes of the resource.

Large: For the issue, environmental effects are clearly noticeable and are sufficient to destabilize important attributes of the resource.

The discussion of each environmental issue in the GEIS includes an explanation of how the significance category was determined. For issues in which probability of occurrence is a key consideration (i.e., accident consequences), the probability of occurrence is factored into the determination of significance. In determining the significance levels, it is assumed that ongoing mitigation measures would continue and that mitigation measures employed during plant construction would be employed during refurbishment, as appropriate. The potential benefits of additional mitigation measures are not considered in determining significance levels.

In addition to determining the significance of environmental impacts associated with an issue for that issue, a determination was made whether the analysis in the GEIS could be applied to all plants and whether additional mitigation measures would be warranted. The categories to which an issue may be assigned follow.

Category 1: For the issue, the analysis reported in the GEIS has shown the following:

(1) the environmental impacts associated with the issue have been determined to apply either to all plants or, for some issues, to plants having a specific type of cooling system or other specified plant or site characteristics;
(2) a single significance level (i.e., small, moderate, or large) has been assigned to the impacts (except for collective off-site radiological impacts from the fuel cycle and from high-level-waste and spent-fuel disposal); and
(3) mitigation of adverse impacts associated with the issue has been considered in the analysis, and it has been determined that additional plant-specific mitigation measures are likely not to be sufficiently beneficial to warrant implementation.

Category 2: For the issue, the analysis reported in the GEIS has shown that one or more of the criteria of Category 1 cannot be met, and therefore, additional plant-specific review is required.

This final GEIS assesses 92 environmental issues. Sixty-eight of these issues are found to be Category 1 and are identified in 10 CFR Part 51 as not requiring additional plant-specific analysis. Guidance on the analyses required for each of the other 24 issues is provided in 10 CFR Part 51. A summary of the findings for the 92 environmental issues is provided in Table 9.1 of this GEIS and summarized in narrative below.

IMPACTS OF REFURBISHMENT

- On-site land use impacts are expected to be of small significance at all sites. Temporary disturbance of land may be mitigated by restoration to its original condition after refurbishment. This is a Category 1 issue.

- Nuclear power plant atmospheric emissions would either remain constant during refurbishment or decrease if the plant were partially or totally shut down. Small quantities of fugitive dust and gaseous exhaust emissions from motorized equipment operation during construction and refurbishment would temporarily increase ambient concentrations of particulate matter and gaseous pollutants in the vicinity of the activity but would not be expected to measurably affect ambient concentrations of regulated pollutants off-site. Additional exhaust emissions from the vehicles of up to 2300 personnel could be cause for some concern in geographical areas of poor or marginal air quality, but a general conclusion about the significance of the potential impact cannot be drawn without considering the compliance status of each site and the numbers of workers to be employed during the outage. This is a Category 2 issue.

- Proven erosion control measures such as best management practices are expected to be implemented at all plants and to minimize impacts to local water quality from runoff in disturbed areas. Consequently, impacts of refurbishment on surface water quality are expected to be of small significance at all plants. Because the effects of refurbishment are considered to be of small significance and potential mitigation measures are likely to be costly, the staff does not consider implementation of mitigation measures beyond best management practices to be warranted. This is a Category 1 issue.

- Additional water requirements during construction and refurbishment would be a small fraction of cooling water requirements of the operating power plant. If the plant were partially or totally shut down, cooling water use would decline. Water use during refurbishment is expected to have impacts of small significance on the local water supply. The only potential mitigation for any increase in water consumption would be to acquire the additional water from some other source. However, because this approach would provide very little, if any, environmental benefit and would be costly, the staff does not consider implementation of additional mitigation to be warranted. This is a Category 1 issue.

- Deep excavations and site dewatering would not be required during refurbishment. Consequently, the impacts of refurbishment on groundwater would be of small significance at all sites. No additional mitigation measures would be warranted because there would be no adverse impacts to mitigate. This is a Category 1 issue.

- Effluent discharges from the cooling system of a nuclear power plant would either remain constant during refurbishment or decrease if the plant were partially or totally shut down. Effects of changes in water withdrawals and discharges during refurbishment would be of small significance. No additional mitigation measures beyond those implemented during the current license term would be warranted because there would be no adverse impacts to mitigate. This is a Category 1 issue.

- The small on-site change in land use associated with refurbishment and construction could disturb or eliminate a small area of terrestrial habitat [up to 4 ha (10 acres)]. The significance of the loss of habitat depends on the importance of the plant or animal species that are displaced and on the availability of nearby replacement habitat. Impacts would be potentially significant only if they involved wetlands, staging or resting areas for large numbers of waterfowl, rookeries, restricted wintering areas for wildlife, communal roost sites, strutting or breeding grounds for gallinaceous birds, or rare plant community types. Because ecological impacts cannot be determined without considering site- and project-specific details, the potential significance of those impacts cannot be determined generically. This is a Category 2 issue.

- Because of refurbishment-related population increases, impacts on housing could be of moderate or large significance at sites located in rural and remote areas, at sites located in areas that have experienced extremely slow population growth (and thus slow or no growth in housing), or where growth control measures that limit housing development are in existence or have recently been lifted. This is a Category 2 issue.

- Tax impacts, which involve small to moderate increases in the direct and indirect tax revenues paid to local jurisdictions, are considered beneficial in all cases.

- In the area of public services, in-migrating workers could induce impacts of small to large significance to education, with the larger impacts expected to occur in sparsely populated areas. Impacts of small to moderate significance may occur to public utilities at some sites. Transportation impacts could be of large significance at some sites. These socioeconomic issues are Category 2.

- The impacts of refurbishment on other public services (public safety, social services, and tourism and recreation) are expected to be of small significance at all sites. No additional mitigation measures beyond those implemented during the current license term would be warranted because mitigation would be costly and the benefits would be small. These are Category 1 issues.

- In-migrating workers could induce impacts of small to moderate significance to off-site land use. The larger impacts are expected to occur in sparsely populated areas. This is a Category 2 issue.

- Based on the findings at the case study sites, refurbishment-related economic effects would range from small benefits to moderate benefits at all nuclear power plant sites. No adverse effects to economic structure would result from refurbishment-related employment.

- Site-specific identification of historic and archaeological resources and determination of impacts to them must occur during the consultation process with the State Historic Preservation Office (SHPO) as mandated by the National Historic Preservation Act. Impacts to historic resources could be large if the SHPO determines that significant historic resources would be disturbed or their historic character would be altered by plant refurbishment activities. The significance of potential impacts to historic and archaeological resources cannot be determined generically. This is a Category 2 issue.

- The impact on aesthetic resources is found to be of small significance at all sites. Because there will be no readily noticeable visual intrusion, consideration of mitigation is not warranted. This is a Category 1 issue.

- Radiation impacts to members of the public are considered to be of small significance because public exposures are within regulatory limits. Also, the estimated cancer risk to the average member of the public is much less than 1×10^{-6}. Because current mitigation practices have resulted in declining public radiation doses for nearly two decades, additional mitigation is not warranted. The impact on human health is a Category 1 issue.

- Occupational radiation exposure during refurbishment meets the standard of small significance. Because the as-low-as-reasonably-achievable (ALARA) program continues to reduce occupational doses, no additional mitigation program is warranted. This is a Category 1 issue.

- The significance of potential impacts to threatened and endangered species cannot be determined generically because compliance with the Endangered Species Act cannot be assessed without site-specific consideration of potential effects on threatened and endangered species. This is a Category 2 issue.

IMPACTS OF OPERATION

- It is not possible to reach a conclusion about the significance of potential impacts to threatened and endangered species at this time because (1) the significance of impacts on such species cannot be assessed without site- and project-specific information that will not be available until the time of license renewal and (2) additional species that are threatened with extinction and that may be adversely affected by plant operations may be identified between the present and the time of license renewal. This is a Category 2 issue.

- The staff examined nine aspects of water quality that might be affected by power plant operations: current patterns at intake and discharge structures, salinity gradients, temperature effects on sediment transport, altered thermal stratification of lakes, scouring from discharged cooling water, eutrophication, discharge of biocides, discharge of other chemical contaminants (e.g., metals), and discharge of sanitary wastes. Open-cycle cooling systems are more likely than other cooling systems to have such effects because they withdraw and discharge very large volumes of water; however, the impacts for each of these effects were found to be of small significance for all plants, regardless of cooling system type. For each type of impact, the staff considered potential mitigation measures but found that none were warranted because they would be costly and would have very small environmental benefits. These are Category 1 issues.

- The staff found no potential for water use conflicts or riparian plant and animal community impacts of moderate or large significance for plants with open-cycle cooling systems because they are used on large water bodies. Because the potential mitigation measures are costly and because the potential benefits are small, the staff does not consider mitigation to be warranted. These are Category 1 issues.

- The staff found that water use conflicts and the effects of consumptive water use on in-stream aquatic and riparian terrestrial communities could be of moderate significance at some plants that employ cooling-tower or cooling-pond systems because they are often located near smaller water bodies. For plants with these cooling systems, these are Category 2 issues.

- The staff examined 12 potential effects that nuclear power plant cooling systems may have on aquatic ecology: (1) impingement of fish; (2) entrainment of fish (early life stages); (3) entrainment of phytoplankton and zooplankton; (4) thermal discharge effects; (5) cold shock; (6) thermal plume barriers to migrating fish; (7) premature emergence of aquatic insects; (8) stimulation of nuisance organisms; (9) losses from predation, parasitism, and disease among organisms exposed to sublethal stresses; (10) gas supersaturation; (11) low dissolved oxygen in the discharge; and (12) accumulation of contaminants in sediments or biota. Except for three potential impacts (entrainment of fish and shellfish, impingement of fish and shellfish, and thermal discharge effects), each of these was found to be of small significance at all plants. Because mitigation would be costly and provide little environmental benefit, no additional mitigation measures beyond those implemented during the current license term are warranted. These are Category 1 issues. The other three impacts would be of small significance at all plants employing cooling-tower cooling systems. Because mitigation would be costly and provide little environmental benefit, no additional mitigation measures beyond those implemented during the current license term are warranted. For those plants, these are Category 1 issues. However, the impacts may be of greater significance at some plants employing open-cycle or cooling-pond systems; and these are Category 2 issues for those plants.

- The staff found that groundwater use of less than 0.0063 m^3/s (100 gal/min) is of small significance because the cone of depression will not extend beyond the site boundary. Conflicts might result from several types of groundwater use by nuclear power plants. If groundwater conflicts arose, they could be resolvable by deepening the affected wells, but no such mitigation is warranted because sites producing less than 0.0063 m^3/s (100 gal/min) would not have a cone of depression that extends beyond the site boundary. This is a Category 1 issue. Plants that extract more than 0.0063 m^3/s (100 gal/min), including plants using Ranney wells, may have groundwater use conflicts of moderate or large significance. Groundwater use is a Category 2 issue for such plants.

- Cooling system makeup water consumption may cause groundwater use conflicts. During times of low flow, surface water withdrawals for cooling tower makeup from small rivers can reduce groundwater recharge. Because the significance of such impacts cannot be determined generically, this is a Category 2 issue.

- Groundwater withdrawals could cause adverse effects on groundwater quality by inducing intrusion of lower-quality groundwater into the aquifer. The staff found that the significance of these potential impacts is of small significance in all cases. Because all plants except Grand Gulf use relatively small quantities of groundwaters and surface water intrusion at Grand Gulf would not preclude current water uses, the staff found that mitigation was not warranted. This is a Category 1 issue.

- Cooling ponds leak an undetermined quantity of water through the pond bottom. Because the water in cooling ponds is elevated in salts and metals, such leakage may contaminate groundwater. The staff found that groundwater quality impacts of ponds that are located in salt marshes would be of small significance in all cases because salt marshes already have poor water quality. This is a Category 1 issue. Cooling ponds that are not located in salt marshes may have groundwater quality impacts of small, moderate, or large significance. This is a Category 2 issue.

- Small amounts of ozone and substantially smaller amounts of oxides of nitrogen are produced by transmission lines; however, ozone concentrations generated by transmission lines are too low to cause any significant effects. The minute amounts of oxides of nitrogen produced are also insignificant. Thus, air quality impacts associated with the operational transmission lines during the renewal term are expected to be of small significance at all sites. Potential mitigation measures would be very costly and are not warranted. This is a Category 1 issue.

- The potential impact of cooling tower drift on crops and ornamental vegetation arising from operations during the license renewal term is expected to be of small significance for all nuclear plants. No mitigation measures beyond those implemented during the current license term are warranted because there have been no measurable effects on crops or ornamental vegetation from cooling tower drift. This is a Category 1 issue.

- The impact of cooling towers on natural plant communities should continue not to result in measurable degradation as a result of license renewal and will therefore be of small significance. Because the impacts of cooling tower drift on native plants are expected to be small and because potential mitigation measures would be costly, no mitigation measures beyond those during the current term license would be warranted. This is a Category 1 issue.

- Bird mortality from collision with power lines associated with nuclear plants is of small significance for all plants because bird mortality is expected to remain a small fraction of total collision mortality associated with all types of man-made objects. Because the numbers of birds killed from collision with cooling towers are not large enough to affect local population stability or species function within the ecosystem, consideration of further mitigation is not warranted. Both bird collision with power lines and bird collision with cooling towers are Category 1 issues.

- Because no threat to the stability of local wildlife populations or vegetation communities is found for any cooling pond, the impacts are found to be of small significance. Potential mitigation measures would include excluding wildlife (e.g., birds) from contaminated ponds, converting to a dry cooling system, or reducing plant output during fogging or icing conditions. The impacts are found to be so minor that consideration of additional mitigation measures is not warranted. These effects of cooling ponds are so minor and so localized that cumulative impacts are not a concern. This is a Category 1 issue.

- Maintaining power-line right-of-ways (ROWs) causes fluctuations in wildlife populations, but the long-term effects are of small significance. The staff found that bird collisions with transmission lines are of small significance. Also, transmission line maintenance and repair would have impacts of only small significance on floodplains and wetlands. In each case, the staff found that potential mitigation measures beyond those implemented during the current license term would be costly and provide little environmental benefit, and thus are not warranted. These are Category 1 issues.

- Wildlife, livestock, and plants residing in power-line electromagnetic fields (EMF) apparently grow, survive, and reproduce as well as expected in the absence of EMF. The potential impact of EMF on terrestrial resources during the license renewal term is considered to be of small significance for all plants. Because the impact is of small significance and because mitigation measures could create additional environmental impacts and would be costly, no mitigation measures beyond those implemented during the current term license would be warranted. This is a Category 1 issue.

- Land use restrictions are necessary within transmission-line ROWs. The staff found these impacts to be of small significance at all sites. Mitigation beyond that imposed when ROWs were established might include relocating the transmission line. The staff concluded that such mitigation would not be warranted because it would be very costly and provide little environmental benefit. This is a Category 1 issue.

- During the license renewal term, the radiation dose commitment to the total worker population is projected to increase less than 5 percent at nuclear power plants under the typical scenario and less than 8 percent at any plant under the conservative scenario. The present operating experience results in about 30,000 person-rem/year for all licensed plants combined. After the period of refurbishment, routine operating conditions are expected to result in 32,000 person-rem/year for all plants combined. The risk associated with occupational radiation exposures after license renewal is expected to be of small significance at all plants. No mitigation measures beyond those implemented during the current license term are warranted because the existing ALARA process continues to be effective in reducing radiation doses. This is a Category 1 issue.

- Among the 150 million people who live within 50 miles of a U.S. nuclear power plant, about 30 million will die of spontaneous cancer unrelated to radiation exposure from nuclear power plants. This number is compared with approximately 5 calculated fatalities associated with potential nuclear-power-plant-induced cancer. The estimated annual cancer risk to the average individual is less than 1×10^{-6}. Public exposure to radiation during the license renewal term is of small significance at all sites, and no mitigation measures beyond those implemented during the current license term are warranted because current mitigation practices have resulted in declining public radiation doses and are expected to continue to do so. This is a Category 1 issue.

- The significance of potential for electrical shock from charges induced by transmission lines that may occur during the license renewal term cannot be evaluated generically because no National Electric Safety Code (NESC) review was performed for some of the earlier licensed plants. For those that underwent an NESC review, a change in the transmission line voltage may have been made since issuance of the initial operating license, or changes in land use since issuance of the original license could have occurred. This is a Category 2 issue.

- There is no consensus among scientists on whether 60-Hz EMF have a measurable human health impact. Because of inconclusive scientific evidence, the chronic effects of EMF would be not be categorized as either a Category 1 or 2 issue. If NRC finds that a consensus has been reached that there are adverse health effects, all license renewal applicants will have to address EMF effects in the license renewal process.

- Occupational health questions related to thermophilic organisms like *Legionella* are currently resolved using proven industrial hygiene principles to minimize worker exposures to these organisms in mists of cooling towers. Adverse occupational health effects associated with microorganisms are expected to be of small significance at all sites. Aside from continued application of accepted industrial hygiene procedures, no additional mitigation measures beyond those implemented during the current license term are warranted. This is a Category 1 issue.

- Thermophilic organisms may or may not be influenced by operation of nuclear power plants. The issue is largely unstudied. However, NRC recognizes a potential health problem stemming from heated effluents. Public health questions require additional consideration for the 25 plants using cooling ponds, lakes, canals, or small rivers because the operation of these plants may significantly enhance the presence of thermophilic organisms. The data for these sites are not now at hand, and it is impossible with current knowledge to predict the level of thermophilic organism enhancement at any given site. Thus, the impacts are not known and are site specific. Therefore, the magnitude of the potential public health impacts associated with thermal enhancement of *N. fowleri* cannot be determined generically. This is a Category 2 issue.

- The principal noise sources at power plants (cooling towers and transformers) do not change appreciably during the aging process. Because noise impacts have been found to be small and generally not noticed by the public, noise impacts are expected to be of small significance at all sites. Because noise reduction methods would be costly, and given that there have been few complaints, no additional mitigation measures are warranted for license renewal. This is a Category 1 issue.

- The staff examined socioeconomic effects of nuclear power plant operations during a license renewal period. Five of these would be of small significance at all sites: education, public safety, social services, recreation and tourism, and aesthetics. Because mitigation measures beyond those implemented during the current license term are costly and would offer little benefit, no additional mitigation measures are warranted. These are Category 1 issues. Four of the socioeconomic effects were found to have moderate or large significance at some sites: housing, transportation, public utilities (especially water supply), and off-site land use. These are Category 2 issues. In addition, the statute (National Historic Preservation Act) requires consultation; thus historic and archaeological resources are Category 2 issues.

ACCIDENTS

- The environmental impacts of postulated accidents were evaluated for the license renewal period in GEIS Chapter 5. All plants have had a previous evaluation of the environmental impacts of design-basis accidents. In addition, the licensee will be required to maintain acceptable design and performance criteria throughout the renewal period. Therefore, the calculated releases from design-basis accidents would not be expected to change. Since the consequences of these events are evaluated for the hypothetical maximally exposed individual at the time of licensing, changes in the plant environment will not affect these evaluations. Therefore, the staff concludes that the environmental impacts of design-basis accidents are of small significance for all plants. Because the environmental impacts of design basis accidents are of small significance and because additional measures to reduce such impacts would be costly, the staff concludes that no mitigation measures beyond those implemented during the current term license would be warranted. This is a Category 1 issue.

- The staff concluded that the generic analysis of severe accidents applies to all plants and that the probability-weighted consequences of atmospheric releases, fallout onto open bodies of water, releases to groundwater, and societal and economic impacts of severe accidents are of small significance for all plants. However, not all plants have performed a site-specific analysis of measures that could mitigate severe accidents. Consequently, severe accidents are a Category 2 issue for plants that have not performed a site-specific consideration of severe accident mitigation and submitted that analysis for Commission review.

URANIUM FUEL CYCLE AND MANAGEMENT OF WASTE

- The radiological and nonradiological environmental impacts of the uranium fuel cycle have been reviewed. The review included a discussion of the values presented in Table S-3, an assessment of the release and impact of ^{222}Rn and of ^{99}Tc, and a review of the regulatory standards and experience of fuel cycle facilities. For the purpose of assessing the radiological impacts of license renewal, the Commission uses the standard that the impacts are of small significance if doses and releases do not exceed permissible levels in the Commission's regulation. Given the available information regarding the compliance of fuel-cycle facilities with applicable regulatory requirements, the Commission has concluded the actual impacts of the fuel cycle are at or below existing regulatory limits. Accordingly, the Commission concludes that individual radiological impacts of the fuel cycle (other than the disposal of spent fuel and high-level waste) are small. With respect to the nonradiological impact of the uranium fuel cycle, data concerning land requirements, water requirements, the use of fossil fuel, gaseous effluent, liquid effluent, and tailings solutions and solids, all listed in Table S-3, have been reviewed to determine the significance of the environmental impacts of a power reactor operating an additional 20 years. The nonradiological environmental impacts attributable to the relicensing of an individual power reactor are found to be of small significance. The individual radiological and the nonradiological effects of the uranium fuel cycle are Category 1 issues.

The radiological impacts of the uranium fuel cycle on human populations over time (collective effects) have been considered within the framework of Table S-3. The 100-year environmental dose commitment to the U.S. population from the fuel cycle, high-level-waste and spent-fuel disposal excepted, is calculated to be about 14,800 man-rem, or 12 cancer fatalities, for each additional 20-year power-reactor operating term. Much of this, especially the contribution of radon releases from mines and tailing piles, consists of tiny doses summed over large populations. This same dose calculation can theoretically be extended to include many tiny doses over additional thousands of years as well as doses outside the United States. The result of such a calculation would be thousands of cancer fatalities from the fuel cycle, but this result assumes that even tiny doses have some statistical adverse health effect that will not ever be mitigated (for example, no cancer cure in the next thousand years) and that these dose projections over thousands of years are meaningful. However, these assumptions are questionable. In particular, science cannot rule out the possibility that there will be no cancer fatalities from these tiny doses. For perspective, the doses are very small fractions of regulatory limits and even smaller fractions of natural background exposure to the same populations. No standards exist that can be used to reach a conclusion as to the significance of the magnitude of the collective radiological effects. Nevertheless, some judgment as to the regulatory NEPA implication of this issue should be made, and it makes no sense to repeat the same judgment in every case. The Commission concludes that these impacts are acceptable in that these impacts would not be sufficiently large to require the NEPA conclusion, for any plant, that the option of extended operation under 10 CFR Part 54 should be eliminated. Accordingly, while the Commission has not assigned a single level of significance for the collective effects of the fuel cycle, this issue is considered Category 1.

There are no current regulatory limits for off-site releases of radionuclides from high-level-waste and spent-fuel disposal at the current candidate repository site at Yucca Mountain. If we assume that limits are developed along the lines of the 1995 National Academy of Sciences report and that, in accordance with the Commission's Waste Confidence Decision, a repository can and likely will be developed at some site that will comply with such limits, peak doses to virtually all individuals will be 100 mrem/year or less. However, while the Commission has reasonable confidence that these assumptions will prove correct, there is considerable uncertainty since the limits are yet to be developed, no repository application has been completed or reviewed, and uncertainty is inherent in the models used to evaluate possible pathways to the human environment. The National Academy report indicates that 100 mrem/year should be considered as a starting point for limits for individual doses but notes that some measure of consensus exists among national and international bodies that the limits should be a fraction of the 100 mrem/year. The lifetime individual risk from 100-mrem/year dose limit is about 3×10^{-3}. Doses to populations from disposal cannot now (or possibly ever) be estimated without very great uncertainty. Estimating cumulative doses to populations over thousands of years is more problematic. The likelihood and consequences of events that could seriously compromise the integrity of a deep geologic repository have been evaluated by the Department of Energy (DOE) and the NRC, and other federal agencies have expended considerable effort to develop models for the design and for the licensing of a high-level-waste repository, especially for the candidate repository at Yucca Mountain. More meaningful estimates of doses to population may be possible in the future as more is understood about the performance of the proposed Yucca Mountain repository. Such estimates would involve very great uncertainty, especially with respect to cumulative population doses over thousands of years. The standard proposed by the NAS is a limit on maximum individual dose. The relationship of potential new regulatory requirements, based on the NAS report, and cumulative population impacts has not been determined, although the report articulates the view that protection of individuals will adequately protect the population for a repository at Yucca Mountain. However, EPA's generic repository standards in 40 CFR Part 191 generally provide an indication of the order of magnitude of cumulative risk to population that could result from the licensing of a Yucca Mountain repository, assuming the ultimate standards will be within the range of standards now under consideration. The standards in 40 CFR Part 191 protect the population by imposing "containment requirements" that limit the cumulative amount of radioactive material released over 10,000 years. The cumulative release limits are based on EPA's population impact goal of 1,000 premature cancer deaths worldwide for a 100,000-metric tonne (MTHM) repository.

Nevertheless, despite all the uncertainty surrounding the effects of the disposal of spent fuel and high-level waste, some judgment as to the regulatory NEPA implications of these matters should be made, and it makes no sense to repeat the same judgment in every case. Even taking the uncertainties into account, the Commission concludes that these impacts are acceptable in that these impacts would not be sufficiently large to require the NEPA conclusion, for any plant, that the option of extended operation under 10 CFR Part 54 should be eliminated. Accordingly, while the Commission has not assigned a single level of significance for the impacts of spent-fuel and high-level-waste disposal, this issue is considered Category 1.

- The radiological and nonradiological environmental impacts from the transportation of fuel and waste attributable to license renewal of a power reactor have been reviewed. Environmental impact data for transportation are provided in Table S-4. The estimated radiological effects are within the Commission's regulatory standards. Radiological impacts of transportation are therefore found to be of small significance when they are within the range of impact parameters identified in Table S-4. The nonradiological impacts are those from periodic shipments of fuel and waste by individual trucks or rail cars and thus would result in infrequent and localized minor contributions to traffic density. These nonradiological impacts are found to be small when they are within the range of impact parameters identified in Table S-4. Programs designed to reduce risk, which are already in place, provide for adequate mitigation. Table S-4 should continue to be the basis for case-by-case evaluations of transportation impacts of spent fuel until such time as detailed analysis of the environmental impacts of transportation to the Yucca Mountain repository becomes available. Transportation of fuel and waste is a Category 2 issue.

- The radiological and nonradiological environmental impacts from the storage and disposal of low-level radiological waste attributable to license renewal of a power reactor have been reviewed. The comprehensive regulatory controls that are in place and the low public doses being achieved at reactors ensure that the radiological impacts to the environment will remain small during the term of the renewed license. The maximum additional on-site land that may be required for low-level waste storage during the term of a renewed license and associated impacts will be small. Nonradiological environmental impacts on air and water will be negligible. The radiological and nonradiological environmental impacts of long-term disposal of low-level waste from any individual plants at licensed sites are small. The need for the consideration of mitigation alternatives within the context of renewal of a power reactor license has been considered, and the Commission concludes that its regulatory requirements already in place provide adequate mitigation incentives for on-site storage of low-level waste and that, for off-site disposal, mitigation would be a site-specific consideration in the licensing of each facility. In addition, the Commission concludes that there is reasonable assurance that sufficient low-level waste disposal capacity will be made available when needed for facilities to be decommissioned consistent with NRC decommissioning requirements. Low-level waste is a Category 1 issue.

- The radiological and nonradiological environmental impacts from the storage and disposal of mixed waste attributable to license renewal of a power reactor have been reviewed. The comprehensive regulatory controls and the facilities and procedures that are in place ensure proper handling and storage, as well as negligible doses and exposure to toxic materials for the public and the environment at all plants. License renewal will not increase the small, continuing risk to human health and the environment posed by mixed waste at all plants. The radiological and nonradiological environmental impacts of long-term disposal of mixed waste from any individual plant at licensed sites are small. The maximum additional on-site land that may be required for mixed waste is a small fraction of that needed for low-level waste storage during the term of a renewed license, and associated impacts will be small. Nonradiological environmental impacts on air and water will be negligible. The radiological and nonradiological environmental impacts of long-term disposal of mixed waste from any individual plants at licensed sites are small. The need for the consideration of mitigation alternatives within the context of renewal of a power reactor license has been considered, and the Commission concludes that its regulatory requirements already in place provide adequate mitigation incentives for on-site storage of mixed waste and that, for off-site disposal, mitigation would be a site-specific consideration in the licensing of each facility. In addition, the Commission concludes that there is reasonable assurance that sufficient mixed waste disposal capacity will be made available when needed for faculties to be decommissioned consistent with NRC decommissioning requirements. Mixed waste is a Category 1 issue.

- The Commission's waste confidence finding at 10 CFR 51.23 leaves only the on-site storage of spent fuel during the term of plant operation as a high-level waste storage and disposal issue at the time of license renewal. The Commission's regulatory requirements and the experience with on-site storage of spent fuel in fuel pools and dry storage have been reviewed. Within the context of a license renewal review and determination, the Commission finds that there is ample basis to conclude that continued storage of existing spent fuel and storage of spent fuel generated during the license renewal period can be accomplished safely and without significant environmental impacts. Radiological impacts will be well within regulatory limits; thus radiological impacts of on-site storage meet the standard for a conclusion of small impact. The nonradiological environmental impacts have been shown to be not significant; thus they are classified as small. The overall conclusion for on-site storage of spent fuel during the term of a renewed license is that the environmental impacts will be small for each plant. The need for the consideration of mitigation alternatives within the context of renewal of a power reactor license has been considered, and the Commission concludes that its regulatory requirements already in place provide adequate mitigation incentives for on-site storage of spent fuel. On-site storage of spent fuel during the term of a renewed operating license is a Category 1 issue.

- The environmental impacts from the storage and disposal of nonradiological waste attributable to the license renewal of a power reactor have been reviewed. Regulatory and operational trends suggest a gradual decrease in quantities generated annually and the impacts during the terms of renewed licenses. Facilities and procedures are in place to ensure continued proper handling and disposal at all plants. Consequently, the generation and management of solid nonradioactive waste during the term of a renewed license is anticipated to result in only small impacts to the environment. Because the facilities and procedures that are in place are expected to ensure continued proper handling and disposal at each plant, additional mitigative measures are not a consideration in the context of a license renewal review. Nonradiological waste is a Category 1 issue.

DECOMMISSIONING

- Decommissioning after a 20-year license renewal would increase the occupational dose no more than 0.1 person-rem (compared with 7,000 to 14,000 person-rem for DECON decommissioning at 40 years) and the public dose by a negligible amount. License renewal would not increase to any appreciable extent the quantity or classification of LLW generated by decommissioning. Air quality, water quality, and ecological impacts of decommissioning would not change as a result of license renewal. There is considerable uncertainty about the cost of decommissioning; however, while license renewal would not be expected to change the ultimate cost of decommissioning, it would reduce the present value of the cost. The socioeconomic effects of decommissioning will depend on the magnitude of the decommissioning effort, the size of the community, and the other economic activities at the time, but the impacts will not be increased by decommissioning at the end of a 20-year license renewal instead of at the end of 40 years of operation. Incremental radiation doses, waste management, air quality, water quality, ecological, and socioeconomic impacts of decommissioning due to operations during a 20-year license renewal term would be of small significance. No mitigation measures beyond those provided by ALARA are warranted within the context of the license renewal process. The impacts of license renewal on radiation doses, waste management, air quality, water quality, ecological resources, and socioeconomics impacts from decommissioning are Category 1 issues.

1. INTRODUCTION

1.1 PURPOSE OF THE GEIS

This Generic Environmental Impact Statement (GEIS) for license renewal of nuclear plants was undertaken to assess what is known about the environmental impacts that could be associated with license renewal and an additional 20 years of operation of individual plants. That assessment is summarized in this GEIS. This GEIS provides the technical basis for an amendment to the Commission's regulations, 10 CFR Part 51, Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions, with regard to the renewal of nuclear power plant operating licenses. The rule amendment and this document were initiated with the objective that the efficiency of the license renewal process be improved by documenting in this GEIS and codifying in the Commission's regulations the environmental impacts that are well understood. Thus, repetitive reviews of those impacts may be avoided. The Commission's decision to undertake a generic assessment of the environmental impacts associated with the renewal of a nuclear power plant operating license was motivated by its belief in the following:

(1) License renewal will involve nuclear power plants for which the environmental impacts of operation are well understood as a result of data evaluated from operating experience to date.
(2) Activities associated with license renewal are expected to be within this range of operating experience, thus environmental impacts can be reasonably predicted.
(3) Changes in the environment around nuclear power plants are gradual and predictable with respect to characteristics important to environmental impact analyses.

1.2 RENEWAL OF A PLANT OPERATING LICENSE—THE PROPOSED FEDERAL ACTION

Under NRC's environmental protection regulations in 10 CFR Part 51, renewal of a nuclear power plant operating license is identified as a major federal action significantly affecting the quality of the human environment, and thus an environmental impact statement (EIS) is required for a plant license renewal review. The EIS requirements for a plant-specific license renewal review are specified in 10 CFR Part 51. NRC's public health and safety requirements that must be met for the renewal of operating licenses for nuclear power plants are found in 10 CFR Part 54. Operating licenses may be renewed for up to 20 years beyond the 40-year term of the initial license. No limit on the number of renewals is specified. Part 54 requires license renewal applicants to perform specified types of evaluations and assessments of their facility and to provide sufficient information for the NRC to determine whether or not continued operation of the facility during the renewal term will endanger public health and safety or the environment. Specifically, licensees will be required to assess the effect of age-related degradation on certain long-lived, passive systems, structures, and components that are within the scope of Part 54. The assessment results will determine what activities and modifications are necessary at the time of license renewal and throughout the renewal term to ensure continued safe operation of the plant. Most utilities are expected to begin preparation for license renewal about 10 to 20 years before expiration of their original operating licenses. The inspection, surveillance, test, and maintenance programs for license renewal would be integrated gradually into plant operations over a period of years. For the purpose of the analysis in this GEIS, NRC anticipates that plant refurbishment undertaken specifically for license renewal would probably be completed within normal plant outage cycles beginning 8 years before the original license expires and one longer outage, if a major refurbishment item is involved. Activities associated with license renewal and operation of a plant for an additional 20 years are discussed in Chapter 2.

1.3 PURPOSE AND NEED FOR THE ACTION

The Commission will act on an applications for license renewal submitted by a licensee of an operating nuclear power plant. Although a licensee must have a renewed license to operate a plant beyond the term of the existing operating license, the possession of that license is just one of a number of conditions that must be met for the licensee to continue plant operation during the term of the renewed license. State regulatory agencies and the owners of the plant would ultimately decide whether the plant will continue to operate based on factors such as need for power or other matters within the State's jurisdiction or the purview of the owners. Economic considerations will play a primary role in the decision made by State regulatory agencies and the owners of the plant. Thus, for license renewal reviews, the Commission has adopted the following definition of purpose and need:

> The purpose and need for the proposed action (renewal of an operating license) is to provide an option that allows for power generation capability beyond the term of a current nuclear power plant operating license to meet future system generating needs, as such needs may be determined by State, utility, and, where authorized, Federal (other than NRC) decision makers.

This definition of purpose and need reflects the Commission's recognition that, absent findings in the safety review required by the Atomic Energy Act of 1954, as amended, or findings in the NEPA environmental analysis that would lead the NRC to reject a license renewal application, the NRC has no role in the energy planning decisions of State regulators and utility officials as to whether a particular nuclear power plant should continue to operate. From the perspective of the licensee and the State regulatory authority, the purpose of renewing an operating license is to maintain the availability of the nuclear plant to meet system energy requirements beyond the term of the plant's current license. The underlying need that will be met by the continued availability of the nuclear plant is defined by various operational and investment objectives of the licensee. Each of these objectives may be dictated by State regulatory requirements or strongly influenced by State energy policy and programs. In cases of interstate generation or other special circumstances, Federal agencies such as the Federal Energy Regulatory Commission (FERC) or the

Tennessee Valley Authority (TVA) may be involved in making these decisions. The objectives of the various entities involved may include lower energy cost, increased efficiency of energy production and use, reliability in the generation and distribution of electric power, improved fuel diversity within the State, and environmental objectives such as improved air quality and smaller land use impacts.

1.4 ALTERNATIVES TO THE PROPOSED ACTION

In Chapter 8, the Commission has considered the environmental consequences of the no action alternative (i.e., denying a license renewal application) and the environmental consequences of the various alternatives available for replacing the lost generating capacity that would be available to a utility and other responsible energy planners. No conclusions are made in this document about the relative environmental consequences of license renewal or the construction and operation of alternative facilities for generating electric energy. The information in the GEIS is available for use by the NRC and the licensee in performing the site-specific analysis of alternatives. This information will be updated periodically, as appropriate. For individual plant reviews, information codified in the rule, information developed in the GEIS, and any significant new information introduced during the plant-specific review, including any information received from the State or members of the public, will be considered in reaching conclusions in the supplemental EIS. For an individual plant review, the environmental impacts of license renewal are to be compared with those of alternative energy sources so as to determine whether the adverse environmental impact of license renewal are so great that preserving the option of license renewal for energy planning decision makers would be unreasonable.

1.5 ANALYTICAL APPROACH USED IN THE GEIS

The GEIS summarizes the approach and findings of a systematic inquiry into the potential environmental consequences of renewing the licenses and operating individual nuclear power plants an additional 20 years. The inquiry identified the attributes of the nuclear power plants, such as major features and plant systems, and the ways the plants can affect the environment. The inquiry also identified the possible refurbishment activities and modifications to maintenance and operating procedures that might be undertaken given the requirements of the safety review as provided for in the Commission's regulations 10 CFR Part 54 or given a utility's motivation for increased economic efficiency. To identify possible initiators of environmental impacts, two scenarios were developed from the possible set of refurbishment activities and continuation of plant operation during the renewal term. One scenario was developed as a typical but somewhat conservative scenario for license renewal, intended to be representative of the type of programs that many licensees seeking license renewal might implement. The other scenario is highly conservative, encompassing considerably more activities, and is intended to characterize a reasonable upper bound of impact initiators that might result from license renewal. These scenarios are discussed in Chapter 2 and in more detail in Appendix B. The linkages between the impact initiators and the environment and the potential environmental impact consequences are developed in the other chapters of the GEIS.

Previous experience with nuclear power plant operation and refurbishment was reviewed in developing the possible scope of environmental impacts that complemented the identification of impact initiators and linkages to the environment. This experience is found in a variety of sources. A list of possible impacts is found in NUREG-0099, Regulatory Guide 4.2, Rev. 2 (July 1976) and in NUREG-0555, "Environmental Standard Review Plans for the Environmental Review of Construction Permit Applications for Nuclear Power Plants" (May 1979). Information was gathered from the environmental impact statements prepared for individual plants at the construction permit and operating license stages. A survey of individual plant operating and refurbishment experience was designed by Oak Ridge National Laboratory (ORNL) and the NRC staff and was administered by the Nuclear Energy Institute (NEI), formerly the Nuclear Utility Management and Resources Council (NUMARC). ORNL analysts reviewed the literature relevant to nuclear power plant impacts on the environment and surveyed by telephone and letter federal, state, and local authorities who have responsibilities that would make them cognizant of the environmental impacts of individual nuclear power plants. The information gathered for this GEIS was supplemented at several stages by comments and information provided by various interests groups at public workshops and by written comments in response to information noticed in the Federal Register. The NRC staff's responses to comments are provided in NUREG-1529, *Public Comments on the Proposed 10 CFR Part 51 Rule for Renewal of Nuclear Power Plant Operating Licenses and Supporting Documents; Review of Concerns and NRC Staff Response.*

The general analytical approach to each environmental issue was to (1) describe the activity that affects the environment, (2) identify the population or resource that is affected, (3) assess the nature and magnitude of the impact on the affected population or resource, (4) characterize the significance of the effect for both beneficial and adverse effects, (5) determine whether the results of the analysis applies to all plants, and (6) consider whether additional mitigation measures would be warranted for impacts that would have the same significance level for all plants.

A standard of significance was established for assessing environmental issues; and, because significance and severity of an impact can vary with the setting of a proposed action, both "context" and "intensity" as defined in the Council on Environmental Quality regulations (40 CFR 1508.27) were considered. With these standards as a basis, each issue was assigned to one of the three following significance levels:

> Small: For the issue, environmental effects are not detectable or are so minor that they will neither destabilize nor noticeably alter any important attribute of the resource. For the purposes of assessing radiological impacts, the Commission has concluded that those impacts that do not exceed permissible levels in the Commission's regulations are considered small.
>
> Moderate: For the issue, environmental effects are sufficient to

alter noticeably but not to destabilize important attributes of the resource.

Large: For the issue, environmental effects are clearly noticeable and are sufficient to destabilize important attributes of the resource.

The discussion of each environmental issue in the GEIS includes an explanation of how the significance category was determined. For issues in which probability of occurrence is a key consideration (i.e., accident consequences), the probability of occurrence has been factored into the determination of significance. In determining the significance levels it was assumed that ongoing mitigation measures would continue and that mitigation measures employed during plant construction would be employed during refurbishment, as appropriate. The potential benefits of additional mitigation measures were not considered in determining significance levels.

In addition to determining the significance of environmental impacts associated with an issue for that issue, a determination was made whether the analysis in the GEIS could be applied to all plants and whether additional mitigation measures would be warranted. The categories to which an issue may be assigned follow.

Category 1: For the issue, the analysis reported in the Generic Environmental Impact Statement has shown:

(1) the environmental impacts associated with the issue have been determined to apply either to all plants or, for some issues, to plants having a specific type of cooling system or other specified plant or site characteristics;
(2) a single significance level (i.e., small, moderate, or large) has been assigned to the impacts (except for collective off-site radiological impacts from the fuel cycle and from high-level waste and spent fuel); and
(3) mitigation of adverse impacts associated with the issue has been considered in the analysis and it has been determined that additional plant-specific mitigation measures are likely not to be sufficiently beneficial to warrant implementation.

The generic analysis of the issue may be adopted in each plant-specific review.

Category 2: For the issue, the analysis reported in the GEIS has shown that one or more of the criteria of Category 1 cannot be met, and therefore, additional plant-specific review is required.

If, for an environmental issue, the three Category 1 criteria apply to all plants, that issue is Category 1, and the generic analysis should be used in a license renewal review for all plant applications and supplemental environmental impact statements. If the three Category 1 criteria apply to a subset of plants that are readily defined by a common plant characteristic, notably the type of cooling system, the population of plants is partitioned into the set of plants with the characteristic and the set without the characteristic. For the set of plants with the characteristic, the issue is Category 1, and the generic analysis should be used in the license renewal review for those plants. For the set of plants without the characteristic, the issue is Category 2, and a site-specific analysis for that issue will be performed as part of the license renewal review. The review of a Category 2 issue may focus on the particular aspect of the issue that causes the Category 1 criteria not to be met. For example, severe accident mitigation design alternatives under the issue "severe accidents" is the focus for a plant-specific review because the other aspects of the issue, specifically the off-site consequences, have been adequately addressed in the GEIS.

1.6 SCOPE OF THE GEIS

This final GEIS assesses 92 environmental issues. Sixty-eight of these issues are found to be Category 1 and are identified in 10 CFR Part 51 as not requiring additional plant-specific analysis. Guidance on the analyses required for each of the other 24 issues is provided in 10 CFR Part 51. A summary of the findings for the 92 environmental issues is provided in Table 9.1 of this GEIS. That table has been codified in Appendix B to Subpart A of 10 CFR Part 51 (Table B-1).

Preparing the plants for an additional 20 years of operations is an important factor in assessing the type and extent of environmental impacts. Consequently, Chapter 2 describes (1) the two scenarios that were developed to characterize refurbishment activities to prepare the plant for operations during the license renewal term and (2) the possible differences between past operations and anticipated operations during the license renewal period. With Chapter 2 as a basis, Chapter 3 projects and assesses the potential environmental impacts associated with refurbishment; and Chapter 4 examines the potential environmental impacts associated with operations during the license renewal period. In most ways, the environmental effects of license renewal are found to be similar to those of normal operations.

The implications for license renewal on the environmental impacts associated with accidents, the uranium fuel cycle and waste management, and decommissioning are discussed in separate chapters. Chapter 5 addresses the ways in which the impacts of potential design basis and severe accidents may be affected by operation of the plants for an additional 20 years. Chapter 6 discusses the extent to which license renewal and an additional 20 years of operation will affect the environmental impacts related to the uranium fuel cycle and the management (storage and disposal) of nonradioactive solid waste, low-level radioactive waste, mixed waste (radioactive and chemically hazardous), spent fuel, and transportation of radioactive wastes as generated at a plant. Chapter 7 assesses the extent to which the license renewal and an additional 20 years of operation would affect the environmental impacts of decommissioning a plant.

Chapter 8 describes the potential environmental effects of terminating plant operations at the end of the current license term and the effects that would be associated with various alternative sources of energy. Because many environmental impacts of energy technologies are site specific, this chapter reaches no conclusions about the significance of these effects nor does it reach any conclusions about the preferability of license renewal or any alternative to it. The information in this chapter is intended to serve as an aid for preparers of plant-specific license renewal impact assessments.

Finally, Chapter 9 summarizes the analytical findings reached in this GEIS.

1.7 IMPLEMENTATION OF THE RULE

1.7.1 General Requirements

The regulatory requirements for performing a NEPA review for a license renewal application are similar to the NEPA review requirements for other major plant licensing actions. Consistent with the current NEPA practice for major plant licensing actions, an applicant is required to submit an environmental report that analyzes the environmental impacts associated with the proposed action, considers alternatives to the proposed action, and evaluates any alternatives for reducing adverse environmental effects. Additionally, the NRC staff is required to prepare a supplemental environmental impact statement for the proposed action, issue the statement in draft for public comment, and issue a final statement after considering public comments on the draft. These requirements are found in the Commissions regulations at 10 CFR Part 51.

The review requirements for license renewal deviates from NRC's traditional NEPA review practice in some areas. First, the amendment codifies certain environmental impacts associated with license renewal that are analyzed in this GEIS. Accordingly, additional analyses for certain impacts codified by this rulemaking need not be presented in an applicant's environmental report for license renewal nor in the Commission's (including NRC staff, adjudicatory officers, and the Commission itself) draft and final SEIS and other environmental documents developed for the proceeding. Secondly, the amendment reflects the Commission's decision to limit its NEPA review for license renewal to a consideration of the environmental effects of the proposed action and alternatives to the proposed action. Finally, the amendment contains a decision standard that the Commission will use in determining the acceptability of the environmental impacts of individual license renewals.

The Commission and the applicant will also in some cases (e.g., severe accident consequences) consider alternatives to reduce or mitigate environmental impacts. The Commission has concluded that, for license renewal, the issues of need for power and utility economics should be reserved for State and utility officials to decide. Accordingly, the NRC will not conduct an analysis of these issues in the context of license renewal or perform traditional cost-benefit balancing in license renewal NEPA reviews. Finally, the rule does not codify any conclusions regarding the subject of alternatives. Consideration of and decisions regarding alternatives will occur at the site-specific stage.

1.7.2 Applicant's Environmental Report

The applicant's environmental report must contain an analysis of the environmental impacts of renewing a license, the environmental impacts of alternatives, and mitigation alternatives. In preparing the analysis of environmental impacts contained in the environmental report, the applicant should refer to the data provided in 10 CFR Part 51, Appendix B. The applicant is not required to provide an analysis in the environmental report of those issues identified as Category 1 issues in Table B-1 in Appendix B. For those issues identified as Category 2 in

Table B-1, the applicant must provide a specified additional analysis beyond that contained in Table B-1. Section 10 CFR 51.53(c)(3)(ii) specifies the subject areas of the analysis that must be addressed for the Category 2 issues.

Pursuant to 10 CFR 51.45(c), 10 CFR 51.53(c)(2) requires the applicant to consider possible actions to mitigate the adverse impacts associated with the proposed action. This consideration is limited to designated Category 2 matters. Pursuant to 10 CFR 51.45(d), the environmental report must include a discussion of the status of compliance with applicable Federal, State, and local environmental standards. Also, 10 CFR 51.53(c)(2) specifically excludes from consideration in the environmental report the issues of need for power, the economic costs and benefits of the proposed action, economic costs and benefits of alternatives to the proposed action, or other issues not related to environmental effects of the proposed action and associated alternatives. In addition, the requirements in 10 CFR 51.45 are consistent with the exclusion of economic issues in 10 CFR 51.53(c)(2).

Pursuant to 10 CFR 51.45(c), 10 CFR 51.53(c)(2) requires the applicant to consider the environmental impacts of alternatives to license renewal in the environmental report. The treatment of alternatives in the environmental report should be limited to the environmental impacts of such alternatives. The amended regulations do not require a discussion of the economic costs and benefits of these alternatives in the environmental report for the operating license renewal stage except as necessary to determine whether an alternative should be included in the range of alternatives considered or whether certain mitigative actions are appropriate. The analysis should demonstrate consideration of a reasonable set of alternatives to license renewal. In preparing the alternatives analysis, the applicant may consider information regarding alternatives in this GEIS.

The Commission has developed a new approach to making decisions for environmental impact statements for license renewal. This decision standard differs from past Commission practice. The amended regulations for license renewal do not require applicants to apply this decision standard to the information generated in their environmental report (although the applicant is not prohibited from doing so if it desires). Under NEPA, the Commission has the final authority and responsibility for making such a decision regarding the environmental acceptability of the proposed renewal license. However, the NRC staff will use the information contained in the environmental report in preparing the environmental impact statement upon which the Commission will base its final decision.

Consistent with the NRC's current NEPA practice, an applicant must include alternatives to reduce or mitigate adverse environmental impacts in its environmental report. However, for license renewal, the Commission has generically considered mitigation for environmental issues associated with renewal and has concluded that no additional site-specific consideration of mitigation is necessary for many issues. The Commission's consideration of mitigation for each issue included identification of current activities that adequately mitigate impacts and an assessment as to whether certain impacts are so insignificant that mitigation is not warranted. The Commission has considered mitigation for all impacts designated as Category 1 in Table B-1. Therefore, a license renewal applicant need not address mitigation for Category 1 issues in Table B-1.

1.7.3 The NRC's Supplemental Environmental Impact Statement

The Commission is required to prepare a supplemental environmental impact statement (SEIS), consistent with 10 CFR 51.20(b)(2). This statement will serve as the Commission's independent analysis of the environmental impacts of license renewal as well as a comparison of these impacts to the environmental impacts of alternatives. This document will also present the preliminary recommendation by the NRC staff regarding the proposed action. The provisions in 10 CFR 51.71 and 51.95 to reflect the Commission's approach to addressing the environmental impacts of license renewal in an SEIS.

The issues of need for power, the economic costs and benefits of the proposed action and economic costs and benefits of alternatives to the proposed action are specifically excluded from consideration in the supplemental environmental impact statement for license renewal by 10 CFR 51.95(c), except as these costs and benefits are either essential for a determination regarding the inclusion of an alternative in the range of alternatives considered or relevant to mitigation. The environmental report does not need to discuss issues related to other than environmental effects of the proposed action and associated alternatives. The requirements in 10 CFR 51.71(d) and (e) are consistent with the exclusion of economic issues in 10 CFR 51.95(c). Additionally, 10 CFR 51.95 allows information from previous NRC site-specific environmental reviews, as well as NRC final generic environmental impact statements, to be referenced in supplemental environmental impact statements.

1.7.4 Public Scoping and Public Comments on the SEIS

Consistent with NRC's NEPA practice, the NRC staff will hold a public meeting in order to inform the local public of the proposed action and receive comments. In addition, the SEIS will be issued in draft for public comment in accordance with 10 CFR 51.91 and 51.93. In both the public scoping process and the public comment process, the Commission will accept comments on all previously analyzed issues and information codified in Table B-1 of 10 CFR Part 51, Appendix B, and will determine whether these comments provide any information that is new and significant compared with that previously considered in the GEIS. If the comments are determined to provide new and significant information bearing on the previous analysis in the GEIS, these comments will be considered and appropriately factored into the Commission's analysis in the SEIS. Public comments on the site-specific additional information provided by the applicant regarding Category 2 issues will be considered in the SEIS.

1.7.5 Commission's Analysis and Preliminary Recommendation

The Commission's draft SEIS will include its analysis of the environmental impacts of the proposed license renewal action and the environmental impacts of the alternatives to the proposed action. The Commission will utilize and integrate the codified environmental impacts of license renewal as provided in Table B-1 of 10 CFR Part 51, Appendix B (supplemented by the underlying analyses in the GEIS), and the appropriate site-specific analyses of Category 2 issues and any new issues identified during the scoping and public comment process, to arrive at a conclusion regarding the sum of the environmental impacts associated with license renewal. These impacts will then be compared, quantitatively or qualitatively as appropriate, with the environmental impacts of the considered alternatives. The analysis of alternatives in the SEIS will be limited to the environmental impacts of these alternatives and will be prepared in accordance with 10 CFR 51.71 and of 10 CFR Part 51, Subpart A, Appendix A. The analysis of impacts of alternatives provided in the GEIS may be referenced in the SEIS as appropriate. The alternatives discussed in the GEIS include a reasonable range of different methods for power generation. The analysis in the draft SEIS will consider mitigation actions for designated Category 2 matters and will consider the status of compliance with Federal, State, and local environmental requirements as required by 10 CFR 51.71(d). Consistent with 10 CFR 51.71(e), the draft supplemental environmental impact statement must contain a preliminary recommendation regarding license renewal based on consideration of the information on the environmental impacts of license renewal and of alternative energy sources contained in the SEIS. To reach its recommendation, the NRC staff must determine whether the adverse environmental impacts of license renewal are so great that preserving the option of license renewal for energy planning decision makers would be unreasonable. This requirement is contained in 10 CFR 51.95(c)(4).

1.7.6 Final Supplemental Environmental Impact Statement

The Commission will issue a final supplemental environmental impact statement for a license renewal application in accordance with 10 CFR 51.91 and 51.93 after considering the public comments related to new issues identified from the scoping and public comment process, Category 2 issues, and any new and significant information regarding previously analyzed and codified Category 1 issues. Pursuant to 10 CFR 51.102 and 51.103, the Commission will provide a record of its decision regarding the environmental impacts of the proposed action. In making a final decision, the Commission must determine whether the adverse environmental impacts of license renewal (when compared with the environmental impacts of other energy generating alternatives) are so great that preserving the option of license renewal for energy planning decision makers would be unreasonable.

All comments on the applicability of the analyses of impacts codified in the rule and the analysis contained in the draft supplemental EIS will be addressed by NRC in the final supplemental EIS in accordance with 40 CFR § 1503.2, regardless of whether the comment is directed to impacts in Category 1 or 2. Such comments will be addressed in following manner:

a. NRC's response to a comment regarding the applicability of the analysis of an impact codified in the rule to the plant in question may be a statement and explanation of its view that the analysis is adequate including, if applicable, consideration of the significance of new information. A commenter dissatisfied with such a response may file a petition for rulemaking under 10 CFR § 2.802. Procedures for the submission of petitions for rulemaking are explained in Appendix I. If the commenter is successful in persuading the Commission that the new information does indicate that the analysis of an impact codified in the rule is incorrect in significant respects (either in general or with respect to the particular plant), then a rulemaking proceeding will be initiated.

b. If the commenter provides new information that is relevant to the plant and is also relevant to other plants (i.e., generic information) and that information demonstrates that the analysis of an impact codified in the final rule is incorrect, the NRC staff will seek Commission approval either to suspend the application of the rule on a generic basis with respect to the analysis or to delay granting the renewal application (and possibly other renewal applications) until the rule can be amended. The updated GEIS would reflect the corrected analysis and any additional consideration of alternatives as appropriate.

c. If a commenter provides new, site-specific information that demonstrates that the analysis of an impact codified in the rule is incorrect with respect to the particular plant, then the NRC staff will seek Commission approval to waive the application of the rule with respect that analysis in that specific renewal proceeding. The supplemental EIS would reflect the corrected analysis as appropriate.

1.8 REFERENCES

NUREG-1529, *Public Comments on the Proposed 10 CFR Part 51 Rule for Renewal of Nuclear Power Plant Operating Licenses and Supporting Documents; Review of Concerns and NRC Response*, U.S. Nuclear Regulatory Commission, Washington, D.C., to be published.

2. DESCRIPTION OF NUCLEAR POWER PLANTS AND SITES, PLANT INTERACTION WITH THE ENVIRONMENT, AND ENVIRONMENTAL IMPACT INITIATORS ASSOCIATED WITH LICENSE RENEWAL

2.1 INTRODUCTION

Currently, 118[1] commercial nuclear power plants are located at 74 sites in 33 of the contiguous United States. Of these, 57 sites are located east of the Mississippi River, with most of this nuclear capacity located in the Northeast (New England states, New York, and Pennsylvania); the Midwest (Illinois, Michigan, and Wisconsin); and the Southeast (the Carolinas, Georgia, Florida, and Alabama). No commercial nuclear power plants are located in Alaska or Hawaii. Approximately half of these 74 sites contain two or three nuclear units per site. Three of the 118 plants have been shut down and will be decommissioned. The plant characteristics and environmental settings for these nuclear power plant sites are provided in Appendix A. Table 2.1 provides a summary overview of the plants considered in preparing this Generic Environmental Impact Statement (GEIS).

The total capacity of generating U.S. commercial nuclear power plants is approximately 99 GW(e), with plant generating capacities ranging from 67 MW(e) to 1270 MW(e). In 1992, the U.S. electric utility industry generated about 2.8×10^{12} kWh, 21.6 percent of which was supplied by nuclear power. The range of annual electricity production for these plants is approximately 390×10^6 kWh/year to 6900×10^6 kWh/year using an assumed annual capacity factor of 62 percent. It is anticipated that the electric utility industry will seek to operate many of these nuclear power plants beyond the current operating license term of 40 years. This GEIS examines how these plants and their interactions with the environment would change if such plants were allowed to operate (under the proposed license renewal regulation 10 CFR Part 54) for a maximum of 20 years past the term of the original plant license of 40 years.

The purpose of this section is to provide an orientation from the perspective of environmental considerations and assessments. Section 2.2 describes commercial nuclear power plants and their major features and plant systems. Section 2.3 describes the ways nuclear power plants interact with and affect the environment. The license renewal rule, particularly its requirements that may result in changes to nuclear plant environmental impacts, is discussed in Section 2.4. Section 2.5 reviews the generation of particular environment impacts, or precursors to such impacts, that are typical of current nuclear plant operation. It discusses the "baseline" values to be used in comparing incremental effects resulting from license renewal. Section 2.6 describes major refurbishment activities and changes that could occur at nuclear power plants during license renewal refurbishment and the extended years of operation. This section provides the background for more thorough evaluations and environmental impact assessments discussed in Sections 3 through 10.

2.2 PLANT AND SITE DESCRIPTION AND PLANT OPERATION

2.2.1 External Appearance and Setting

Nuclear power plants generally contain four main buildings or structures:

- Containment or reactor building. A massive containment structure that houses the reactor vessel, the suppression pool [boiling-water reactors (BWRs) only], steam generators, pressurizer [pressurized-water reactors (PWRs) only], pumps, and associated piping. The building is generally designed to withstand such disasters as hurricanes, earthquakes, and aircraft collisions. The containment's ability to withstand such disasters, as well as the effects of accidents initiated by system failures, is the principal deterrent to release of radioactive materials to the environment.
- Turbine building. Plant structures that house the steam turbine and generator, condenser, waste heat rejection system, pumps, and equipment that supports those systems.
- Auxiliary buildings. Buildings that house such support systems as the ventilation system, the emergency core cooling system, the water treatment system, and the waste treatment system, along with fuel storage facilities and the plant control room.
- Cooling towers. Structures designed to remove excess heat from the condenser without dumping such heat directly into water bodies.

A plant site also contains a large switchyard, where the electric voltage is stepped up and fed into the regional power distribution system, and may also include various administrative and security buildings. During the operating life of a plant, its basic appearance remains unchanged.

Typically, nuclear power plant sites and the surrounding area are flat-to-rolling countryside in wooded or agricultural areas. More than 50 percent of the sites have 80-km (50-mile) population densities of less than 200 persons per square mile, and over 80 percent have 80-km (50-mile) densities of less than 500 persons per square mile. The most notable exception is the Indian Point Station, located within 80 km (50 miles) of New York City, which has a projected 1990 population density within 80 km (50 miles) of almost 2000 persons per square mile.

Site areas range from 34 ha (84 acres) for the San Onofre Nuclear Generating Station in California to 12,000 ha (30,000 acres) for the McGuire Nuclear Station in North Carolina. As shown in Table 2.1, 28 site areas range from 200 to 400 ha (500 to 1000 acres), and an additional 12 sites are in the 400- to 800-ha (1000- to 2000-acre) range. Thus, almost 60 percent of the plant sites encompass 200 to 800 ha (500 to 2000 acres). Larger land-use areas are associated with plant cooling systems that include reservoirs, artificial lakes, and buffer areas.

2.2.2 Reactor Systems

U.S. reactors employed for domestic electric power generation are conventional (thermal) light-water reactors (LWRs), using water as moderator and coolant. The two types of LWRs are PWRs (Figure 2.1) and BWRs (Figure 2.2). Of the 118 power reactors in the United States, 80 are PWRs and 38 are BWRs.

Table 2.1 Nuclear power plant baseline information

Plant	Unit	Operating license	License expiration	Electrical rating [MW(e)]	Reactor type[a]	Steam supply system vendor[b]	Cooling system[c]	Cooling water source	Condenser flow rate (10^3 gal/min)	Intake structure	Discharge structure	Total site area (acres)	Nearest city	Transmission corridor (acres)	1990 population (50 miles)
Arkansas Nuclear One	1	1974	2014	850	PWR	B&W	OT	Dardanelle Reservoir	765	3220-ft canal	520-ft canal	1,160	Little Rock, Ark.	3,700	200,000
	2	1978	2018	912	PWR	CE	NDCT		422						
Beaver Valley	1	1976	2016	835	PWR	WEST	NDCT	Ohio River	480	At river edge	At river edge	501	Pittsburgh	Uses existing corridor	3,740,000
	2	1987	2027	836	PWR	WEST	NDCT		480						
Bellefonte Nuclear Plant	1	—	—	1,213	PWR	B&W	NDCT	Guntersville Lake	410	Intake channel	Submerged diffuser	1,500	Huntsville, Ala.	2,900	1,070,000
	2	—	—	1,213	PWR	B&W	NDCT		410						
Big Rock Point Nuclear Plant	1	1962	2002	72	BWR	GE	OT	Lake Michigan	49	Underwater crib	Open discharge canal	600	Sault Ste. Marie, Canada	—	200,000
Braidwood Station	1	1987	2027	1,120	PWR	WEST	CCCP	Kankakee River	730	At lake shore	Surface flume	4,457	Joliet, Ill.	2,376	4,510,000
	2	1988	2028	1,120	PWR	WEST	CCCP		730						
Browns Ferry Nuclear Power Station	1	1973	2013	1,065	BWR	GE	OT with towers	Tennessee River	630	In small river inlet	Diffuser pipes	840	Huntsville, Ala.	1,350	760,000
	2	1974	2014	1,065	BWR	GE			630						
	3	1976	2016	1,065	BWR	GE			630						
Brunswick Steam Electric Plant	1	1976	2016	821	BWR	GE	OT	Cape Fear River	675	3-mile canal from river	6-mile canal to Atlantic Ocean	1,200	Wilmington, N.C.	3,500	230,000
	2	1974	2014	821	BWR	GE	OT		675						
Byron Station	1	1985	2025	1,120	PWR	WEST	NDCT	Rock River	632	On river bank	Discharge to river	1,398	Rockford, Ill.	2,000	1,000,000
	2	1987	2027	1,120	PWR	WEST	NDCT		632						
Callaway Plant	1	1984	2024	1,171	PWR	WEST	NDCT	Missouri River	530	From river	To river	3,188	Columbia, Mo.	1,140	400,000
Calvert Cliffs Nuclear Power Plant	1	1974	2014	845	PWR	CE	OT	Chesapeake Bay	1,200	560 ft from shore	850 ft from shore	1,135	Washington, D.C.	1,990	3,030,000
	2	1976	2016	845	PWR	CE	OT		1,200						
Catawba Nuclear Station	1	1985	2025	1,145	PWR	WEST	MDCT	Lake Wylie	660	Skimmer wall	Cove of lake	391	Charlotte, N.C.	584	1,590,000
	2	1986	2026	1,145	PWR	WEST	MDCT		660						
Clinton Power Station	1	1987	2027	933	BWR	GE	OT	Salt Creek	569	Shoreline of creek	3-mile flume	14,090	Decatur, Ill.	906	730,000
Comanche Peak Steam Electric Station	1	1989	2029	1,150	PWR	WEST	OT	Squaw Creek Reservoir	1,030	Shore of reservoir	Canal to reservoir	7,669	Ft. Worth, Tex.	458	1,130,000
	2	—	—	1,150	PWR	WEST	OT		1,030						

See footnotes at end of table

Table 2.1 (continued)

Plant	Unit	Operating license	License expiration	Electrical rating [MW(e)]	Reactor type[a]	Steam supply system vendor[b]	Cooling system[c]	Cooling water source	Condenser flow rate (10^3 gal/min)	Intake structure	Discharge structure	Total site area (acres)	Nearest city	Transmission corridor (acres)	1990 population (50 miles)
Donald C. Cook Nuclear Power Plant	1 2	1974 1977	2014 2017	1,030 1,100	PWR PWR	WEST WEST	OT OT	Lake Michigan	800 800	2,250 ft from shore	1,250 ft from shore	650	South Bend, Ind.	3,300	1,250,000
Cooper Nuclear Station	—	1974	2014	778	BWR	GE	OT	Missouri River	631	At shoreline	At shoreline	1,090	Lincoln, Neb.	6,862	180,000
Crystal River Nuclear Plant	3	1977	2017	825	PWR	B&W	OT	Gulf of Mexico	680	16,000 ft from shore	13,000 ft canal	4,738	Gainesville, Fla.	2,140	440,000
Davis-Besse Nuclear Power Station	1	1977	2017	906	PWR	B&W	NDCT	Lake Erie	480	Submerged 3,000 ft off shore	Submerged 900 ft off shore	954	Toledo, Ohio	1,800	1,920,000
Diablo Canyon Nuclear Power Plant	1 2	1984 1985	2024 2025	1,086 1,119	PWR PWR	WEST WEST	OT OT	Pacific Ocean	863 863	At shore with break wall	Surface to ocean	750	Santa Barbara, Calif.	6,000	300,000
Dresden Nuclear Power Station	2 3	1969 1971	2010 2011	794 794	BWR BWR	GE GE	Cooling lake and spray canal	Kankakee River	471 471	Canal from Kankakee River	Cooling lake to Illinois River	953 + 1,274 cooling pond	Joliet, Ill.	2,250	6,820,000
Duane Arnold Energy Center	1	1974	2014	538	BWR	GE	MDCT	Cedar River	290	Shoreline	Canal to shoreline	500	Cedar Rapids, Iowa	1,160	620,000
Joseph M. Farley Nuclear Plant	1 2	1977 1981	2017 2021	829 829	PWR PWR	WEST WEST	MDCT MDCT	Chattahoochee River	635 635	River to storage pond	At river bank	1,850	Columbus, Ga.	5,300	390,000
Enrico Fermi Atomic Power Plant	2	1985	2025	1,093	BWR	GE	NDCT	Lake Erie	837	At edge of lake	Pond to lake	1,120	Detroit	180	5,370,000
James A. FitzPatrick Nuclear Power Plant	—	1974	2014	816	BWR	GE	OT	Lake Ontario	353	From lake	To lake	702	Syracuse, N.Y.	1,000	820,000
Fort Calhoun Station	1	1973	2013	478	PWR	CE	OT	Missouri River	360	At shore	At shore	660	Omaha, Neb.	186	770,000
Robert Emmett Ginna Nuclear Power Plant	1	1969	2009	470	PWR	WEST	OT	Lake Ontario	356	Lake bottom	Open canal	338	Rochester, N.Y.	280	1,140,000
Grand Gulf Nuclear Station	1	1984	2024	1,250	BWR	GE	NDCT	Mississippi River	572	Collector wells	Discharge via barge slip	2,100	Jackson, Miss.	2,300	350,000

See footnotes at end of table.

Table 2.1 (continued)

Plant	Unit	Operating license	License expiration	Electrical rating [MW(e)]	Reactor type[a]	Steam supply system vendor[b]	Cooling system[c]	Cooling water source	Condenser flow rate (10^3 gal/min)	Intake structure	Discharge structure	Total site area (acres)	Nearest city	Transmission corridor (acres)	1990 population (50 miles)
Haddam Neck (Connecticut Yankee)	—	1967	2007	582	PWR	WEST	OT	Connecticut River	372	Shoreline	Canal to river	525	Meridian, Conn.	985	3,630,000
Shearon Harris Nuclear Power Plant	1	1987	2027	900	PWR	WEST	NDCT	Buckhorn Creek	483	Reservoir on creek	To reservoir	10,744	Raleigh, N.C.	3,500	1,430,000
Edwin I. Hatch Nuclear Plant	1	1974	2014	776	BWR	GE	MDCT	Altamaha River	556	Edge of river	120 ft from shore	2,244	Savannah, Ga.	4,691	330,000
	2	1978	2018	784	BWR	GE									
Hope Creek Generating Station	1	1986	2026	1,067	BWR	GE	NDCT	Delaware River	552	Edge of river	10 ft from shore	740	Wilmington, Del.	912	4,850,000
Indian Point Station	2	1973	2013	873	PWR	WEST	OT	Hudson River	840	At river bank	Channel to river	239	White Plains, N.Y.	10	15,190,000
	3	1976	2016	965	PWR	WEST									
Kewaunee Nuclear Power Plant	—	1973	2013	535	PWR	WEST	OT	Lake Michigan	420	1,750 ft from shore	At shoreline	908	Green Bay, Wisc.	1,066	640,000
La Salle County Station	1	1982	2022	1,078	BWR	GE	Cooling pond	Illinois River	645	From cooling pond	To cooling pond	3,060	Joliet, Ill.	2,278	1,160,000
	2	1984	2024	1,078	BWR	GE									
Limerick Generating Station	1	1985	2025	1,055	BWR	GE	NDCT	Schuylkill River	450	From river	To river	595	Reading, Pa.	7	6,970,000
	2	1990	2030	1,055	BWR	GE	NDCT								
Maine Yankee Atomic Plant	—	1973	2013	825	PWR	CE	OT	Back River	426	River bank	Bay on Back River	740	Portland, Maine	220	640,000
William B. McGuire Nuclear Station	1	1981	2021	1,180	PWR	WEST	OT	Lake Norman	675	Submerged and surface at shoreline	2,000-ft canal discharge	30,000	Charlotte, N.C.	62	1,750,000
	2	1983	2023	1,180	PWR	WEST									
Millstone Nuclear Power Plant	1	1970	2010	660	BWR	GE	OT	Long Island Sound	420	Niantic Bay	Via holding ponds	500	New Haven, Conn.	927	2,760,000
	2	1975	2015	870	PWR	CE	OT		523						
	3	1986	2026	1,154	PWR	WEST	OT		907						
Monticello Nuclear Generating Plant	—	1970	2010	545	BWR	GE	OT with towers	Mississippi River	280	Canal	Canal	1,325	Minneapolis, Minn.	1,454	2,170,000
North Anna Power Station	1	1978	2018	907	PWR	WEST	OT	Lake Anna	940	Lake shore	Via cooling pond	18,643	Richmond, Va.	3,528	1,150,000
	2	1980	2020	907	PWR	WEST									

See footnotes at end of table.

Table 2.1 (continued)

Plant	Unit	Operating license	License expiration	Electrical rating [MW(e)]	Reactor type[a]	Steam supply system vendor[b]	Cooling system[c]	Cooling water source	Condenser flow rate (10^3 gal/min)	Intake structure	Discharge structure	Total site area (acres)	Nearest city	Transmission corridor (acres)	1990 population (50 miles)
Nine Mile Point Nuclear Station	1	1968	2008	620	BWR	GE	OT	Lake Ontario	250	Pipelines 1,000 ft off shore	Diffuser pipe	900	Syracuse, N.Y.	1,640	820,000
	2	1987	2027	1,080	BWR	GE	NDCT		580						
Oconee Nuclear Station	1	1973	2013	887	PWR	B&W	OT	Lake Keowee	680	710-ft deep skimmer wall	765 ft deep	510	Greenville, S.C.	7,800	990,000
	2	1973	2013	887	PWR	B&W									
	3	1974	2014	887	PWR	B&W									
Oyster Creek Generating Station	1	1969	2009	650	BWR	GE	OT	Barnegat Bay	460	Forked River from bay	Forked River to bay	1,416	Atlantic City, N.J.	322	4,030,000
Palisades Nuclear Plant	1	1972	2012	805	PWR	CE	MDCT	Lake Michigan	405	Crib 3,300 ft from shore	108-ft canal	487	Kalamazoo, Mich.	2,250	1,170,000
Palo Verde Generating Station	1	1985	2025	1,270	PWR	CE	MDCT	Phoenix City Sewage Treatment Plant	560	35-mile pipe	Evaporation ponds	4,050	Phoenix, Ariz.	16,600	1,180,000
	2	1986	2026	1,270	PWR	CE									
	3	1987	2027	1,270	PWR	CE									
Peach Bottom Atomic Power Station	2	1973	2013	1,065	BWR	GE	OT with towers	Conowingo Pond	750	Small intake pond	5,000-ft canal	620	Lancaster, Pa.	1,030	4,660,000
	3	1974	2014	1,065	BWR	GE									
Perry Nuclear Power Station	1	1986	2026	1,205	BWR	GE	NDCT	Lake Erie	545	Multiport 2,250 ft off shore	Diffuser 1,650 ft off shore	1,100	Euclid, Ohio	1,500	2,480,000
Pilgrim Nuclear Power Station	1	1972	2012	655	BWR	GE	OT	Cape Cod Bay	311	Edge of bay	850-ft canal	517	Brockton, Mass.	174	4,440,000
Point Beach Nuclear Plant	1	1970	2010	497	PWR	WEST	OT	Lake Michigan	350	1,750 ft from shore	Flumes 150 ft from shore	2,065	Green Bay, Wisc.	3,321	610,000
	2	1972	2012	497	PWR	WEST									
Prairie Island Nuclear Generating Plant	1	1973	2013	530	PWR	WEST	MDCT or OT	Mississippi River	294	Short canal	Basin to towers and/or river	560	Minneapolis, Minn.	973	2,290,000
	2	1974	2014	530	PWR	WEST									
Quad-Cities Station	1	1972	2012	789	BWR	GE	OT	Mississippi River	471	Edge of river	14,000-ft spray canal	784	Davenport, Iowa	1,400	740,000
	2	1972	2012	789	BWR	GE									
Rancho Seco Nuclear Station	1	1974	2014	918	PWR	B&W	NDCT	Folsom Canal	446	3.5-mile pipe	1.5-mile pipe to reservoir	2,480	Sacramento, Calif.	870	2,010,000

See footnotes at end of table.

Table 2.1 (continued)

Plant	Unit	Operating license	License expiration	Electrical rating [MW(e)]	Reactor type[a]	Steam supply system vendor[b]	Cooling system[c]	Cooling water source	Condenser flow rate (10^3 gal/min)	Intake structure	Discharge structure	Total site area (acres)	Nearest city	Transmission corridor (acres)	1990 population (50 miles)
River Bend Station	1	1985	2025	936	BWR	GE	MDCT	Mississippi River	508	At river bank	Into river	3,342	Baton Rouge, La.	1,014	800,000
H. B. Robinson Plant	2	1970	2010	700	PWR	WEST	OT	Lake Robinson	482	Edge of lake	4.2-mile canal	5,000	Columbia, S.C.	1,024	740,000
Salem Nuclear Generating Station	1	1976	2016	1,115	PWR	WEST	OT	Delaware River	1,100	Edge of river	500 ft into river	700	Wilmington, Del.	3,900	4,810,000
	2	1981	2021	1,115	PWR	WEST									
San Onofre Nuclear Generating Station	1	1967	2007	436	PWR	WEST	OT	Pacific Ocean	341	3,200 to 3,400 ft off shore	2,600 to 8,500 ft from shore	84	Oceanside, Calif.	1,100	5,430,000
	2	1982	2022	1,070	PWR	CE			797						
	3	1983	2023	1,080	PWR	CE			797						
Seabrook Station	1	1990	2032	1,198	PWR	WEST	OT	Atlantic Ocean	399	7,000 ft off shore	5,500 ft off shore	896	Lawrence, Mass.	1,545	3,760,000
Sequoyah Nuclear Plant	1	1980	2020	1,148	PWR	WEST	OT and/or NDCT	Chickamauga Lake	522	From lake	To lake	525	Chattanooga, Tenn.	1,260	930,000
	2	1981	2021	1,148	PWR	WEST									
Shoreham Nuclear Power Station	—	—	—	819	BWR	GE	OT	Long Island Sound	574	Intake canal	Diffuser system	499	New Haven, Conn.	39	5,390,000
South Texas Project	1	1988	2028	1,250	PWR	WEST	CCCP	Colorado River	907	Bank of river	Bank of river	12,350	Galveston, Texas	4,773	270,000
	2	1989	2029	1,250	PWR	WEST									
St. Lucie Plant	1	1976	2016	830	PWR	CE	OT	Atlantic Ocean	491	1,200 ft off shore	>1,200 ft off shore	1,132	West Palm Beach, Fla.	760	690,000
	2	1983	2023	830	PWR	CE									
Virgil C. Summer Nuclear Station	1	1982	2022	900	PWR	WEST	OT	Lake Monticello	485	Intake at shoreline	Discharge pond to lake	2,200	Columbia, S.C.	1,576	910,000
Surry Power Station	1	1972	2012	788	PWR	WEST	OT	James River	840	1.7-mile canal	2900-ft canal	840	Newport News, Va.	4,420	1,900,000
	2	1973	2013	788	PWR	WEST									
Susquehanna Steam Electric Station	1	1982	2022	1,050	BWR	GE	NDCT	Susquehanna River	448	River bank	240 ft from bank	1,075	Wilkes-Barre, Pa.	1,800	1,500,000
	2	1984	2024	1,050	BWR	GE									
Three Mile Island Nuclear Station	1	1974	2014	819	PWR	B&W	NDCT	Susquehanna River	430	At river bank	At shoreline	472	Harrisburg, Pa.	1,790	2,170,000

See footnotes at end of table.

Table 2.1 (continued)

Plant	Unit	Operating license	License expiration	Electrical rating [MW(e)]	Reactor type[a]	Steam supply system vendor[b]	Cooling system[c]	Cooling water source	Condenser flow rate (10^3 gal/min)	Intake structure	Discharge structure	Total site area (acres)	Nearest city	Transmission corridor (acres)	1990 population (50 miles)
Trojan Nuclear Plant	1	1975	2015	1,130	PWR	WEST	NDCT	Columbia River	429	At river bank	350 ft from bank	635	Portland, Ore.	1,260	1,850,000
Turkey Point Plant	3 4	1972 1973	2012 2013	693 693	PWR PWR	WEST WEST	Closed-cycle canal	Biscane Bay	624	Intake canal and barge canal	Canal system	24,000	Miami	817	2,700,000
Vermont Yankee Nuclear Power Station	1	1973	2013	540	BWR	GE	OT and towers	Connecticut River	366	Edge of river	Edge of river	125	Holyoke, Mass.	1,550	1,510,000
Vogtle Electric Generating Plant	1 2	1987 1989	2027 2029	1,101 1,160	PWR PWR	WEST WEST	NDCT	Savannah River	510	At river bank	Near shoreline	3,169	Augusta, Ga.	—	630,000
Waterford Steam Electric Station	3	1985	2025	1,104	PWR	CE	OT	Mississippi River	975	At river bank	At river bank	3,561	New Orleans	280	1,970,000
Watts Bar Nuclear Plant	1 2	— —	— —	1,170 1,170	PWR PWR	WEST WEST	NDCT NDCT	Chickamauga Lake	410	At lake bank	Holding pond to lake	1,170	Chattanooga, Tenn.	3,165	950,000
Washington Nuclear Project (WNP)	2	1984	2024	1,100	BWR	GE	MDCT	Columbia River	550	Offshore	175 ft from shoreline	Department of Energy, Hanford Reservation	Richland, Wash.	Hanford Reservation	280,000
Wolf Creek Generation Station	1	1985	2025	1,170	PWR	WEST	CCCP	Wolf Creek	500	Cooling lake	Cooling lake to embayment	9,818	Topeka, Kansas	2,900	200,000
Yankee Nuclear Power Station	1	1960	2000	175	PWR	WEST	OT	Deerfield River	140	Sherman Pond, 90 ft below surface	Sherman Pond	2,000	Pittsfield, Mass.	—	1,720,000
Zion Nuclear Plant	1 2	1973 1973	2013 2013	1,040 1,040	PWR PWR	WEST WEST	OT OT	Lake Michigan	735	2600 ft off shore	760 ft off shore	250	Waukegan, Ill.	145	7,480,000

[a] PWR = pressurized-water reactor; BWR = boiling-water reactor.

[b] B-W = Babcock and Wilcox; GE = General Electric; WEST = Westinghouse; C-E = Combustion-Engineering.

[c] OT = once through; NDCT = natural draft cooling tower; MDCT = mechanical draft cooling tower; CCCP = closed cycle cooling pond, lake, or reservoir.

ORNL-DWG95-7681

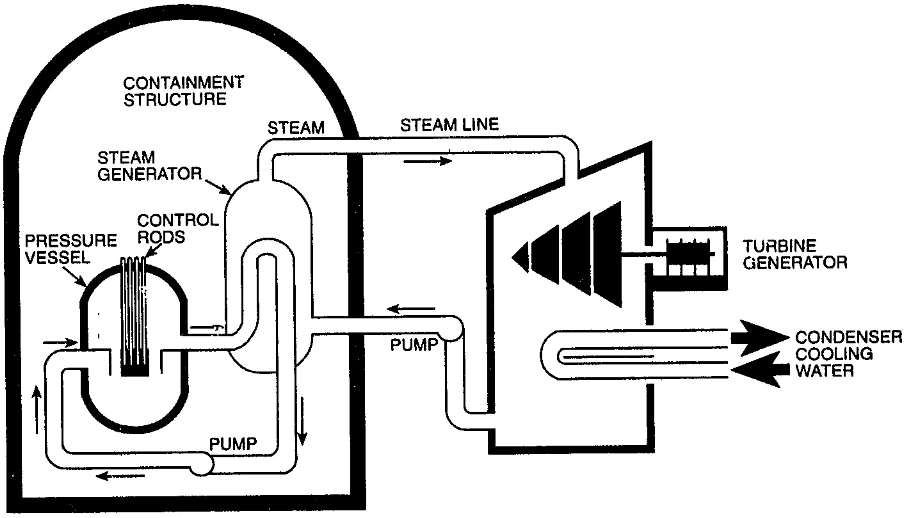

Figure 2.1 Pressurized-water-reactor power generation system.

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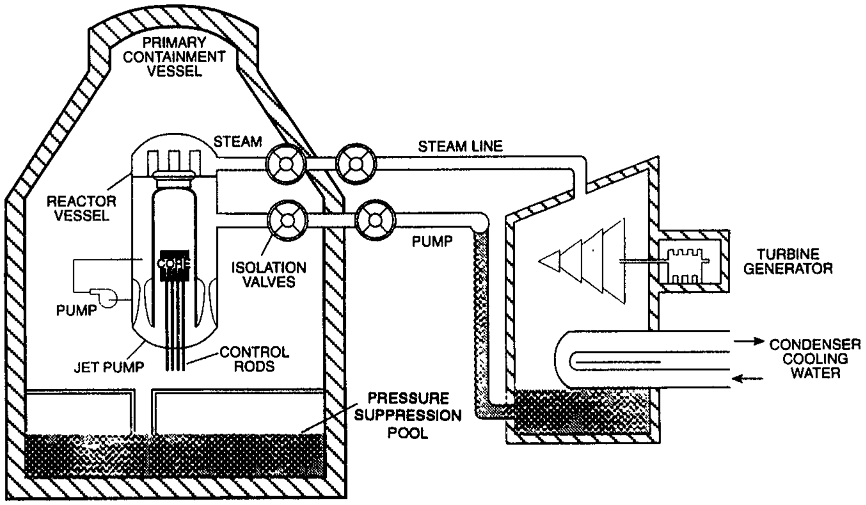

Figure 2.2 Boiling-water-reactor generating system.

In the PWR, reactor heat is transferred from the primary coolant to a secondary coolant loop that is at a lower pressure, allowing steam to be generated in the steam generator. The steam then flows to a turbine for power production. In contrast, the BWR generates steam directly within the reactor core, which passes through moisture separators and steam dryers and then flows to the turbine.

All domestic power reactors employ a containment structure as a major safety feature to prevent the release of radionuclides in the event of an accident. PWRs employ three types of containments: (1) large, dry containments; (2) subatmospheric containments; and (3) ice condenser containments. Of the 80 U.S. PWRs, 65 have large, dry containments; 7 have subatmospheric containments; and 8 have ice condenser containments. BWR containments typically are composed of a suppression pool and dry well. Three types of BWR containments (Mark I, Mark II, and Mark III) have evolved. There are 24 Mark I, 10 Mark II, and 4 Mark III containment designs in the United States.

NUREG/CR-5640 provides a comprehensive overview and description of U.S. commercial nuclear power plant systems.

2.2.3 Cooling and Auxiliary Water Systems

The predominant water use at a nuclear power plant is for removing excess heat generated in the reactor by condenser cooling. The quantity of water used for condenser cooling is a function of several factors, including the capacity rating of the plant and the increase in cooling water temperature from the intake to the discharge. The larger the plant, the greater the quantity of waste heat to be dissipated, and the greater the quantity of cooling water required.

In addition to removing heat from the reactor, cooling water is also provided to the service water system and to the auxiliary cooling water system. The volume of water required for these systems for once-through cooling is usually less than 15 percent of the volume required for condenser cooling. In closed-cycle cooling, the additional water needed is usually less than 5 percent of that needed for condenser cooling.

Of the 118 nuclear reactors, 48 use closed-cycle cooling systems (see Table 2.2, which groups the 74 plant sites into three broad categories according to environment). Most closed-cycle systems use cooling towers. Some closed-cycle system units use a cooling lake or canals for transferring heat to the atmosphere. Once-through cooling systems are used at 70 units. A few of these systems are augmented with helper cooling towers to reduce the temperature of the effluent released to the adjacent body of water.

In closed-cycle systems, the cooling water is recirculated through the condenser after the waste heat is removed by dissipation to the atmosphere, usually by circulating the water through large cooling towers constructed for that purpose. Several types of closed-cycle cooling systems are currently used by the nuclear power industry. Recirculating cooling systems consist of either natural draft or mechanical draft cooling towers, cooling ponds, cooling lakes, or cooling canals. Because the predominant cooling mechanism associated with closed-cycle systems is evaporation, most of the water

Table 2.2 **Types of cooling systems used at nuclear power sites**

Plant site	State	Cooling system[a]
Coastal or estuarine environment		
Diablo Canyon Nuclear Power Plant	California	Once through
San Onofre Nuclear Generating Station	California	Once through
Millstone Nuclear Power Plant	Connecticut	Once through
Crystal River Nuclear Plant	Florida	Once through
St. Lucie Plant	Florida	Once through
Turkey Point Plant	Florida	Cooling canal
Maine Yankee Atomic River Plant	Maine	Once through
Calvert Cliffs Nuclear Power Plant	Maryland	Once through
Pilgrim Nuclear Power Plant	Massachusetts	Once through
Seabrook Station	New Hampshire	Once through
Hope Creek Generating Station	New Jersey	Towers (natural draft)
Oyster Creek Generating Station	New Jersey	Once through
Salem Nuclear Generating Station	New Jersey	Once through
Indian Point Station	New York	Once through
Shoreham Nuclear Power Station	New York	Once through
Brunswick Steam Electric Plant	North Carolina	Once through
South Texas Project	Texas	Cooling pond
Surry Power Station	Virginia	Once through
Great Lakes shoreline environment		
Zion Nuclear Plant	Illinois	Once through
Big Rock Point Nuclear Plant	Michigan	Once through
Donald C. Cook Nuclear Power Plant	Michigan	Once through
Enrico Fermi Atomic Power Plant	Michigan	Towers (natural draft) and pond
Palisades Nuclear Plant	Michigan	Towers (mechanical draft)
James A. FitzPatrick Nuclear Power Plant	New York	Once through
Robert Emmett Ginna Nuclear Power Plant	New York	Once through
Nine Mile Point Nuclear Station	New York	Once through and towers
Davis-Besse Nuclear Power Station	Ohio	Towers (natural draft)
Perry Nuclear Power Station	Ohio	Towers (natural draft)
Kewaunee Nuclear Power Plant	Wisconsin	Once through
Point Beach Nuclear Plant	Wisconsin	Once through
Freshwater riverine or impoundment environment		
Bellefonte Nuclear Plant	Alabama	Towers (natural draft)
Browns Ferry Nuclear Power Plant	Alabama	Once through and helper towers
Joseph M. Farley Nuclear Plant	Alabama	Towers (mechanical draft)
Palo Verde Generating Station	Arizona	Towers (mechanical draft)
Arkansas Nuclear One	Arkansas	Once through and towers
Rancho Seco Nuclear Station	California	Towers (natural draft)
Haddam Neck Plant (Connecticut Yankee)	Connecticut	Once through
Edwin I. Hatch Nuclear Plant	Georgia	Towers (mechanical draft)
Vogtle Electric Generating Plant	Georgia	Towers (natural draft)
Braidwood Station	Illinois	Cooling pond
Byron Station	Illinois	Towers (natural draft)
Clinton Power Station	Illinois	Cooling pond

Table 2.2 (continued)

Plant site	State	Cooling system[a]
Freshwater riverine or impoundment environment (continued)		
Dresden Nuclear Power Station	Illinois	Spray canal and cooling pond
La Salle Country Station	Illinois	Cooling pond
Quad Cities Station	Illinois	Once through
Duane Arnold Energy Center	Iowa	Towers (mechanical draft)
Wolf Creek Generation Station	Kansas	Cooling pond
River Bend Station	Louisiana	Towers (mechanical draft)
Waterford Steam Electric Station	Louisiana	Once through
Yankee Nuclear Power Station	Massachusetts	Once through
Monticello Nuclear Generating Plant	Minnesota	Variable (mechanical draft)
Prairie Island Nuclear Generating Plant	Minnesota	Variable (mechanical draft)
Grand Gulf Nuclear Station	Mississippi	Towers (natural draft)
Callaway Plant	Missouri	Towers (natural draft)
Cooper Nuclear Station	Nebraska	Once through
Fort Calhoun Station	Nebraska	Once through
Shearon Harris Nuclear Power Plant	North Carolina	Towers (natural draft)
William B. McGuire Nuclear Station	North Carolina	Once through
Trojan Nuclear Plant	Oregon	Towers (natural draft)
Beaver Valley	Pennsylvania	Variable (natural draft)
Limerick Generating Station	Pennsylvania	Towers (natural draft)
Peach Bottom Atomic Power Station	Pennsylvania	Once through and towers (mechanical draft)
Susquehanna Steam Plant Station	Pennsylvania	Towers (natural draft)
Three Mile Island Nuclear Station	Pennsylvania	Towers (natural draft)
Catawba Nuclear Station	South Carolina	Towers (mechanical draft)
Oconee Nuclear Station	South Carolina	Once through
H. B. Robinson Plant	South Carolina	Cooling pond
Virgil C. Summer Nuclear Station	South Carolina	Cooling pond
Sequoyah Nuclear Plant	Tennessee	Variable (natural draft)
Watts Bar Nuclear Plant	Tennessee	Towers (natural draft)
Comanche Peak	Texas	Once through
Vermont Yankee Nuclear Power Station	Vermont	Once through and helper towers
North Anna Power Station	Virginia	Once through
Washington Nuclear Project-2	Washington	Towers (mechanical draft)

[a] Of the 48 plants with closed-cycle cooling systems, 15 use mechanical draft cooling towers, 25 use natural draft cooling towers, 4 use a canal system, and 4 use a cooling lake. Of the 70 plants with once-through cooling systems, 24 discharge to a river, 11 discharge to the Great Lakes, 19 discharge to the ocean or an estuary, and 16 discharge to a reservoir or lake. Five of the once-through plants can also switch to cooling towers.

used for cooling is consumed and is not returned to a water source.

In a once-through cooling system, circulating water for condenser cooling is drawn from an adjacent body of water, such as a lake or river, passed through the condenser tubes, and returned at a higher temperature to the adjacent body of water. The waste heat is dissipated to the atmosphere mainly by evaporation from the water body and, to a much smaller extent, by conduction, convection, and thermal radiation loss.

All sites with two or three reactors use the same cooling system for all reactors, except for two sites: Arkansas Nuclear One in Arkansas and Nine Mile Point in New York. These two sites use once-through cooling for one unit and closed-cycle for the other.

For both once-through and closed-cycle cooling systems, the water intake and discharge structures are of various configurations to accommodate the source water body and to minimize impact to the aquatic ecosystem. The intake structures are generally located along the shoreline of the body of water and are equipped with fish protection devices (ORNL/TM-6472). The discharge structures are generally of the jet or diffuser outfall type and are designed to promote rapid mixing of the effluent stream with the receiving body of water. Biocides and other chemicals used for corrosion control and for other water treatment purposes are mixed with the condenser cooling water and discharged from the system.

In addition to surface water sources, some nuclear power plants use groundwater as a source for service water, makeup water, or potable water. Other plants operate dewatering systems to intentionally lower the groundwater table, either by pumping or by using a system of drains, in the vicinity of building foundations.

2.2.4 Radioactive Waste Treatment Systems

During the fission process, a large inventory of radioactive fission products builds up within the fuel. Virtually all of the fission products are contained within the fuel pellets. The fuel pellets are enclosed in hollow metal rods (cladding), which are hermetically sealed to further prevent the release of fission products. However, a small fraction of the fission products escapes the fuel rods and contaminates the reactor coolant. The primary system coolant also has radioactive contaminants as a result of neutron activation. The radioactivity in the reactor coolant is the source of gaseous, liquid, and solid radioactive wastes at LWRs.

The following sections describe the basic design and operation of PWR and BWR radioactive-waste-treatment systems.

2.2.4.1 Gaseous Radioactive Waste

For BWRs, the sources of routine radioactive gaseous emissions to the atmosphere are the air ejector, which removes noncondensable gases from the coolant to improve power conversion efficiency, and gaseous and vapor leakages, which, after monitoring and filtering, are discharged to the atmosphere via the building ventilation systems.

The off-gas treatment system collects noncondensable gases and vapors that are exhausted at the condenser via the air ejectors. These off-gases are processed through a series of delay systems and filters to remove airborne radioactive particulates and halogens, thereby minimizing the quantities of the radionuclides that might be released. Building ventilation system exhausts are another source of gaseous radioactive wastes for BWRs.

PWRs have three primary sources of gaseous radioactive emissions:

- discharges from the gaseous waste management system;
- discharges associated with the exhaust of noncondensable gases at the main

condenser if a primary-to-secondary system leak exists; and
- radioactive gaseous discharges from the building ventilation exhaust, including the reactor building, reactor auxiliary building, and fuel-handling building.

The gaseous waste management system collects fission products, mainly noble gases, that accumulate in the primary coolant. A small portion of the primary coolant flow is continually diverted to the primary coolant purification, volume, and chemical control system to remove contaminants and adjust the coolant chemistry and volume. During this process, noncondensable gases are stripped and routed to the gaseous waste management system, which consists of a series of gas storage tanks. The storage tanks allow the short-half-life radioactive gases to decay, leaving only relatively small quantities of long-half-life radionuclides to be released to the atmosphere. Some PWRs are using charcoal delay systems rather than gas storage tanks (e.g., Seabrook).

2.2.4.2 Liquid Radioactive Waste

Radionuclide contaminants in the primary coolant are the source of liquid radioactive waste in LWRs. The specific sources of these wastes, the modes of collection and treatment, and the types and quantities of liquid radioactive wastes released to the environment are in many respects similar in BWRs and PWRs. Accordingly, the following discussion applies to both BWRs and PWRs, with distinctions made only where important differences exist.

Liquid wastes resulting from LWR operation may be placed into the following categories: clean wastes, dirty wastes, detergent wastes, turbine building floor-drain water,[1] and steam generator blowdown (PWRs only). *Clean wastes* include all liquid wastes with a normally low conductivity and variable radioactivity content. They consist of reactor grade water, which is amenable to processing for reuse as reactor coolant makeup water. Clean wastes are collected from equipment leaks and drains, certain valve and pump seal leaks not collected in the reactor coolant drain tank, and other aerated leakage sources. These wastes also include primary coolant. *Dirty wastes* include all liquid wastes with a moderate conductivity and variable radioactivity content that, after processing, may be used as reactor coolant makeup water. Dirty wastes consist of liquid wastes collected in the containment building sump, auxiliary building sumps and drains, laboratory drains, sample station drains, and other miscellaneous floor drains. *Detergent wastes* consist principally of laundry wastes and personnel and equipment decontamination wastes and normally have a low radioactivity content. *Turbine building floor-drain wastes* usually have high conductivity and low radionuclide content. In PWRs, *steam generator blowdown* can have relatively high concentrations of radionuclides depending on the amount of primary-to-secondary leakage. Following processing, the water may be reused or discharged.

Each of these sources of liquid wastes receives varying degrees and types of treatment before storage for reuse or discharge to the environment under the site National Pollutant Discharge Elimination System (NPDES) permit. The extent and types of treatment depend on the chemical and radionuclide content of the waste; to increase the efficiency of waste processing, wastes of similar characteristics are batched before treatment.

The degree of processing, storing, and recycling of liquid radioactive waste has steadily increased among operating plants. For example, extensive recycling of steam generator blowdown in PWRs is now the typical mode of operation, and secondary side wastewater is routinely treated. In addition, the plant systems used to process wastes are often augmented with the use of commercial mobile processing systems. As a result, radionuclide releases in liquid effluent from LWRs have generally declined or remained the same.

2.2.4.3 Solid Radioactive Waste

Solid low-level radioactive waste (LLW) from nuclear power plants is generated by removal of radionuclides from liquid waste streams, filtration of airborne gaseous emissions, and removal of contaminated material from various reactor areas. Liquid contaminated with radionuclides comes from primary and secondary coolant systems, spent-fuel pools, decontaminated wastewater, and laboratory operations. Concentrated liquids, filter sludges, waste oils, and other liquid sources are segregated by type, flushed to storage tanks, stabilized for packaging in a solid form by dewatering, slurried into 55-gal steel drums, and stored on-site in shielded Butler-style buildings or other facilities until suitable for off-site disposal (NUREG/CR-2907). These buildings usually contain volume reduction facilities to reduce the volume of LLW requiring off-site disposal (EPRI NP-5526-V1).

High-efficiency particulate filters are used to remove radioactive material from gaseous plant effluents. These filters are compacted in volume reduction facilities that have volume reduction equipment and are disposed of as solid wastes.

Solid LLW consists of contaminated protective clothing, paper, rags, glassware, compactible and noncompactible trash, and non–fuel-irradiated reactor components and equipment. Most of this waste comes from plant modifications and routine maintenance activities. Additional sources include tools and other material exposed to the reactor environment (EPRI-NP-5526-V1; EPRI NP-5526-V2). Before disposal, compactible trash is usually taken to on- or off-site VR facilities. Compacted dry active waste is the largest single form of LLW disposed from nuclear plants, comprising one-half and one-third of total average annual volumes from PWRs and BWRs, respectively (EPRI NP-5526V1).

Volume reduction efforts have been undertaken in response to increased disposal costs and the passage of the 1980 Low Level Radioactive Waste Policy Act and the 1985 Low Level Radioactive Waste Policy Amendments Act (LLRWPAA) (Pub. L. 96-573; Pub. L. 99-240), which require LLW disposal allocation systems for nuclear plants (see Section 6.3). Volume reduction is performed both on- and off-site. The most common on-site volume reduction techniques are high-pressure compacting of waste drums, dewatering and evaporating wet wastes, monitoring waste streams to segregate wastes, minimizing the exposure of routine equipment to contamination, and decontaminating and sorting radioactive or nonradioactive batches before off-site shipment. Off-site waste management vendors compact compactible wastes at ultra-high pressure (supercompaction); incinerate dry active waste; separate and incinerate oily, organic wastes; solidify the ash; and occasionally undertake waste crystallization and asphalt solidification of resins and sludges

(EPRI NP-6163; EPRI NP-5526-V1; EPRI NP-5526-V2; DOE/RW-0220).

Spent fuel contains fission products and actinides produced when nuclear fuel is irradiated in reactors, as well as any unburned, unfissioned nuclear fuel remaining after the fuel rods have been removed from the reactor core. After spent fuel is removed from reactors, it is stored in racks placed in storage pools to isolate it from the environment. Delays in siting an interim monitored retrievable storage (MRS) facility or permanent repository, coupled with rapidly filling spent-fuel pools, have led utilities to seek other storage solutions, including expansion of existing pools, aboveground dry storage, longer fuel burnup, and shipment of spent fuel to other plants (Gerstberger 1987; DOE RW-0220).

Pool storage has been increased through (1) enlarging the capacity of spent-fuel racks, (2) adding racks to existing pool arrays ("dense-racking"), (3) reconfiguring spent fuel with neutron-absorbing racks, and (4) employing double-tiered storage (installing a second tier of racks above those on the pool floor).

Efforts are under way to develop dry storage technologies; these include casks, silos, dry wells, and vaults (DOE December 1989). Dry storage facilities are simpler and more readily maintained than fuel pools. They are growing in favor because they offer a more stable means of storage and require relatively little land area (less than 0.2 ha—half an acre in most cases) (Johnson 1989). Dry storage is currently in use at about 5 percent of the sites.

2.2.4.4 Transportation of Radioactive Materials

There are four types of radioactive material shipments to and from nuclear plants: (1) routine and refurbishment-generated LLW transported from plants to disposal facilities, (2) routine LLW shipped to off-site facilities for volume reduction, (3) nuclear fuel shipments from fuel fabrication facilities to plants for loading into reactors (generally occurring on a 12- to 18-month cycle), and (4) spent-fuel shipments to other nuclear power plants with available storage space (an infrequent occurrence usually limited to plants owned by the same utility).

Workers and others are protected from exposure during radioactive material transport by the waste packaging. Operational restrictions on transport vehicles, ambient radiation monitoring, imposition of licensing standards (which ensure proper waste certification by testing and analysis of packages), waste solidification, and training of emergency personnel to respond to mishaps are also used (NUREG-0170; O'Sullivan 1988). Additional regulations may be imposed by states and communities along transportation corridors (Pub. L. 93-633; OTA-SET-304).

A typical PWR makes approximately 44 shipments of LLW per year; an average BWR makes 104 shipments per year (EPRI NP-5983). Most of this LLW is Class A waste packaged in 55-gal drums or other "Type A" containers and shipped to disposal facilities on flatbed trucks (DOE August 1989). (A "Type A" container permits no release of radioactive material under normal transportation conditions and must maintain sufficient shielding to limit radiation exposure to handling personnel).

LLW shipments require manifests that describe the contents of the packages to permit inspection by state, local, and facility personnel and to ensure that the waste is suitable for a particular disposal facility (NUREG-0945).

Currently, the only spent-fuel shipments from nuclear plants are to other plants. A few spent-fuel shipments have, in the past, been made to fuel reprocessing plants. These shipments are packaged in "Type B" casks designed to retain the highly radioactive contents under normal and accident conditions. These containers range in size from 23–36 metric tons (25–40 tons) for truck shipment (each cask is capable of holding seven fuel assemblies) to 109 metric tons (120 tons) for rail transport (with a capacity for 36 assemblies) (DOE/RW-0065). The casks are resistant to both small-arms fire and high-explosive detonation (NUREG-0170).

2.2.5 Nonradioactive Waste Systems

Nonradioactive wastes from nuclear power plants include boiler blowdown (continual or periodic purging of impurities from plant boilers), water treatment wastes (sludges and high saline streams whose residues are disposed of as solid waste and biocides), boiler metal cleaning wastes, floor and yard drains, and stormwater runoff. Principal chemical and biocide waste sources include the following:

- Boric acid used to control reactor power and lithium hydroxide used to control pH in the coolant. (These chemicals could be inadvertently released because of pipe or steam generator leakage.)
- Sulfuric acid, which is added to the circulating water system to control scale.
- Hydrazine, which is used for corrosion control. (It is released in steam generator blowdown.)
- Sodium hydroxide and sulfuric acid, which are used to regenerate resins. (These are discharged after neutralization.)
- Phosphate in cleaning solutions.
- Biocides used for condenser defouling.

Other small volumes of wastewater are released from other plant systems depending on the design of each plant. These are discharged from such sources as the service water and auxiliary cooling systems, water treatment plant, laboratory and sampling wastes, boiler blowdown, floor drains, stormwater runoff, and metal treatment wastes. These waste streams are discharged as separate point sources or are combined with the cooling water discharges.

2.2.6 Nuclear Power Plant Operation and Maintenance

Nuclear power reactors are capable of generating electricity continuously for long periods of time. However, they operate neither at maximum capacity nor continuously for the entire term of their license. Plants can typically operate continuously for periods of time ranging from 1 year to 18 months on a single fuel load. Scheduled and unscheduled maintenance outages and less than peak power generation resulting from diminished consumer demand, or operational decisions, have reduced the power output for the U.S. nuclear power industry as a whole to an average annual capacity of between 58 and 73 percent of the maximum capability for the years 1975 through 1993, inclusive (NUREG-1350, vol. 6).

Maintenance activities are routinely performed on systems and components to help ensure the safe and reliable operation of the plant. In addition, inspection, testing, and surveillance activities are conducted throughout the operational life of a nuclear power plant to maintain the current licensing basis of the plant and ensure compliance with federal, state, and local requirements regarding the environment and public safety.

Nuclear power plants must periodically discontinue the production of electricity for refueling, periodic in-service inspection (ISI), and scheduled maintenance. Refueling cycles occur approximately every 12 to 18 months. The duration of a refueling outage is typically on the order of 2 months. Enhanced or expanded inspection and surveillance activities are typically performed at 5- and 10-year intervals. These enhanced inspections are performed to comply with Nuclear Regulatory Commission (NRC) and/or industry standards or requirements such as the American Society of Mechanical Engineers Boiler and Pressure Vessel Code. Five-year ISIs are scheduled for the 5th, 15th, 25th, and 35th years of operation, and 10-year ISIs are performed in the 10th, 20th, and 30th years. Each of these outages typically requires 2 to 4 months of down time for the plant. For economic reasons, many of these activities are conducted simultaneously (e.g., refueling activities typically coincide with the ISI and maintenance activities).

Many plants also undertake various major refurbishment activities during their operational lives. These activities are performed to ensure both that the plant can be operated safely and that the capacity and reliability of the plant remain at acceptable levels. Typical major refurbishments that have occurred in the past include replacing PWR steam generators, replacing BWR recirculation piping, and rebuilding main steam turbine stages. The need to perform major refurbishments is highly plant-specific and depends on factors such as design features, operational history, and construction and fabrication details. The plants may remain out of service for extended periods of time, ranging from a few months to more than a year, while these major refurbishments are accomplished. Outage durations vary considerably, depending on factors such as the scope of the repairs or modifications undertaken, the effectiveness of the outage planning, and the availability of replacement parts and components.

Each nuclear power plant is part of a utility system that may own several nuclear power plants, fossil-fired plants, or other means of generating electricity. An on-site staff is responsible for the actual operation of each plant, and an off-site staff may be headquartered at the plant site or some other location. Typically, from 800 to 2300 people are employed at nuclear power plant sites during periods of normal operation, depending on the number of operating reactors located at a particular site. The permanent on-site work force is usually in the range of 600 to 800 people per reactor unit. However, during outage periods, the on-site work force typically increases by 200 to 900 additional workers. The additional workers include engineering support staff, technicians, specialty craftspersons, and laborers called in both to perform specialized repairs, maintenance, tests, and inspections and to assist the permanent staff with the more routine activities carried out during plant outages.

2.2.7 Power-Transmission Systems

Power-transmission systems associated with nuclear power plants consist of switching stations (or substations) located on the plant site and transmission lines located primarily off-site. These systems are required to transfer power from the generating station to the utility's network of power lines in its service area.

Switching stations transfer power from generating sources to power lines and regulate the operation of the power system. Transformers in switching stations convert the generated voltage to voltage levels appropriate for the power lines. Equipment for regulating system operation includes switches, power circuit breakers, meters, relays, microwave communication equipment, capacitors, and a variety of other electrical equipment. This equipment meters and controls power flow; improves performance characteristics of the generated power; and protects generating equipment from short circuits, lightning strikes, and switching surges that may occur along the power lines. Switching stations occupy on-site areas generally two to four times as large as areas occupied by reactor and generator buildings, but are not as visible as the plant buildings.

The length of power transmission lines constructed for nuclear plants varies from a few miles for some plants to hundreds of miles for others. Power line systems include towers (structures), insulator strings, conductors, and ground wires strung between towers. Power lines associated with nuclear plants usually have voltages of 230 kV, 345 kV, 500 kV, or 765 kV (see Section 4.5.1). They operate at a low frequency of 60 Hz (60 cycles per second) compared with frequencies of 55–890 MHz for television transmitters and 1000 MHz and greater for microwaves.

Most power line towers are double wooden poles ("H-frame" structure) or metal lattice structures that support one or two sets of conductors (three conductors per set; see Section 4.5.1). Tower height, usually between 21 and 51 m (70 and 170 ft), increases with line voltage. Strings of insulators connect the conductors to the towers. The tops of the towers support two ground wires that transmit the energy of lightning strikes to the ground. Thus, the ground wires prevent lightning strikes to the conductors, minimize the occurrence of power system outages, and protect vital power system components that could be damaged by lightning-caused power surges on the conductors.

2.3 PLANT INTERACTION WITH THE ENVIRONMENT

This section describes how nuclear plants interact with the environment. Nuclear power plants are sited, designed, and operated to minimize impacts to the environment, including plant workers. Land that could be used for other purposes is dedicated to electric power production for the life of the plant. The aesthetics of the landscape are altered because of the new plant structures; the surface and groundwater hydrology and terrestrial and aquatic ecology may be affected; the air quality may be affected; and, finally, the community infrastructure and services are altered to accommodate the influx of workers into the area. The environmental impact from plant operation is determined largely by waste effluent streams (gaseous, liquid, and solid); the plant cooling systems; the exposure of plant workers to radiation; and plant expenditures, taxes, and jobs.

Operational activities associated with nuclear power plants, including maintenance actions, often produce liquid discharges that are released to the surrounding environment. The major liquid effluent occurs in once-through cooling systems which discharge heat and chemicals into a receiving body of water, but all nuclear power plants have liquid effluents to some extent. To operate, power plants must obtain an NPDES permit that specifies discharge standards and monitoring requirements, and they are required to be strictly in compliance with the limits set by the permit. NPDES permits are issued by the Environmental Protection Agency (EPA) or a designated state water quality agency. They must be renewed every 5 years.

Any gaseous effluents generated are similarly controlled by the EPA and state permitting agencies, which require compliance with the Clean Air Act and any amendments added by the states. On-site incineration of waste products is controlled in this manner.

2.3.1 Land Use

Nuclear power plants are large physical entities. Land requirements generally amount to several hundred hectares for the plant site, of which 20 to 40 ha (50 to 100 acres) may actually be disturbed during plant construction. Other land commitments can amount to many thousands of hectares for transmission line rights-of-way (ROWs) and cooling lakes, when such a cooling option is used.

Nuclear power plants that began initial operation after the promulgation of the National Environmental Policy Act of 1969 (Pub. L. 91-190) or the Endangered Species Act of 1973 (Pub. L. 93-205) are sited and operate in compliance with these laws. Any modifications to the plants after the effective dates of these acts must be in compliance with the requirements of these laws. The Endangered Species Act applies to both terrestrial and aquatic biota. The individual states may also have requirements regarding threatened and endangered species; the state-listed species may vary from those on the federal lists.

2.3.2 Water Use

Nuclear power plants withdraw large amounts of mainly surface water to meet a variety of plant needs (Section 2.2.3). Water withdrawal rates are large from adjacent bodies of water for plants with once-through cooling systems. Flow through the condenser for a 1,000-MW(e) plant may be 45 to 65 m^3/s (700,000 to 1,000,000 gal/min). Water lost by evaporation from the heated discharge is about 60 percent of that which is lost through cooling towers. Additional water needs for service water, auxiliary systems, and radioactive waste systems account for 1 to 15 percent of that needed for condenser cooling.

Water withdrawal from adjacent bodies of water for plants with closed-cycle cooling systems is 5 to 10 percent of that for plants with once-through cooling systems, with much of this water being used for makeup of water by evaporation. With once-through cooling systems, evaporative losses are about 40 percent less but occur externally in the adjacent body of water instead of in the closed-cycle system. The average makeup water withdrawals for several recently constructed plants having closed-cycle cooling, normalized to 1,000 MW(e), are about 0.9 to 1.1 m^3/s (14,000 to 18,000 gal/min). Variation results from cooling tower design, concentration factor of recirculated water, climate at the site, plant operating conditions, and other plant-specific factors.

Consumptive loss normalized to 1,000 MW(e) is about 0.7 m^3/s (11,200 gal/min), which is about 80 percent of the water volume taken in. Consumptive water losses remove surface water from other uses downstream. In those areas experiencing water availability problems, nuclear power plant consumption may conflict with other existing or potential closed-cycle uses (e.g., municipal and agricultural water withdrawals) and in-stream uses (e.g., adequate in-stream flows to protect aquatic biota, recreation, and riparian communities). The environmental impacts of consumptive water use are considered in Sections 4.2.1 and 4.2.2.

As discussed in Section 2.2.3, some nuclear power plants use groundwater as an additional source of water. The rate of usage varies greatly among users. Many plants use groundwater only for the potable water system and require less than 0.006 m^3/s (100 gal/min); however, withdrawals at other sites can range from 0.02 to 0.2 m^3/s (400 to 3000 gal/min). Impacts associated with groundwater use are discussed in Sections 4.2.2, 4.3.2, and 4.4.3.

Nuclear plant water usage must comply with state and local regulations. Most states require permits for surface water usage. Groundwater usage regulations vary considerably from state to state, and permits are typically required.

2.3.3 Water Quality

Water quality is impacted by the numerous nonradioactive liquid effluents discharged from nuclear power plants (Section 2.1.6). Discharges from the heat dissipation system account for the largest volumes of water and usually the greatest potential impacts to water quality and aquatic systems, although other systems may contribute heat and toxic chemical contaminants to the effluent. The relatively small volumes of water required for the service water and auxiliary cooling water systems do not generally raise concerns about thermal or chemical impacts to the receiving body of water. However, because effluents from these systems contain contaminants that could be toxic to aquatic biota, their concentrations are regulated under the power plant's NPDES discharge permit. The quality of groundwater may also be diminished by water from cooling ponds seeping into the underlying groundwater table.

Sewage wastes and cleaning solvents, including phosphate cleaning solutions, are treated as sanitary wastes. They are treated before release to the environment so that, after release, their environmental impacts are minimized. In cases where nonradioactive sanitary or other wastes cannot be processed by on-site water treatment systems, the wastes are collected by independent contractors and trucked to off-site treatment facilities. Water quality issues relate to the following: NPDES permit system for regulating low-volume wastewater, adequate wastewater treatment capacity to handle increased flow and loading associated with operational changes to the plant and discharges of wastes through emission of phosphates from utility laundries, suspended solids and coliforms from sewage treatment discharges, and other effluents that cause excessive biological oxygen demand.

Many power plants are periodically treated with biocidal chemicals (most commonly some form of chlorine) to control fouling and bacterial slimes. Discharge of these chemicals to the receiving body of water can have toxic effects on aquatic organisms. The biological and water quality impacts of discharges from the discharge systems are considered in Sections 4.2, 4.3, and 4.4.

Chlorine is used widely as a biocide at nuclear power plants and represents the largest potential source of chemically toxic release to the aquatic environment. Chlorine application as a cooling system biocide is typically by injection in one of several different forms, including chlorine gas or sodium hypochlorite. It may be injected at the intake or targeted at various points (such as the condensers) on an intermittent or continuous basis. Such treatments control certain pest organisms such as the Asiatic clam or the growth of bacterial or fungal slime (TVA 1978). The control of biological pests or growths is critical to maintaining optimum system performance and minimizing operating costs (EPRI CS-3748).

Because of the evolution of the guidelines pertaining to chlorine and changes in biocide technologies over the past 15 years, the potential for any adverse impacts of chlorine has been decreasing. Improvements in dechlorination technologies are likely to significantly reduce the level of chlorine in the aquatic environment. Given the critical need for controlling biofouling in the cooling system, both alternative and chlorine treatment technologies are expected to keep pace with regulatory requirements.

All effluent discharges are regulated under the provisions of the Clean Water Act and the implementing effluent guidelines, limitations, and standards established by EPA and the states. Conditions of discharge for each plant are specified in its NPDES permit issued by the state or EPA.

2.3.4 Air Quality

Transmission lines have been associated with the production of minute amounts of ozone and oxides of nitrogen. These issues are associated with corona, the breakdown of air very near the high-voltage conductors. Corona is most noticeable for the higher-voltage lines and during foul weather. Through the years, line designs have been developed that greatly reduce corona effects.

The effluents created and released from the incineration of any waste products must comply with EPA and state requirements regarding air quality. Permits for release of controlled amounts of these effluents to the atmosphere are controlled by state permitting agencies. Because nuclear power plants generally do not produce gaseous effluents, the impact on air quality is minimal.

2.3.5 Aquatic Resources

Operation of the once-through (condenser cooling) system requires large amounts of water that are withdrawn directly from surface waters. These surface waters contain aquatic organisms that may be injured or killed through their interactions with the power plant. Aquatic organisms that are too large to pass through the intake debris screens, which commonly have a 1-cm (0.4-in.) mesh, and that cannot move away from the intake, may be impinged against the screens. If the organisms are held against the screen for long periods, they will suffocate; if they receive severe abrasions, they may die. Impingement can harm large numbers of fish and large invertebrates (e.g., crabs, shrimp, and jellyfish).

Aquatic organisms that are small enough to pass through the debris screens will travel through the entire condenser cooling system and be exposed to heat, mechanical, and pressure stresses, and possibly biocidal chemicals, before being discharged back to the body of water. This process, called entrainment, may affect a wide variety of small plants (phytoplankton), invertebrates (zooplankton), fish eggs, and larvae (ichthyoplankton). Entrainment mortality is variable. Conditions at some plants with once-through cooling may result in relatively low levels of mortality, although at such plants the volumes of water (and numbers of entrained organisms) are often high. On the other hand, generally no aquatic organisms survive at plants with closed-cycle cooling that recirculate water through cooling towers, although the volumes of water withdrawn are relatively low. Biological effects of entrainment and impingement are considered in Section 4.2.3.

Discharges from the plant heat rejection system may affect the receiving body of water through heat loading and chemical contaminants, most notably chlorine or other biocides. Heated effluents can kill aquatic organisms directly by either heat shock or cold shock. In addition, a number of indirect or sublethal stresses are associated with thermal discharges that have the potential to alter aquatic communities (e.g., increased incidence of disease, predation, or parasitism, as well as changes in dissolved gas concentrations).

As stated in Section 2.3.3, all effluent discharges are regulated by the Clean Water Act and standards established by the EPA and the individual states. Conditions of discharge for each plant are specified in the NPDES permit issued for that plant.

2.3.6 Terrestrial Resources

A number of ongoing issues associated with terrestrial resources can arise in the immediate area around the plant or its power transmission lines. Most power lines are located on easements (or ROWs) that the utility purchased from the landowner. Land uses on the easements are limited to activities compatible with power-line operation. In areas with rapidly growing vegetation, utilities must periodically cut or spray the vegetation to prevent it from growing so close to the conductors that it causes short circuits and endangers power line operation. Other terrestrial resource issues can result from changes in local hydrology. Such changes can occur from altered contouring of the land, reduced tree cover, and increased paving. These changes can reduce the value of land and contribute to local erosion and flooding. Additional impacts can include the effects of cooling tower effluent drift, reduced habitat for plants and animals, disruption of animal transit routes, and bird collisions with cooling towers and transmission lines.

Each plant planning to apply for license renewal will need to consult with the appropriate agency administering the Endangered Species Act of 1973 about the presence of threatened or endangered species. Compliance with the Endangered Species Act will be a necessary part of each plant's environmental documentation at the time of license renewal.

2.3.7 Radiological Impacts

2.3.7.1 Occupational Exposures

Plant workers conducting activities involving radioactively contaminated systems or working in radiation areas can be exposed to radiation. Most of the occupational radiation dose to nuclear plant workers results from external radiation exposure rather than from internal exposure from inhaled or ingested radioactive materials. Experience has shown that the dose to nuclear plant workers varies from reactor to reactor and from year to year. Since the early 1980s, when NRC regulatory requirements and guidance placed increased emphasis on maintaining nuclear power plant occupational radiation exposures as low as reasonably achievable, there has been a decreasing trend in the average annual dose per nuclear plant worker.

The effect of plant refurbishment on occupational doses is evaluated in Sections 3.8.2 and in Appendix B. Similarly, the effect of continued operation associated with license renewal on occupational doses is evaluated in Section 4.6.3.

2.3.7.2 Public Radiation Exposures

Commercial nuclear power reactors, under controlled conditions, release small amounts of radioactive materials to the environment during normal operation. These releases result in radiation doses to humans that are small relative to doses from natural radioactivity. Nuclear power plant licensees must comply with NRC regulations (e.g., 10 CFR Part 20, Appendix I to 10 CFR Part 50, 10 CFR Part 50.36a, and 40 CFR Part 190) and conditions specified in the operating license.

Potential environmental pathways through which persons may be exposed to radiation originating in a nuclear power reactor include atmospheric and aquatic pathways. Radioactive materials released under controlled conditions include fission products and activation products. Fission product releases consist primarily of the noble gases and some of the more volatile materials like tritium, isotopes of iodine, and cesium. These materials are monitored carefully before release to determine whether the limits on releases can be met. Releases to the aquatic pathways are similarly monitored. Radioactive materials in the liquid effluents are processed in radioactive waste treatment systems (Section 2.2.4). The major radionuclides released to the aquatic systems are tritium, isotopes of cobalt, and cesium.

When an individual is exposed through one of these pathways, the dose is determined in part by the exposure time, and in part by the amount of time that the radioactivity inhaled or ingested is retained in the individual's body. The major exposure pathways include the following:

- inhalation of contaminated air,
- drinking milk or eating meat from animals that graze on open pasture on which radioactive contamination may be deposited,
- eating vegetables grown near the site, and
- drinking (untreated) water or eating fish caught near the point of discharge of liquid effluents.

Other less important exposure pathways include external irradiation from surface deposition; consumption of animals that drink irrigation water that may contain liquid effluents; consumption of crops grown near the site using irrigation water that may contain liquid effluents; shoreline, boating, and swimming activities; and direct off-site irradiation from radiation coming from the plant.

Radiation doses to the public are calculated in two ways. The first is for the maximally exposed person (that is, the real or hypothetical individual potentially subject to maximum exposure). The second is for average individual and population doses. Doses are calculated using site-specific data where available. For those cases in which site-specific data are not readily available, conservative (overestimating) assumptions are used to estimate doses to the public.

2.3.7.3 Solid Waste

Both nonradioactive and radioactive wastes are generated at nuclear power plants. The nonradioactive waste is generally not of concern unless it is classified as Resource Conservation and Recovery Act (RCRA) waste. All waste that is hazardous, that is, classified as RCRA waste, is packaged and disposed of in a licensed landfill consistent with the provisions of RCRA.

Hazardous chemicals, properly handled and controlled, do not present a major health risk to personnel at nuclear power plants, but they must be understood and treated carefully. Hazardous chemicals may be encountered in the work environment during adjustments to the chemistry of the primary and secondary coolant systems, during biocide application for fouling of heat removal equipment, during repair and replacement of equipment containing hazardous oils or other chemicals, in solvent cleaning, and in the repair of equipment. Exposures to hazardous chemicals are minimized by observing good industrial hygiene practices. Disposal of essentially all of the hazardous chemicals used at nuclear power plants is regulated by RCRA or NPDES permits.

Solid radioactive waste consists of LLW, mixed waste, and spent fuel. LLW is generated by removal of radionuclides from liquid waste streams, filtration of airborne gaseous emissions, and removal of contaminated material from the reactor environment.

Mixed waste is LLW that contains chemically hazardous components as defined under RCRA. Mixed waste consists primarily of decontamination wastes and ion exchange resins. The volume of mixed wastes produced at nuclear power plants is typically a small fraction of their overall waste stream, accounting for less than 3 percent by volume of the annual LLW discharged.

Spent fuel is produced during reactor operations. The buildup of fission products and actinides during normal operation prevents the continued use of the fuel assembly. Spent fuel is stored at the reactor site. Uncertainty exists as to when an MRS or permanent spent-fuel repository may become available. However, NRC has examined this issue and determined that licensees may, without significant impact on the environment, store spent fuel on-site for 80 years after ceasing reactor operation (55 FR 38474).

Four major considerations must be addressed when managing solid radioactive waste: (1) the adequacy of interim storage on-site in lieu of permanent off-site disposal, (2) transport of the radiological wastes to disposal sites over the nation's highways and railways, (3) worker and public radiation exposure resulting from handling and processing operations and transportation, and (4) final disposal.

LLW is normally temporarily stored on-site before being shipped to licensed LLW disposal facilities. Previously these facilities were at Barnwell, South Carolina; Beatty, Nevada; and Hanford, Washington. Under the Low Level Radioactive Waste Policy Act of 1980 and the LLRWPAA of 1985, states must secure their own disposal capacity for LLW generated within their boundaries after 1992 by forming waste compacts that are responsible for siting regional disposal facilities, or by siting their own disposal facilities.

For disposal purposes, mixed waste is principally regulated by NRC (10 CFR Part 61). Although the LLRWPAA of 1985 required states to certify they are capable of providing storage and disposal of mixed wastes in an NRC/EPA-licensed facility by 1992, there are currently no licensed disposal facilities accepting commercially generated mixed waste. Because these facilities are not yet available, mixed waste is currently stored on-site.

Originally, disposal of spent fuel in a deep-geological repository was contemplated. However, because of delays in siting a permanent repository on the part of the Department of Energy and delays in developing an interim MRS facility, as required by the Nuclear Waste Policy Act of 1982, nuclear power plants are storing their spent fuel on-site.

LLW is compacted and packaged, typically in 55-gal drums, then transported via truck or railcar. The packaging and transportation of both LLW and mixed waste must comply with EPA requirements. NRC specifications for reviewing the environmental effects of the transport of spent fuel are contained in the Table S-4 Rule (54 FR 187; 10 CFR Part 51.52). States and communities along transportation corridors may impose additional restrictions on the transport of nuclear waste.

Workers receive radiation exposure during the storage and handling of radioactive waste and during the inspection of stored radioactive waste. However, this source of exposure is small compared with other sources of exposure at operating nuclear plants. Members of the general public are also exposed when the LLW is shipped to a disposal site. No other type of radioactive waste is currently being transported from the reactor sites. The public radiation exposures from radioactive material transportation have been addressed generically in Table S-4 of 10 CFR Part 51. Table S-4 indicates that the cumulative dose to the exposed public from the transport of both LLW and spent fuel is estimated to be about 0.03 person-sievert (3 person-rem) per reactor year.

2.3.8 Socioeconomic Factors

2.3.8.1 Work Force

Although the size of the work force varies considerably among U.S. nuclear power plants, the on-site staff responsible for operational activities generally consists of 600 to 800 personnel per reactor unit. The average permanent staff size at a nuclear power plant site ranges from 800 to 2400 people, depending on the number of operating reactors at the site. In rural or low population communities, this number of permanent jobs can provide employment for a substantial portion of the local work force. Table 2.3 depicts mean employment during normal operations in the 1975–1990 period, grouped by the number of reactors.

In addition to the work force needed for normal operations, many nonpermanent personnel are required for various tasks that occur during outages, for example, refueling outages, ISIs, or major refurbishments. Between 200 and 900 additional workers may be employed during these outages to perform the normal outage maintenance work. These are work force personnel who will be in the local community only a short time, but during these periods of extensive maintenance activities, the additional personnel will have a substantial effect on the locality. Table 2.4 indicates the levels of additional personnel typically required for different types of outages.

A substantial portion of the regular plant work force is normally involved in many of the efforts listed in Table 2.4, supplemented as needed by contractor personnel for support during specialized projects. Peak crew sizes are greatly affected by the specific requirements at each plant, utility decisions to make major repairs to systems and components to improve or sustain plant performance, and the relative phasing (schedule overlap) of these activities. Exact crew sizes can, therefore, vary widely from plant to plant.

2.3.8.2 Community

Typically, the immediate environment in which a nuclear power plant is located is rural, but the population density of the larger area surrounding the plant and the distance from a medium- or large-sized metropolitan center varies substantially across sites. Most sites, however, are not extremely remote [i.e., not more than about 30 km (20 miles) from a community of 25,000 or 80 km (50 miles) from a community of 100,000]. The significance of any given nuclear power plant to its host area will depend to a large degree on its location, with the effects generally being most concentrated in those communities

Table 2.3 Changes in mean operations-period employment at nuclear power plants over time

Operations period	One-unit plants[a]	Two-unit plants[a]	Three-unit plants[a]
Current[b]	832 (34)	1247 (28)	2404 (4)
1985-1989	841 (30)	1094 (26)	2095 (4)
1980-1984	447 (19)	946 (21)	1078 (3)
1975-1979	233 (17)	515 (16)	699 (3)

[a] Number in parentheses indicates number of plants providing data.

[b] Approximately half the respondents reported data for 1989 and half for 1990.

Table 2.4 **Mean additional employment per reactor unit associated with three outage types at nuclear power plants**

Outage type[a]	Number of workers
Typical planned (58)	783
In-service inspection (23)	734
Largest single (45)	1148

[a] Number in parentheses indicates number of plants providing data for the survey (NUMARC).

closest to the plant. Major influences on the local communities include the plant's effects on employment, taxes, housing, off-site land use, economic structure, and public services.

As noted in Section 2.3.8.1, the average nuclear power plant directly employs 800 to 2400 people. Many hundreds of additional jobs are provided through plant subcontractors and service industries in the area. In rural communities, industries that provide this number of jobs at relatively high wages are major contributors to the local economy. In addition to the beneficial effect of the jobs that are created, local plant purchasing and worker spending can generate considerable income for local businesses.

Nuclear power plants represent an investment of several billion dollars. Such an asset on the tax rolls is extraordinary for rural communities and can constitute the major source of local revenues for small or remote taxing jurisdictions. Often, this revenue can allow local communities to provide higher quality and more extensive public services with lower tax rates. In general, capital expenditures and large changes in public services are seldom necessitated by the presence of the plant and its operating workers, particularly after local communities have adapted to greater and more dynamic changes experienced during plant construction.

As this discussion indicates, nuclear power plants can have a significant positive effect on their community environment. These effects are stable and long term. Because these socioeconomic effects generally enhance the economic structure of the local community, nuclear power plants are accepted by the community, and indeed, become a major positive contributor to the local environs.

2.4 LICENSE RENEWAL—THE PROPOSED FEDERAL ACTION

This section provides a brief overview of the most significant requirements of the proposed revision to 10 CFR Part 54, "Nuclear Power Plant License Renewal" (FR 59, no. 174, p. 46574).

Under the license renewal rule (10 CFR Part 54), nuclear power plant licensees would be allowed to operate their plants for a maximum of 20 years past the terms of their original 40-year operating licenses provided that certain requirements are met (Section 1.1). The rule requires licensees submitting license renewal applications to perform specified types of evaluations and assessments of their facilities, and to provide sufficient information for the NRC to determine whether continued operation of the facility during the renewal term would endanger public safety or the environment.

License renewal will be based on ensuring plant compliance with its current licensing basis (i.e., the original plant licensing basis as amended during the initial license term). In addition, licensees will be required to demonstrate for certain important systems, structures, and components (SSCs) that the effects of aging will be managed in the renewal period in a manner so that the important functions of these SSCs will be maintained. The SSCs of concern in the renewal period are those which traditionally do not have readily monitorable performance or condition characteristics and include most passive, long-lived plant SSCs. Therefore, the NRC's license renewal rule requires a systematic review of, at least, passive, long-lived SSCs that support safety or other critical functions of a nuclear power plant (as delineated in the rule). To make these determinations regarding these SSCs, it is expected that licensees will implement aging management activities for SSCs for which current programs may not be adequate to ensure continued functionality in the renewal term. These aging management activities are expected to include surveillance, on-line monitoring, inspections, testing, trending, repair, refurbishment, replacement, and recordkeeping, as appropriate.

The license renewal rule seeks to ensure that the effects of aging in the period of extended operation are adequately managed. The rule allows credit for existing programs and regulatory requirements that continue to be applicable in the period of extended operation and that provide adequate management of the effects of aging for SSCs. This provision includes credit for rules or requirements, such as those incorporated in the maintenance rule, which could impact license renewal activities performed to detect and mitigate age-related functionality degradation.

The rule requires an integrated plant assessment (IPA). License renewal applicants must perform an IPA to determine which SSCs will be subject to additional review. The IPA would then determine whether additional programs, over and above the current operational and maintenance programs, are required to manage the effects of aging so that equipment function is maintained.

In addition, the license renewal rule requires licensees submitting an application for license renewal to provide the following:

- information noting any changes in the current licensing basis that occur during NRC's review of the submittal; and
- an evaluation of time-limited aging analyses (i.e., issues such as fatigue, equipment qualification, and reactor-vessel neutron embrittlement which have inherent time limits associated with them).

Key aspects of 10 CFR Part 54 could result in environmental impacts because of the requirements imposed. These key aspects are (1) the enhanced surveillance, on-line monitoring, inspections, testing, trending, and recordkeeping (SMITTR) on SSCs identified in the IPA and (2) the resulting actions taken to ensure that aging would be effectively managed and that the functionality of these SSCs would be maintained throughout the term that the new license would be in effect.

Note that the license renewal rule does not require any specific repairs, refurbishments, or modifications to nuclear facilities, but only that appropriate actions be taken to ensure the continued functionality of SSCs in the scope of the rule.

2.5 BASELINE ENVIRONMENTAL IMPACT INITIATORS ASSOCIATED WITH CONTINUED OPERATION OF NUCLEAR POWER PLANTS

The previous sections identified the various types of environmental impacts associated with current nuclear power plant operation. Before discussing incremental impacts associated with license renewal, it is useful to first establish a baseline from which to evaluate incremental effects. This baseline is provided by current experience with nuclear power plant operation and the related interactions with the environment. This section presents quantitative information on selected environmental "impact initiators." The term "impact initiators" is defined, followed by estimates of the quantities of each initiator currently generated by typical nuclear power plant operation.

2.5.1 Definition of Environmental Impact Initiators

The terms "environmental impact initiators" and "impact initiators" as used here refer to the precursors to possible environmental impacts. For example, the incremental work force needed to accomplish license renewal activities is not an environmental impact, but the associated effects on housing, transportation, schools, etc., are environmental or socioeconomic impacts. The environmental impact initiators that need to be quantified to estimate overall environmental effects resulting from license renewal are as follows:

- Labor hours and work force size associated with on-site craft workers, engineering and administrative personnel, and health physics personnel are needed to estimate socioeconomic impacts to communities affected by personnel employed temporarily at nuclear plants.
- Labor costs are used to estimate both economic impacts to affected communities and economic viability of extended plant operation through license renewal.
- Occupational radiation exposure is used to estimate radiation-related impacts to workers.
- Capital costs of hardware, materials, and equipment are used both to estimate tax-base-related impacts to affected communities and to provide information related to the overall economics of license renewal.
- Radioactive waste types, volumes, and disposal costs are used to estimate environmental impacts related to the disposal of such wastes.

These impact initiators are the key elements expected to change, relative to current nuclear plant operation, as a result of actions taken to support license renewal. Other environmental considerations, including water usage, land usage, chemical usage/discharges, and air quality, are not anticipated to change significantly as a result of license renewal activities.

The impact initiators assessed—labor force, labor costs, capital costs, occupational radiation exposure, and radioactive waste volumes—help determine most of the potential changes in environmental impacts resulting from license renewal. For example, estimates of refurbishment labor and capital cost, together with a description of the types of refurbishment activities that might be undertaken, help define potential environmental impacts related to refurbishment period land use, water use, air quality, socioeconomics, nonradiological solid wastes, etc. The impact initiators assessed form a sufficient set from which to assess most license renewal-related environmental impacts. Also, the focus is on changes in impact initiators originating from plant activities, as opposed to changes in the plant environs or receptors (e.g., changes in the population affected by the plant).

2.5.2 Baseline Environmental Impact Initiator Estimates

The following discussions provide estimates of the baseline quantities for each of the foregoing impact initiators. These baseline quantities are typical of current nuclear plant operation.

2.5.2.1 Baseline Work Force Size and Expenditures for Labor

Table 2.3 indicates that the current work force at nuclear plant sites is typically in the range of 830 to 2400 permanent staff, depending on the number of operating reactors at a site. On-site personnel responsible for operational activities generally number between 600 and 800 per reactor unit. The average number of permanent staff per reactor unit is estimated to be about 700 people, and this number is approximately the same for both BWRs and PWRs. Assuming a normal 40-hour work week for most on-site staff, this staffing translates into an annual labor effort of about 1.5 million labor hours per unit. The permanent staff is augmented by temporary workers called in to assist with outage activities and special projects. The associated expenditures for labor, including an allowance of roughly 20 percent for temporary staff to support outages and special projects, is estimated to be about $77,000,000 annually per unit.

2.5.2.2 Baseline Capital Expenditures

Nuclear power plants incur expenditures for three major types of capital additions. There are (1) major plant retrofits needed to satisfy NRC requirements to ensure safe plant operation (e.g., changes required as a result of resolution of a generic safety issue), (2) major repairs needed to keep the plant operational (such as main turbine-generator repairs), and (3) discretionary activities undertaken to improve plant performance and labor productivity (DOE/EIA-0547). Expenditures for capital additions have varied widely from plant to plant and from one year to another. In 1989, the average expenditure for capital additions was about $24 per kilowatt, or roughly $24 million for a 1000-MW(e) plant (1989 dollars). These expenditures equate to about $28 million per year per 1000-MW(e) plant in 1994 dollars.

2.5.2.3 Baseline Occupational Radiation Exposure

Occupational radiation exposures vary considerably from plant to plant and from year to year at a given plant. The long-term trends indicate that overall worker exposure has been decreasing on a per-plant basis. The average occupational exposure for the year 1989 was roughly 4.4 person-sievert (440 person-rem) per plant at BWRs and about 3 person-sievert (300 person-rem) per plant at PWRs. For the years 1991 to 1993, the average exposure for all U.S. nuclear plants was about 2.5 person-sievert (250 person-rem) per plant (NUREG-1350, v.6). Significant deviations from these averages are routinely experienced, depending largely on whether a given plant had an outage during a given year and the nature and extent of refurbishment or repair activities undertaken during outages.

2.5.2.4 Baseline Radioactive Waste Generation

Section 2.2.4.3 discussed the different types of radioactive wastes typically generated at nuclear power plants. The type of waste generated in the greatest volumes is LLW. The volume of LLW disposed of annually has shown a decreasing trend over the past several years. Most recently, the amount of LLW disposed of at PWRs has been about 250 m^3/year (8800 ft^3/year); in contrast, the amount disposed of at BWRs has been about 560 m^3/year (19,700 ft^3/year).

Small volumes of mixed wastes are also generated by nuclear plant operation. However, any such waste that cannot be treated to eliminate the chemical hazards is currently stored on-site at the nuclear plants and not shipped for disposal.

U.S. reactors generate high-level wastes, primarily in the form of spent fuel. The quantities of spent fuel generated on a per-reactor-year basis is not expected to change with license renewal.

2.6 ENVIRONMENTAL IMPACT INITIATORS ASSOCIATED WITH LICENSE RENEWAL AND CONTINUED OPERATION

2.6.1 Scope and Objectives of Section 2.6

A major objective of the GEIS is to support the proposed changes to 10 CFR Part 51 by defining the issues that need to be addressed by the NRC and the applicants in plant-specific license renewal proceedings. First, the environmental issues are defined by characterizing and evaluating the actions and activities that may be undertaken by licensees in pursuit of license renewal and extended plant life. These actions and activities are then used to characterize their associated potential environmental impacts.

This section discusses potential actions nuclear power plant licensees may undertake to achieve license renewal and an extended plant life. This section also estimates the extent of the environmental initiators associated with these actions during license renewal and the extended term of operation.

The preceding section noted that the license renewal rule requires that the functionality of important SSCs be maintained throughout the period of the renewed license. To provide this assurance, licensees will likely undertake enhanced SMITTR activities on SSCs identified in the IPA and, based on the findings of these efforts, take appropriate action to ensure that aging is effectively managed and that the functionality of these SSCs is maintained. Incremental repair, refurbishment, and/or replacement of SSCs, as well as related changes to plant operations and maintenance, may be performed to ensure that this objective is achieved. These actions, either directly or indirectly, will produce incremental impacts to the local environment. These incremental effects are over and above those expected if plants were simply to continue to operate as at present.

Licensees may also choose to undertake various refurbishment and upgrade activities at their nuclear facilities to better maintain or improve reliability, performance, and economics of power plant operation during the extended period of operation. These are activities which would be performed at the option of the licensee and which are in addition to those performed to satisfy the license renewal rule requirements.

The set of activities undertaken is expected to vary widely from plant to plant. Some plants may require little refurbishment and upgrading. Other plants may require considerable refurbishment and upgrading. For purposes of the GEIS, two types of license renewal programs were considered for which the environmental impact initiators were developed:

- a "typical" or "mid-stream" license renewal program, intended to be representative of the type of program that many plants seeking license renewal might implement, and
- a "conservative" or "bounding" program encompassing considerably more activities by licensees, intended to characterize an upper bound, or near upper bound, of the impacts that could be generated at a nuclear power plant.

Each program applies to both BWRs and PWRs. Thus, there are four separate cases or scenarios considered: a typical BWR, an upper bound or conservative BWR, a typical PWR, and a conservative PWR.

The typical scenarios can be used to estimate environmental impacts from an "average" license renewal program and to estimate the nationwide impacts of the total nuclear power plant population. The bounding license renewal scenarios, being much more conservative, are intended to address what might occur for those plants whose impacts will be considerably greater than is typical of the nuclear power reactor population as a whole.

Section 2.6.2 presents the bases and assumptions used in developing the different license renewal scenarios. Section 2.6.3 describes and characterizes the typical license renewal scenarios and the resulting environmental impact initiators. The conservative scenario program is described in Section 2.6.4.

2.6.2 Bases, Assumptions, and Approach

2.6.2.1 Structures, Systems, and Components of Interest

The SSCs of interest for assessing license renewal-related environmental impacts are those that are critical to the safe operation of the plant and that traditionally do not have readily monitorable performance characteristics, which means that the effects of aging may go undetected and lead to the loss of SSC functionality. Many structures and components in currently-licensed LWRs are subject to programs such as the maintenance rule, periodic surveillances, and periodic replacement and refurbishment and have readily monitorable performance or condition characteristics so that these programs can reveal the effects of aging in sufficient time to prevent loss of SSC functionality. However, many other nuclear plant components, such as passive, long-lived structures and components, may not be subject to programs which reveal the effects of aging in sufficient time to ensure their functionality. Therefore, these passive, long-lived structures and components are the items that may need new or incremental aging management activities. The SSCs used in the current evaluation are discussed in Sections 2.6.3.1 and 2.6.4.1 for the typical and conservative programs, respectively.

2.6.2.2 Definition of Candidate Aging Management Activities

A comprehensive list of possible license renewal-related activities with potential environmental impacts was developed. Emphasis was placed on defining those activities clearly associated with license renewal, that is, those activities which would not be included in a continuation or extrapolation of the activities that occurred during the original licensing term. The types of activities considered ranged from enhanced inspection programs to component replacement. In turn, the potential environmental impacts of each identified activity were examined and analyzed.

Following the identification of candidate SSCs and the related aging management activities for each of the different license renewal programs, quantitative estimates of potential environmental impact initiators were developed. The estimates apply to a particular approach to aging management.

The data needed to characterize aging management activities were developed in the context of the four major license renewal programs previously identified: a typical BWR, a conservative BWR, a typical PWR, and a conservative PWR. Each program consisted of the following:

- lists of SSCs for which incremental activities would be performed to ensure that safe and economical operation could be achieved throughout the extended life of the plant;
- lists of the activities performed on each SSC to manage aging;
- the number of times each activity would be performed, accounting for repetitive actions on individual SSCs and the number of similar items in the plant subject to these activities; and
- the specific times during which each activity is performed.

The generic license renewal programs utilized in this evaluation were based on similar schedules for carrying out the selected aging management activities. Any major refurbishment work called for by the programs was assumed to start shortly after a renewed license had been granted. In these example programs, this would occur in roughly year 30 of the original 40-year license term. This work was assumed to be completed over several successive outages, including one at the end of the 40th year of plant operation. Incremental SMITTR actions, and the installation of enhanced or additional surveillance and monitoring equipment and systems, were also assumed to be initiated at this time. The SMITTR actions continue throughout the remaining life of the plants. This is true for both the typical and conservative case scenarios.

2.6.2.3 Incremental Effects Only

All aging management programs of interest to the current effort deliberately omit, to the extent possible, current practice as it has evolved and is expected to evolve in the license renewal period. The programs also exclude any changes in the basic design or technology of the plant. Rather, they include only those activities that would constitute a discrete change in the plant's operation and maintenance program and would be implemented only after issuance of the renewal license. In particular, all normal repair activities, as well as any activities undertaken to satisfy recently enacted requirements such as the Maintenance Rule, are considered to fall within the scope of current practice and were excluded from consideration. Therefore, the impact initiators considered here are incremental to those resulting from the extension of current practice.

2.6.2.4 Reference Plant Size and Characteristics

All assessments presented here reflect design features and quantities consistent with 1000-MW(e) plant designs. For the PWRs, the features and sizing chosen were consistent with those for a four-loop Westinghouse plant design with a large dry containment. The BWR features used were representative of designs utilizing internal jet pumps and two recirculation loops. Mark III containment features were used.

2.6.2.5 Reference SMITTR Program

The generic BWR and PWR aging management programs used in the present evaluations for both the typical and conservative scenarios were based on the safety-centered SMITTR programs that were used in the regulatory analysis for 10 CFR Part 54 (NUREG-1362). These basic SMITTR programs were supplemented by activities planned for the Lead Plant programs (Sciacca 1/3/93 and Sciacca 1/13/93). In addition, the aging management programs used as the basis for the current impact initiator estimates included actions anticipated for non–safety-related systems and equipment, but which licensees may undertake to maintain or enhance plant availability and performance. The conservative case scenarios, in particular, assumed considerable expansion of the basic Part 54 programs to include actions on many balance-of-plant SSCs. The inclusion of activities directed toward non–safety-related SSCs considerably expanded the number of times given activities would be performed and significantly increased the variety of activities performed, compared with those considered for the 10 CFR Part 54 Regulatory Analysis. The inclusion of aging management activities beyond those characterized for safety-centered SMITTR programs enhances the comprehensiveness and conservatism of the estimates used in the preparation of the GEIS conservative cases. The typical license renewal program scenarios also include more SMITTR actions than those used for the 10 CFR Part 54 assessments, but to a lesser degree than the conservative case scenarios. The typical program SMITTR activities incremental to those anticipated under Part 54 were included to allow for voluntary actions on the part of licensees to better manage aging of balance-of-plant SSCs. All typical program activities were reviewed for possible overlap with the Maintenance Rule activities; any activities perceived to fall within the scope of the Maintenance Rule or other rules were eliminated from the programs.

2.6.2.6 Major Refurbishments and Replacements

The major refurbishment/replacement class of activities included in the license renewal programs characterized here is intended to encompass actions which typically take place only once in the life of a nuclear plant, if at all. Replacement of BWR recirculation piping and PWR steam generators falls into this category of activities. Many such activities were included in the conservative case license renewal scenarios. The items making up this category include both activities which have already been performed at some operating LWRs and activities which have not yet been performed, at least not to the extent assumed for the purpose of defining potential environmental impacts. The inclusion of activities which have already been performed on some existing nuclear plants is based on the premise that there are certain plants in the reactor population that will not have to perform these activities during the current license term, but that would elect to perform these major activities to enable safe and economic operation for the incremental term allowed with license renewal. In addition, major refurbishment activities included in these example license renewal programs encompass all areas of a nuclear power plant (e.g., structures, mechanical and electrical systems, fluid systems). This approach further ensures that the impacts characterized for the conservative case scenarios have a high probability of bounding the impacts likely to accrue to any individual plant seeking license renewal and extended plant operation.

The typical scenarios, in contrast, included fewer major refurbishment activities of this type. For these scenarios the assumption was made that most plants will have ongoing effective maintenance and refurbishment programs that preclude the need for refurbishment/replacement of all but a few components and structures.

2.6.2.7 Prototypic License Renewal Schedule

Figure 2.3 shows representative timelines for the license renewal process of a nuclear plant. The timelines shown were judged to be reasonable by the NRC staff. The schedule is applicable to both the typical and conservative license renewal scenarios. The upper timeline shows the relationship of the new license period to the initial license period. The lower line indicates the various outage types and their assumed timing over the period covered by a renewed license. The key underlying assumption for the timelines is that the licensee should be assured by the NRC 10 years before the expiration of its current operating license that the plant in question is suitable for license renewal. These 10 years are required for the licensee to arrange for alternative sources of power should a renewed license not be granted. The license renewal process is presumed to start with the licensee initiating a number of studies and analyses to support the license renewal application 3 years before submitting the application to the NRC. The NRC would then perform a detailed review of the application and, in the successful cases, issue a new license (with conditions) within 2 years after the application is received. The new license would go into effect at that point, covering the balance of the original 40-year term, as well as the additional 20-year term.

It was assumed that licensees would initiate incremental aging detection and management activities as soon as the new license was granted, as called for by 10 CFR Part 54. Discretionary major refurbishment activities might also be undertaken early into the license renewal term.

2.6.2.8 Schedule for Performing Major Refurbishment Activities

The reference schedule assumes that major refurbishment activities associated with

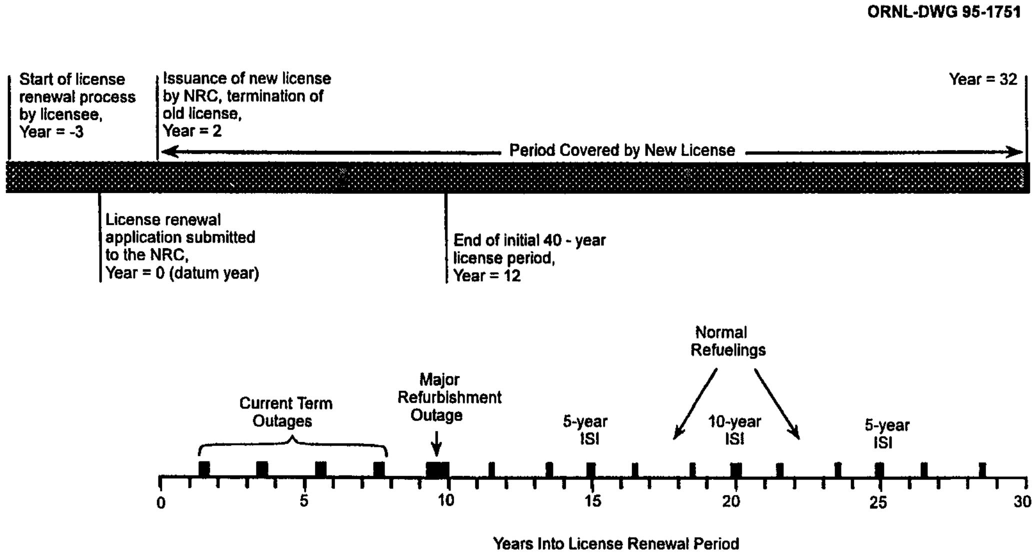

Figure 2.3 License renewal schedule and outage periods considered for environmental impact initiator definition.

license renewal are started shortly after the new license is granted, and that these are accomplished over several successive outages. They are completed by the time the plant completes its 40th year of operation, which is about 10 years into the new license term. The schedule for performing any major refurbishment activities will undoubtedly be highly plant specific, and such activities could well be spread throughout the term of the renewed license. Earlier timing of these activities provides the utilities with more time to recover the cost of the investment through the sale of energy produced. Thus, the schedules utilized for the present evaluations are reasonable, but alternative schedules are also possible.

The schedules utilized were similar for both the BWR and PWR programs. However, the typical programs have little need for an extended outage because the extent of major refurbishment activities is relatively modest. The "major refurbishment outage" duration for the typical programs was reduced compared with that deemed necessary for the conservative case scenarios.

2.6.2.9 Outage Types and Durations

Activities carried out in support of license renewal and extended plant life were assumed to be performed primarily during selected outages. Five types of outages were used: normal refuelings, 5-year ISI outages, 10-year ISI outages, current term refurbishment outages, and major refurbishment outages. Figure 2.3 illustrates when these outages are assumed to occur. The current term outages fall within the 40-year period initially covered by the plant's current license, but with license renewal they occur during the period covered by the new license.

Outage types and durations were established to allow estimation of the rates at which environmental impacts might be generated as a result of license renewal activities. For example, the number of workers required at a site for a given outage is dependent on the amount of work to be performed (labor hours), the time available to accomplish the work, and the number of labor hours expended per person-week or person-day. The number of workers so identified, in turn, allows estimation of potential socioeconomic and other impacts to affected communities.

Table 2.5 summarizes the different outage types and durations for both reactor types and for both the typical and conservative license renewal scenarios. Additional discussion of the basis used in selecting outage durations is provided in Appendix B.

2.6.3 Typical License Renewal Scenario

The characteristics of the typical license renewal program are discussed briefly in Section 2.6.3.1. Listings of the SSCs likely to be subject to incremental aging management activities are provided. Listings of the types of SMITTR actions and major refurbishment activities that may be performed as part of a typical license renewal program are reviewed and discussed in Appendix B. Section 2.6.3.2 summarizes the impact initiator quantities expected to be generated by such a program. Section 2.6.3.2 compares the impact initiator quantities for the typical program scenarios with the impactor initiator quantities currently produced from routine reactor operation.

2.6.3.1 Characterization of Typical License Renewal Programs

The characterization of license renewal programs required that three key types of information be developed:
(1) identification of the SSCs likely to be subject to incremental aging management activities, (2) candidate lists of the activities to be performed on these systems and components to suitably manage aging effects that could have potential environmental consequences, and (3) identification of environmental attributes (impact initiators) associated with those activities. The typical programs are intended to be representative of the typical or "average" plant's activities in support of license renewal. However, the typical programs are still somewhat conservative; that is, some plants will not require all of the actions identified in the typical programs. The typical license renewal scenarios were based on the following.

- The Monticello and Yankee Rowe lead plant life extension (PLEX) programs were carefully reviewed. Activities included in either program were, with some exceptions, incorporated into the typical license renewal scenarios. The information obtained from the lead plants was also used to establish both the numbers of SSCs subject to a given activity and the schedule for performing such activities.
- All activities included in the Part 54 Regulatory Analysis which were pertinent to passive, long-lived SSCs and which were not likely to be implemented because of other rules or regulations were retained as incremental actions. The Part 54 activities were retained both to maintain consistency with the updated Part 54

Regulatory Analysis and to allow for a modest amount of conservatism in the typical scenarios.

- As noted previously, recently enacted rules and regulations, in particular the Maintenance Rule, were taken into account in developing typical license renewal or PLEX-related activities.
- Surveys were made to help establish the likelihood that certain major activities would be performed by typical licensees seeking license renewal. In particular, assessments were made relative to steam generator replacement and reactor vessel annealing for PWRs, and for recirculation piping replacement for BWRs. These assessments reviewed the fraction of the affected reactor population that has already performed these refurbishment/replacement activities and ascertained whether such activities might need to be repeated for extended plant life. Based on the results of these reviews, it was assumed that typical license renewal programs will not need to include many such major activities.

Table 2.5 Outage duration summary

	Outage duration (months)	
Outage type	Conservative	Typical
Refueling	2	2
5-Year in-service inspection	3	3
10-Year in-service inspection	4	3
Current-term outage (refurbishment)	4	3
Major refurbishment outage	9	4

Typical program structures, systems, and components subject to incremental activities

Tables 2.6 and 2.7 list the SSCs used in the typical program evaluations for which incremental activities are assumed to be conducted during license renewal and extended life. Table 2.6 lists the items subject to incremental SMITTR actions; Table 2.7 lists items subject to major refurbishment/replacement activities. Table 2.6 includes SSCs subject to the addition of new or improved condition monitoring systems, as well as those subject to incremental SMITTR activities. Most of the items in these tables are common to both BWRs and PWRs.

Although the specific numbers of components and design features may be different for these two reactor types, they are similar enough that the environmental impacts resulting from aging management

Table 2.6 Typical program structures and components subject to incremental SMITTR[a] activities in support of license renewal

Item	BWR/PWR[b]
AC or DC busses	Both
Actuation and instrumentation channels	Both
Bellows	BWR
Building cranes and hoists	Both
BWR control rod drive mechanisms	BWR
BWR recirculation pumps and motors	BWR
Check valves	Both
Compressed air system	Both
Containment	Both
Emergency diesel generators	Both
Fan coolers	Both
Fuel pool	Both
Heat exchangers	Both
Heating, ventilation, and air conditioning	Both
Hydraulic or air operated valves	Both
Main condensor	Both
Main generator	Both
Main turbine	Both
Metal containment, including suppression chamber	BWR
Motor-operated valves	Both
Motor-driven pumps and motors	Both
Nuclear steam supply system supports	Both
PWR critical concrete structure—containment	PWR
PWR reactor coolant pump	PWR
Reactor pressure vessel	Both
Reactor pressure vessel internals	Both
Turbine-driven pumps and turbines	Both

[a] SMITTR = surveillance, on-line monitoring, inspections, testing, trending, and recordkeeping.
[b] BWR = boiling-watert reactor; PWR = pressurized-water reactor.

Table 2.7 Typical program systems, structures, and components subject to major refurbishment or replacement activities

Item	BWR/PWR[a]
BWR safe ends and recirculation and feedwater piping inside containment	BWR
Compressed air system	Both
Containment	Both
Emergency diesel generators	Both
Main generator	Both
Major structures, including buildings and pipe enclosures	Both
Motor-operated valves	Both
Piping sections	Both
Reactor containment building	Both
Reactor pressure vessel	Both
Reactor pressure vessel internals	Both
Steam generators	PWR
Storage tanks	Both

[a] BWR = boiling-water reactor; PWR = pressurized-water reactor

activities on these items will be reasonably similar for both reactor types. Differences in the numbers of like items employed in each plant design were taken into account in assessing impacts.

Certain SSCs such as the reactor recirculation piping for BWRs and steam generators for PWRs are unique to the plant design type. Potential impacts from aging management activities on such items were treated separately for the two major plant categories.

Definition of aging management activities

The incremental aging management activities carried out to allow operation of a nuclear power plant beyond the original 40-year license term will be from one of two broad categories: (1) SMITTR actions, most of which are repeated at regular intervals, and (2) major refurbishment or replacement actions, which usually occur fairly infrequently and possibly only once in the life of the plant for any given item.

Most of the SMITTR activities included in the present assessment were taken from the Safety-Centered Aging Management program defined previously and utilized for the 10 CFR Part 54 License Renewal Regulatory Analysis (NUREG-1362). However, the current effort includes additional items and activities, because the previous analysis focused only on SSCs important to safety, whereas for the current efforts it has been assumed that licensees will also perform actions aimed at ensuring reliable and efficient electrical power production. Thus, many balance-of-plant SSCs are included here which were not included in the 10 CFR Part 54 evaluations.

In certain cases a SMITTR activity could involve replacement or refurbishment of the SSC being addressed. Any such SMITTR replacement/refurbishment activities for a particular item typically occur more than once in the extended life of the plant.

Table B.1 of Appendix B lists the incremental SMITTR actions used as the basis for estimating license renewal environmental impacts. It indicates the specific aging detection and mitigation actions performed on each SSC of concern. These activities include some which are undertaken only to improve reliability or economic performance; thus, Table B.1 includes several active components in addition to the passive, long-lived SSCs that are the focus of 10 CFR Part 54.

Table B.2 of Appendix B lists the major refurbishment or replacement activities used to estimate environmental impacts. The table indicates the fractions or portions of the SSCs involved which are subject to the stated actions. Unless otherwise noted, 100 percent of an SSC was assumed to be replaced or refurbished. As with the list of actions cited in Table B.1, the quantities assumed were based in part on the information provided in the industry pilot and lead plant studies and from reported existing industry experience on major refurbishments (Sciacca 1/3/93 and 1/13/93). In other cases engineering judgment provided the basis for the portions of the systems or structures being replaced or refurbished. The extent of major refurbishments envisioned for typical license renewal programs is fairly modest.

2.6.3.2 Typical Program Incremental Initiator Quantities

Table 2.8 summarizes the typical program impact initiator quantities resulting from the incremental SMITTR and major refurbishment/replacement activities assumed to be carried out in support of license renewal and extended plant life. Estimates of the amounts generated are shown for each of the outage types previously discussed, during which these impact initiators are expected to be generated from license renewal activities. Separate estimates are provided for BWRs and PWRs. All figures are shown on a per-plant basis (i.e., for a single nuclear plant).

A comparison of the figures shown in Table 2.8 with current reactor experience as discussed in Section 2.5.2 indicates that, for the typical license renewal scenario, incremental license renewal effects are expected to be relatively modest. For example, with current nuclear plant operation, roughly 1.5 million person-hours are expended each year for on-site operations and maintenance activities. The incremental efforts associated with license renewal-related activities are estimated to add between 500,000 and 700,000 person-hours for all such activities over the remaining

Table 2.8 Typical license renewal program environmental impact initiators

Outage type	Labor hours	Additional on-site personnel	Waste volumes (as-shipped) (m^3)	Occupational rad exps (person-sieverts)	Waste disposal costs (1994$)[a]	Labor costs (1994$)[a]	Capital costs (1994$)[a]	Total on-site costs (1994$)[a]	Off-site costs (1994$)[a]	Total costs (1994$)[a]
Boiling-water reactors										
Full power operation (20 yrs)	0	0	0	0.00	0	0	0	0	0	0
Normal refueling[b]	4,148	10	2	0.04	23,000	196,940	215,460	435,400	47,751	483,151
5-yr ISI[c] refueling[d]	38,675	63	17	0.71	244,000	1,789,900	314,100	2,348,000	0	2,348,000
10-yr ISI refueling[e]	62,208	110	30	0.91	424,000	3,082,450	589,550	4,096,000	0	4,096,000
Current term refurbishments[f]	45,294	71	17	0.10	245,000	1,715,040	579,360	2,539,400	177,347	2,716,747
Major refurbishment outage[g]	298,375	361	69	1.53	976,000	12,585,040	57,589,360	71,150,400	13,804,688	84,955,088
Total all occurrences	660,000	—	220	4.57	3,052,000	27,700,000	62,800,000	93,600,000	14,900,000	108,500,000
Pressurized-water reactors										
Full power operation (20 yrs)	0	0	0	0.00	0	0	0	0	0	0
Normal refueling[b]	3,488	8	1	0.03	18,000	166,265	145,635	329,900	27,179	357,079
5-yr ISI refueling[d]	20,935	33	11	0.30	153,000	953,750	185,250	1,292,000	13,886	1,305,886
10-yr ISI refueling[e]	37,482	60	22	0.51	313,000	1,691,600	309,400	2,314,000	831	2,314,831
Current term refurbishments[f]	45,924	72	18	0.11	272,000	1,741,880	580,920	2,594,800	176,530	2,771,330
Major refurbishment outage[g]	219,018	264	44	0.79	1,631,000	9,108,830	49,380,970	60,120,800	12,068,028	72,188,828
Total all occurrences	510,000	—	170	2.61	3,482,000	21,000,000	53,500,000	78,000,000	13,000,000	91,000,000

Notes:

[a] All cost figures are undiscounted 1994 dollars
[b] 8 occurrences, 2-month duration each
[c] ISI = in-service inspection
[d] 2 occurrences, 3-month duration each
[e] 1 occurrence, 4-month duration
[f] 4 occurrences, 4-month duration each
[g] 1 occurrence, 9-month duration

To convert m^3 to ft^3, multiply by 35.32.
To convert person-sievert to person-rem, multiply by 100.

Source: Science and Engineering Associates, Inc., January 1995.

life of a typical plant. Thus, the license renewal activities would add roughly 20,000 person-hours per year, which is a small increment compared to the 1.5 million person-hours per year typical of current reactor operation.

Table 2.8 indicates that the number of additional on-site personnel needed to accomplish license renewal-related activities is quite modest for most periods when such activities will be performed. The exception is the major refurbishment outage, when an average of between 200 and 400 additional personnel may be needed. Note that these personnel are in addition to the 700- to 800-person temporary work force typically called in to assist with current outages at nuclear power plants (see Table 2.4). The estimates of additional personnel presented in Table 2.8 are based on the assumption that the incremental work efforts are spread uniformly over the entire duration of the associated outages. In reality, some peaking of staffing requirements will occur during each outage. Additional analyses were performed to evaluate the extent of such peaking, and these analyses are discussed in Appendix B. For the typical BWR license renewal scenario, these analyses indicated that the on-site temporary work force would peak at about 1000 personnel. This peak occurs during the major refurbishment outage, and it includes the temporary work force needed to accomplish refueling and routine outage activities (e.g. routine maintenance and ISI activities) as well as license renewal-related activities. For the PWR, the corresponding temporary worker requirements reach a peak at about 900 additional staff. This peak requirement occurs during the current term outages.

The incremental occupational radiation exposure estimated to accrue because of license renewal activities is between 2.5 and 5 person-sievert (250 and 500 person-rem). On an annualized basis, this represents an increase in annual exposures of about 3 to 4 percent relative to current reactor operation experience.

LLW generation resulting from license renewal activities is projected to be between 185 and 220 m^3 (6,000 and 8,000 ft^3) of as-shipped LLW over the remaining life of the plants. Currently, PWRs typically generate about 250 m^3/year (8800 ft^3/year); the amount disposed of at BWRs has been about 560 m^3/year (19,700 ft^3/year). Thus, the amount of LLW expected to be added because of license renewal activities is roughly the equivalent of one-half to one year's production of waste under current operating conditions. This represents an increment over the remaining life of the plants of about 1 to 3 percent relative to what would be produced with continued present-basis plant operation.

Table 2.8 presents several types of costs associated with license renewal and extended plant life. These include incremental costs associated with additional labor, waste disposal, capital costs, and off-site costs (off-site engineering and administrative support). For the typical BWR license renewal program, the total incremental costs are estimated to be almost $110 million; those for the typical PWR program are estimated to be about $90 million. Although these costs will be incurred over the remaining life of a plant, more than half of these costs might well be incurred in the first few years after a renewed license is granted. For comparison purposes, recent non-fuel operations and maintenance (O&M) costs at U.S. nuclear plants have averaged about $75 million per year for a 1000-MW(e) plant, and capital additions have averaged about $28 million per year (1994 dollars). Thus, the estimated labor and capital expenditures associated with incremental license renewal activities over the remaining life of a plant with a renewed license are the equivalent of roughly a year's expenditures for O&M and capital additions currently experienced by LWRs, or less than a 5 percent increase for such expenditures on an annualized basis.

2.6.4 Conservative License Renewal Scenario

The characteristics of the conservative case license renewal programs are discussed briefly in Section 2.6.4.1. As was done in Section 2.6.3.1 for the typical programs, listings are provided of the SSCs likely to be subject to incremental aging management activities. Listings of the types of SMITTR actions and major refurbishment activities that may be performed as part of a conservative license renewal program are reviewed and discussed in Appendix B. Section 2.6.4.2 summarizes the impact initiator quantities expected to be generated by such programs and compares the impact initiator quantities for the conservative program scenarios with the impactor initiator quantities currently produced in routine reactor operation.

2.6.4.1 Characterization of the Conservative Program

The conservative license renewal scenarios are intended to capture what might occur for those outlier plants whose impacts will be considerably greater than what is typical of the reactor population as a whole. Because these conservative, or bounding, programs are quite comprehensive, they subsume impacts from more atypical plants.

The conservative case license renewal scenario uses a conservative basis for projecting activities and impacts. The primary bases and assumptions are as follows.

- In contrast with the typical programs, the recently enacted rules and regulations, in particular the Maintenance Rule, were not taken into account in revising license renewal or PLEX-related activities. This simplified approach was taken because accounting for such effects would have a negligible impact on the estimates of environmental impact initiator quantities.
- All activities included in the Part 54 Regulatory Analysis were retained as incremental actions. In many instances, the number of SSCs subjected to particular SMITTR activities was increased to reflect optional actions on the part of licensees to better ensure reliable and economical service for balance-of-plant systems and components.
- The major refurbishment and replacement activities included in the programs are quite expansive and encompass all aspects of the plant designs (e.g., structural, mechanical, and electrical). Similarly, the extent of such activities for particular SSCs is considerable in most cases and is more extensive than that anticipated for the average plant seeking license renewal.
- As was previously noted, several of the major refurbishment activities included in the present estimates have already occurred at many nuclear plants. These are activities such as steam generator replacement in PWRs and recirculation piping replacement in BWRs. These activities are included in the conservative case scenarios to encompass those plants that must perform such activities to achieve the desired extended plant life and efficiency, but that have not already done so or that might have to repeat such actions.

License renewal program definition

Conservative program SSCs subject to incremental activities. The conservative program SSCs assumed to be subject to incremental SMITTR activities included all of the SSCs identified in Table 2.6 for the typical program. In addition, the conservative program included the items listed in Table 2.9. The conservative program, in most instances, also included a greater number of a given type of SSC subject to SMITTR actions than did the typical programs. For example, the conservative programs included roughly twice the number of motor-operated valves subject to incremental aging detection and mitigation actions as did the typical programs. This approach was taken with the conservative programs to encompass what might occur at outlier plants.

Both the SSCs subject to incremental SMITTR activities and those subject to major refurbishment activities for the conservative program are more inclusive than those included in the typical program scenarios. A comparison of Tables 2.6 and 2.7 with Tables 2.9 and 2.10 readily demonstrates the more comprehensive nature of the conservative program compared with the typical program scenarios.

Table 2.9 Conservative program additional structures and components subject to incremental SMITTR[a] activities in support of license renewal

Item	BWR/PWR[b]
BWR control rod drive mechanism	BWR
Compressed air system	Both
Emergency diesel generator	Both
Fan cooler	Both
Main turbine	Both

[a] SMITTR = surveillance, on-line monitoring, inspections, testing, trending, and recordkeeping.

[b] BWR = boiling-water reactor; PWR = pressurized-water reactor.

Table 2.10 lists items subject to major refurbishment/replacement activities. Most of the items in these tables are common to both BWRs and PWRs.

Definition of conservative program aging management activities. As for the typical programs, the incremental aging management activities carried out for the conservative license renewal scenarios to allow operation beyond the original 40-year license term will include both SMITTR activities and major refurbishment activities.

The SMITTR activities associated with the conservative programs are quite similar to those developed for the typical programs, except that they cover additional types and numbers of SSCs. The scenarios developed

Table 2.10 Conservative program systems, structures, and components subject to major refurbishment or replacement activities

Item	BWR/PWR[a]
Building crane	Both
BWR recirculation pump and motor	BWR
BWR safe ends and recirculation and feedwater piping	BWR
Concrete imbedments	Both
Condensate storage tank	Both
Control room communication systems	Both
Electrical cables in and out of containment	Both
Electrical raceways	Both
Emergency diesel generator	Both
Feedwater heater	Both
Heating, ventilation, and air conditioning	Both
Main generator	Both
Main turbine	Both
Major structures, including buildings and pipe enclosures	Both
Metal containment, including suppression chamber	BWR
Nuclear steam supply system supports	Both
Pressurizer and surge line	PWR
Piping section	Both
PWR coolant and feedwater piping inside containment	PWR
Radioactive waste processing system	Both
Reactor containment building	Both
Reactor pressure vessel	Both
Reactor pressure vessel internals	Both
Steam generator	PWR
Steam valve	Both
Switchyard	Both
Turbine pedestal	Both
Ultimate heat sink structures	Both

[a] BWR = boiling-water reactor; PWR = pressurized-water reactor.

for the conservative programs assumed that many balance-of-plant SSCs would be subject to license renewal-related activities to better ensure reliable and economical operation for the extended life of the plant.

Table B.1 of Appendix B lists the incremental SMITTR actions used as the basis for estimating license renewal environmental impacts. It indicates the specific aging detection and mitigation actions performed on each SSC of concern.

Table B.1 indicates the specific SMITTR activities included in each type of program, but it does not indicate the number of SSCs subject to a particular activity. The programs defined for the conservative case scenarios in all instances match or exceed the number of SSCs included in the corresponding typical license renewal programs.

The list of major replacement and refurbishment activities included here was derived largely from areas of concern identified in the industry pilot and lead NP-5181M, EPRI NP-5289P, EPRI NP-5002). This is true for both the conservative and typical scenarios. Those studies did not necessarily indicate that all of the items addressed should be replaced or undergo major overhauls. However, for all items addressed, there was sufficient concern over their long-term integrity that investigators thought, as a minimum, that additional analysis was warranted.

Although replacement may not have been indicated for the pilot and lead plants, at least a few plants may well face extensive actions of this type to ensure safe and economical operation throughout the renewal term. Therefore, regardless of the specific determinations for the pilot and lead plants, the SSCs of concern identified in those studies form a representative list of candidate items for inclusion in major replacement and refurbishment actions for outlier plants, and thus for the conservative scenarios. Other items included in this list were drawn from actions that have already occurred at one or several operating power plants. BWR recirculation piping replacement and PWR steam generator replacement fall into this category. Although many plants will undertake the replacement of such items during the current license term, there may be other plants which would undertake such tasks only to allow for extended plant operation. Inclusion of these activities in the conservative scenario evaluations provides for an upper bound estimate of what at least a few plants may undertake for license renewal.

Table B.2 of Appendix B lists the major refurbishment or replacement activities used to estimate environmental impacts for the conservative case scenarios. Unless otherwise noted, 100 percent of an SSC was assumed to be replaced or refurbished.

2.6.4.2 Conservative Program Incremental Initiator Quantities

Table 2.11 summarizes the conservative program impact initiator quantities resulting from the incremental SMITTR and major refurbishment/replacement activities assumed to be carried out in support of license renewal and extended plant life. A comparison with the estimates provided for the typical programs (Table 2.8) indicates that the conservative program scenario estimates of impact initiator quantities are factors of four to six greater than those for the typical programs. The type of information provided in Table 2.11 is identical to that provided in Table 2.8. Separate estimates are provided for BWRs and PWRs, and all figures are shown on a per-plant basis.

Table 2.11 Conservative license renewal program environmental impact initiators

Outage type	Labor hours	Additional on-site personnel	Waste volumes (as-shipped) (m^3)	Occupational rad exps (person-sieverts)	Waste disposal costs (1994$)[a]	Labor costs (1994$)[a]	Capital costs (1994$)[a]	Total on-site costs (1994$)[a]	Off-site costs (1994$)[a]	Total costs (1994$)[a]
Boiling-water reactors										
Full power operation (20 yrs)	49,900	1	0	0.00	0	2,089,856	0	2,089,856	0	2,089,856
Normal refueling[b]	11.352	27	5	0.10	64,182	556,407	612,043	1,232,632	131,856	1,364,488
5-yr ISI[c] refueling[d]	48,406	78	21	0.27	290,508	2,258,137	712,251	3,260,896	0	3,260,896
10-yr ISI refueling[e]	101,308	122	38	1.08	537,102	4,585,522	1,250,536	6,373,160	0	6,373,160
Current term refurbishments[f]	732,280	866	233	1.91	3,303,684	28,170,043	10,843,605	42,317,332	3,122,803	45,440,135
Major refurbishment outage[g]	1,642,760	867	814	15.61	11,525,736	73,719,268	119,968,099	205,213,104	28,546,104	233,759,207
Total all occurrences	4,910,000	—	1,900	26.66	26,372,000	202,000,000	170,900,000	399,300,000	42,100,000	441,400,000
Pressurized-water reactors										
Full power operation (20 yrs)	49,900	1	0	0.00	0	2,089,856	0	2,089,856	0	2,089,856
Normal refueling[b]	8,733	21	3	0.07	46,166	406,936	410,540	863,642	79,897	943,539
5-yr ISI refueling[d]	28,550	46	13	0 35	185,790	1294,224	451,076	1,931,090	50,734	1,981,824
10-yr ISI refueling[e]	62,295	75	29	0.66	416,620	2,867,021	845,401	4,129,042	74,282	4,203,324
Current term refurbishments[f]	768,460	909	264	2.00	2,889,204	29,607,382	9,687,766	43,184,352	2,821,826	46,006,178
Major refurbishment outage[g]	3,241,260	1,713	1,324	13.80	20,204,944	139,806,842	110,947,895	270,959,681	26,185,773	297,145,454
Total all occurrences	6,550,000	—	2,500	23.74	36,919,300	269,000,000	154,700,000	460,700,000	38,300,000	499,000,000

Notes:

[a] All cost figures are undiscounted 1994 dollars
[b] 8 occurrences, 2-month duration each
[c] ISI = in-service inspection
[d] 2 occurrences, 3-month duration each
[e] 1 occurrence, 4-month duration
[f] 4 occurrences, 4-month duration each
[g] 1 occurrence, 9-month duration

To convert m^3 to ft^3, multiply by 35 32
To convert person-sievert to person-rem, multiply by 100

Source: Science and Engineering Associates, Inc., January 1995.

A comparison of the figures shown in Table 2.11 with current reactor experience as discussed in Section 2.5.2 indicates that, for the conservative license renewal scenario, incremental license renewal effects are expected to be fairly significant. The incremental efforts associated with license renewal-related activities are estimated to add between 5 million and 7 million person-hours for all such activities over the remaining life of a conservative plant. These increments for license renewal can be compared with the roughly 1.5 million person-hours expended annually with current reactor operation.

If the license renewal efforts were uniformly spread over the 30-year period that a renewed license would be in effect, they would increase annual labor requirements by 10 to 15 percent. The effect of the incremental license renewal labor will be even more significant for certain periods. For example, the number of additional workers needed to accomplish the major refurbishment activities during the major refurbishment outage could potentially double or triple the number needed during a normally scheduled outage. The projected number of additional workers needed for the BWR major refurbishment outage is almost 900, averaged over the entire outage. For certain periods during this outage, the number of additional workers is estimated to be about 1200. For the PWR, the outage average increment in additional personnel needed for the major refurbishment outage is about 1700, and the number is expected to peak at about 2300 for certain periods during this outage. Note that these estimates of peak incremental personnel include the 700- to 800-person temporary work force typically called in to assist with current outages at nuclear power plants (see Table 2.4). Appendix B provides additional discussion of license renewal-related incremental staffing requirements.

The overall occupational radiation exposure estimated to accrue because of conservative program license renewal activities is between 23 and 24 person-sievert (2300 and 2400 person-rem). The large increase compared with the exposures anticipated for the typical programs is largely a result of the extensive major refurbishment activities expected to be undertaken with the conservative program scenarios. On an annualized basis, this is equivalent to an increase in annual exposures of about 20 to 30 percent relative to current reactor operation experience.

LLW generation from license renewal activities is projected to be between 1,900 and 2,500 m^3 (65,000 and 90,000 ft^3) of as-shipped LLW over the remaining life of the plants. Currently, PWRs typically generate about 250 m^3/year (8800 ft^3/year); the amount disposed of at BWRs has been about 560 m^3/year (19,700 ft^3/year). Thus, the amount of LLW expected to be added because of conservative program license renewal activities represents several years worth of production of waste under current operating conditions. This represents an increment over the remaining life of the plants of about 11 percent annually for the BWRs and about 30 percent annually for the PWRs relative to what would be produced with present-basis, continued plant operation. The larger percentage of PWR LLW results primarily from the large volume of the steam generators, which it is assumed will be replaced for the conservative program.

Table 2.11 indicates that the overall incremental costs associated with conservative program license renewal activities are projected to be in the range of $450 million to $500 million per plant (1994 dollars). With current nuclear plant operation, annual expenditures for fuel, O&M, and capital costs are in the range of $150 million to $250 million, depending on individual plant conditions. Thus, the license renewal expenditures represent 2 to 4 years of current overall operating costs.

2.6.5 Impact Initiator Estimate Uncertainties

The NRC staff believes that the license renewal scenarios presented in Section 2.6.4 reasonably characterize both the nature and magnitude of licensee activities that may be undertaken in support of license renewal and extended plant life. Both the typical and conservative programs include some discretionary activities that are assumed to be undertaken by licensees to better ensure economical and reliable plant operation, and that are in addition to those activities performed to meet the requirements of 10 CFR Part 54. The licensee actions in response to the 10 CFR Part 54 requirements, believed to be fairly modest, consist of a considerably smaller set of activities than those characterized for the typical license renewal scenarios. Appendix B presents estimates of impact initiator quantities strictly related to meeting the requirements of the license renewal rule. Thus, a broad spectrum of license renewal programs are possible, and the license renewal-related environmental impacts can vary widely from one plant to another, depending on specific plant conditions and on discretionary activities undertaken by each licensee/applicant. This variability in program characteristics, coupled with uncertainties in parameter values used to estimate specific initiator quantities, results in a considerable degree of uncertainty in the estimates presented in Tables 2.8 and 2.11. Although a rigorous uncertainty analysis has not been performed, the estimates of individual impact initiators provided in Table 2.8 for the typical programs are judged to have uncertainties in the range of ±30 percent. The more bounding assumptions employed for the conservative scenarios reduce the likelihood that the actual impact initiators experienced could be much higher than those presented in Table 2.11. The uncertainty range for the Table 2.11 estimates, therefore, is judged to be on the order of +10 percent to -30 percent.

2.7 SUMMARY

This chapter described operating U.S. nuclear power plants and described the nature of their interactions with the environment. The basic requirements of the license renewal rule, 10 CFR Part 54, were reviewed with the focus on aspects which may result in incremental environmental impacts. Chapter 2 also described both typical and conservative license renewal programs characterized for the purpose of estimating license renewal-related environmental impacts. Estimates were provided of environmental impact initiators associated with these programs. These impact initiators are used in the balance of this document to identify and quantify anticipated environmental impacts associated with nuclear power plant license renewal.

2.8 ENDNOTES

1. Construction of nuclear units Grand Gulf Unit 2, Perry Unit 2, and Washington Nuclear Project Units 1, 3, 4, and 5 has been suspended; therefore,

these units are not considered in this GEIS.

2. This category is generally discussed as a separate source of liquid waste primarily for PWRs in which the water has a different radionuclide content and chemistry from primary coolant.

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3. ENVIRONMENTAL IMPACTS FROM NUCLEAR POWER PLANT REFURBISHMENT

3.1 INTRODUCTION

This chapter addresses the environmental impacts of refurbishment activities at an operating nuclear power plant in anticipation of license renewal. Section 2.4 describes the activities to be undertaken to prepare a nuclear power plant for operation following license renewal (see Tables 2.6 and 2.7). These activities will include (1) enhanced inspection, surveillance, testing, and maintenance and (2) repair, replacement, modification, and refurbishment of plant systems, structures, and components. For some plants, replacement of large components of the nuclear steam supply system (e.g., steam generator or pressurizer) is conceivable, as is repair or replacement of pumps, pipes, control rod systems, electronic circuitry, electrical and plumbing systems, or motors. Upgrading radioactive waste storage facilities could also be required because of increased low-level radioactive waste (LLW) generation and because a permanent high-level-waste repository is not yet available. Construction of new transmission lines is not expected to occur in conjunction with license renewal, although repair or replacement of structures may be needed occasionally. For example, wooden-pole structures may need rebuilding or replacement every 50–60 years. If construction of new lines is proposed, the impacts would be reviewed in accordance with the requirements of 10 CFR Part 51.

Refurbishment activities could result in environmental impacts beyond those that occur during normal plant operation. For example, site excavation and grading associated with construction of new waste storage facilities could result in fugitive dust emissions, localized air quality impacts, erosion, sedimentation, and disturbance of both aquatic and terrestrial ecosystems. Moreover, refurbishment could (1) require a sizable addition to the work force, (2) increase the radiation exposure to workers, and (3) generate increased quantities of LLW. These potential impacts are evaluated in the sections that follow.

3.2 ON-SITE LAND USE

Farming and other types of land use occur on some nuclear plant sites. Some utilities have designated portions of their nuclear plant sites for land uses such as recreation, management of natural areas, and wildlife conservation. Changes in on-site land use at a nuclear plant could result if additional new spent fuel and interim LLW storage facilities were required. (Waste generation, handling, and disposal are discussed in Chapter 6.) Incremental land use resulting from license renewal-related activities, even major refurbishments, is expected to be modest. The greatest land use needs for such activities are projected to occur during the major refurbishment outages of the conservative license renewal scenarios. Major activities such as steam generator replacement in pressurized-water reactors (PWRs), recirculation piping replacement in boiling-water reactors (BWRs), replacement of some reactor vessel internal structures, main turbine repairs, and general structural refurbishments are projected to occur for a few reactor plants during these outages.

Incremental land use associated with license renewal activities can be estimated from prior related experience within the U.S. nuclear industry. For example, a recent steam generator replacement at a U.S. PWR required about 1 ha (~2.5 acres) of land area to accommodate laydown, staging, handling, temporary storage, personnel processing, mockup and training, and related needs. The major activities projected to occur for the conservative license renewal scenarios are expected to require temporary land use for activities such as staging of new components and removing old components. In addition, the large number of temporary workers needed to accomplish the major refurbishment activities will likely require that temporary facilities be installed for on-site parking, training, site security access, office space, change areas, fabrication shops, mockups, and related needs. Based on previous experience with major refurbishments at nuclear power plants, it is expected that ~1–4 ha (~2.5–10 acres) of land may be needed to accommodate these refurbishment activities. Once these major activities and the major outages are completed, this land might be returned to its prior uses. Alternatively, the land could be used for on-site storage of LLW, spent fuel, and contaminated components such as steam generators until final off-site disposal is possible. Thus, some or all of the same land may be used both for the temporary major refurbishment needs and for the longer-term needs associated with on-site storage of waste materials. However, radioactive wastes are stored in remote parts of the site by some utilities in order to minimize worker radiation exposure and to avoid interference with routine activities. Typical license renewal scenario incremental land use requirements are bounded by those projected for the conservative scenarios.

The site is already owned by the utility and any land used for refurbishment activities will likely be within the exclusion area. Even if the land used for dry storage of spent fuel is on a remote part of the site, the impacts will be small. The U.S. Nuclear Regulatory Commission (NRC) has written a number of environmental assessments for on-site dry cask storage facilities and has reached a "finding of no significant impact" (FONSI) for each. The FONSI was reached considering the amount of land actually disturbed, the range of possible environmental impacts, and alternative uses of the land. On-site land use impacts are expected to be of small significance at all sites. Temporary disturbance of land may be mitigated by restoration to its original condition after refurbishment, or after site decommissioning. This is a Category 1 issue.

3.3 AIR QUALITY

Most plant refurbishment activities associated with license renewal would be performed on equipment inside existing buildings and would not generate atmospheric emissions. The only potential sources of impacts to air quality would be (1) fugitive dust from site excavation and grading for construction of any new waste storage facilities and (2) emissions from motorized equipment and workers' vehicles.

Air quality impacts from these sources would be minor and of short duration. The disturbed area for the waste storage facilities and laydown areas, if required, is expected to be 4 ha (10 acres) or less (Section 3.2). During site excavation and grading, some particulate matter in the form of fugitive dust would be released into the atmosphere, but fugitive dust consists primarily of large particles that settle quickly and thus have minimal adverse public health effects. Because construction would probably occur within an existing plant yard, much less site preparation would be necessary than for a previously undisturbed site. Because of the (1) small size of the disturbed area, (2) relatively short construction period, (3) availability of paved roadways at existing facilities, and (4) use of the best management practices (such as seeding and wetting), fugitive dust resulting from these construction activities should be minimal.

Heavy construction vehicles and other construction equipment would generate exhaust emissions (which would include small amounts of carbon monoxide, oxides of nitrogen, volatile organic compounds, and particulate matter). These would be temporary and localized. Additional emissions would result from the vehicles of up to about 2300 construction, refurbishment, and refueling personnel during most of the 9-month refurbishment outage (Figure B.6). For refurbishment occurring in geographical areas of poor or marginal air quality, these vehicle exhaust emissions could be cause for some concern. The 1990 Clean Air Act Amendments include a provision that no federal agency shall support any activity that does not conform to a state implementation plan designed to achieve the National Ambient Air Quality Standards for criteria pollutants (sulfur dioxide, nitrogen dioxide, carbon monoxide, ozone, lead, and particulate matter less than 10 μm in diameter). On November 30, 1993, the U.S. Environmental Protection Agency (EPA) issued a final rule (58 FR 63214) implementing the new statutory requirements, effective January 31, 1994. The final rule requires that federal agencies prepare a written conformity analysis and determination for each pollutant where the total of direct and indirect emissions caused by a proposed federal action would exceed established threshold emission levels in a nonattainment or maintenance area. An area is designated as nonattainment for a criteria pollutant if it does not meet National Ambient Air Quality Standards for the pollutant. A maintenance area is one that a state has redesignated from nonattainment to attainment.

Based on EPA's interpretation that mobile emissions from workers' vehicles should generally be considered as indirect emissions in a conformity analysis, a screening analysis was performed which indicated that the emissions from 2300 vehicles may exceed the thresholds for carbon monoxide, oxides of nitrogen, and volatile organic compounds (the latter two contribute to the formation of ozone) in nonattainment and maintenance areas. In addition, the amount of road dust generated by the vehicles traveling to and from work would exceed the threshold for particulate matter less than 10 μm in serious nonattainment areas. However, the assumption of adding 2300 workers' vehicles to existing traffic forms an upper bound of potential emissions; in reality, some workers would carpool to the refurbishment sites, while others would be driving to other construction sites if the proposed refurbishment activities were not occurring. In addition, EPA suggests that there may be some flexibility in the rigor of a conformity analysis, particularly with regard to the specific site, the extent of refurbishment, the pollutants which are in nonattainment, the severity of the nonattainment, the state regulatory agency, and the federal agency's control over workers' vehicles. In summary, vehicle exhaust emissions could be cause for some concern, but a general conclusion about the significance of the potential impact cannot be drawn without considering the compliance status of each site and the number of workers expected to be employed during the outage. This is a Category 2 issue.

3.4 SURFACE WATER AND GROUNDWATER QUALITY

3.4.1 Surface Water

Refurbishment could impact surface water quality as a result of the effects of (1) refurbishment- or construction-related discharges to surface water and (2) project-related surface water consumption. Changes in water quality could affect aquatic biota and water uses (fishing, recreation, and water supply).

Because most refurbishment activities would be conducted indoors (Section 2.6), discharges would be readily controlled, thereby minimizing the potential for impacts on surface water quality. The construction of new structures for storage of spent fuel or LLW could require modest amounts of site excavation and grading, but there are no features unique to the refurbishment that would require unusual construction practices. Procedures for the control of nonpoint-source pollution from construction activities as mandated by Section 319 of the Clean Water Act are well known. Mitigative measures were developed at each nuclear power plant site to control impacts during original plant construction. These measures, which are listed in the environmental statements related to the issuance of construction permits, include controlling drainage by ditches, berms, and sedimentation basins; prompt revegetation to control erosion; stockpiling and reusing excavated topsoil; and various other techniques used to control soil erosion and water pollution. These same types of site-specific mitigation measures (often referred to as best management practices) are expected to be implemented during refurbishment to minimize impacts on surface water quality and aquatic biota. Therefore, the potential impacts of refurbishment on surface water quality are expected to be negligible (small) for all plants. Impacts of refurbishment on surface water quality and aquatic biota could be further reduced by additional mitigative measures, such as more stringent construction control techniques. However, because the effects of refurbishment are considered to be of small significance and potential mitigation measures are likely to be costly, the staff does not consider the implementation of mitigation measures beyond "best management practices" to be warranted. This is a Category 1 issue.

Water consumption during refurbishment would not change from pre-refurbishment requirements unless the plant were temporarily shut down. If refurbishment activities resulted in more or longer plant outages than are typical for the facility, both cooling water withdrawals and routine permitted discharges of heat, biocides, or other chemical contaminants in the cooling system effluent would be reduced. The additional quantities of water required during construction for mixing, cleaning, and dust suppression would be negligible. For these reasons, water consumption impact during refurbishment is expected to be of small significance or beneficial for all plants. The only potential mitigation for any increase in water consumption would be to acquire the additional water from some other source. However, because this approach would provide very little, if any, environmental benefit and would be costly, the staff does not consider implementation of additional mitigation to be warranted. This is a Category 1 issue.

3.4.2 Groundwater

No liquid wastes were discharged to groundwater during construction of nuclear power plants, and none is expected to occur during refurbishment. During construction, liquid construction wastes were either temporarily retained in lined evaporation ponds or stored in drums for shipment to off-site disposal facilities. Because liquid construction wastes would be handled similarly during refurbishment no impacts to groundwater quality is expected.

The only impacts on groundwater quality reported during nuclear plant construction resulted from groundwater dewatering associated with deeply excavated building foundations and cooling water canals at sites close to the ocean. Groundwater dewatering at sites near the ocean can adversely affect groundwater quality by inducing saltwater intrusion. Deep excavations and site dewatering would not be required at any plant so no saltwater intrusion or groundwater quality impacts would occur.

Because refurbishment would not affect groundwater quality in any way, refurbishment would neither cause nor contribute to impacts on groundwater at any site. While there are several ways of mitigating adverse impacts to groundwater quality, no mitigation measures are warranted because there would be no adverse impacts to mitigate. This is a Category 1 issue.

3.5 AQUATIC ECOLOGY

Aquatic biota could be affected by adverse changes in water quality caused by construction or by changes in plant operation; however, if mitigative measures developed for the site during and since original construction are used, adverse effects on water quality and thus on aquatic biota would be minimal (Section 3.4.1). Potential impacts on aquatic biota from changes in operating conditions of the plant during refurbishment are expected to be small at all sites.

Effects of refurbishment on aquatic organisms are considered to be of small significance if plant-induced changes are localized and populations of aquatic organisms in the receiving waterbody are not reduced. During a major refurbishment outage there would be a reduction or elimination of cooling water withdrawals and discharges of heat, biocides, or other permitted chemicals in the cooling effluent. No adverse effects on aquatic biota would be caused at any power plant by reduced entrainment of organisms into the cooling system, reduced impingement against the intake screens, or reduced discharges of chemicals from any power plant site. Because no adverse effects on aquatic organisms are anticipated during refurbishment, the effects are considered to be of small significance for all plants. Since any effects would be minor and localized, they would not contribute to cumulative impacts. Water quality impacts could be readily controlled using current mitigative measures, and the reduction in cooling system operation during major refurbishment outages would reduce the number of aquatic organisms impacted by entrainment, impingement, and nonradiological discharges. Hence, no mitigation measures beyond those already implemented in the current license period would be needed. The effect of refurbishment on aquatic biota is a Category 1 issue.

3.6 TERRESTRIAL ECOLOGY

The potential loss of plant and animal habitat resulting from laydown areas and possible construction of new waste storage facilities during refurbishment at nuclear power plant sites would be the principal terrestrial ecology concern. The amount of on-site land that could be disturbed would be expected to be ~1–4 ha (2.5–10 acres). No off-site habitat loss would be expected to occur except to the extent that refurbishment may cause increased residential and commercial growth in nearby communities (see Section 3.7.5). No off-site power-line expansions (construction of new lines, upgrading of existing lines, or right-of-way expansion) are expected as part of license renewal; licensees must notify the NRC of such major modifications. Rebuilding wooden pole structures, however, may be necessary about every 50–60 years.

The significance of lost habitat depends on the importance of the plant or animal community involved. Particularly important habitats are wetlands, riparian habitats, staging or resting areas for large numbers of waterfowl, rookeries, restricted wintering areas for wildlife (e.g., winter deer yards), communal roost sites, strutting or breeding grounds of gallinaceous birds, and areas containing rare plant communities (e.g., Atlantic white cedar swamps). Such habitats are uncommon and are unlikely to occur on most plant sites. However, if such resources do occur on plant sites, refurbishment activities should be planned to avoid them to the extent feasible. If no important resource would be affected, the impacts would be considered minor and of small significance. If important resources could be affected by refurbishment activities, the impacts would be potentially significant. Because the significance of ecological impacts cannot be determined without considering site-specific and project-specific details, and because mitigation may be warranted, this is a Category 2 issue.

3.7 SOCIOECONOMIC IMPACTS

3.7.1 Introduction

This section describes the socioeconomic impacts associated with nuclear power plant refurbishment. Based on a literature search and citation review, the following plant-induced socioeconomic impacts were chosen for in-depth evaluation: changes to local housing (i.e., availability, costs, and characteristics); the magnitude of new nuclear plant tax payments in relation to total revenues in host communities; disruptions of local public services (i.e., education, transportation, public safety, social services, public utilities, and tourism and recreation); changes of local land use and development patterns; local employment levels; and disturbances to historic and aesthetic resources at and around the plant site. Of these socioeconomic impacts only those directly affecting the natural and built environment are carried forward to the decision whether to renew an operating license. The regional economic impact—including income, employment, and taxes—is not considered in the license renewal decision. The impacts discussed in this chapter are only those *new* impacts expected to be caused by refurbishment-related activities. Impacts are discussed for each plant's "impact" or "study" area, which includes those jurisdictions in which the most pronounced socioeconomic impacts are expected. Plant-induced population growth, while not an impact itself, was studied as a potential influence on a number of the impacts listed above.

For this analysis, the socioeconomic impacts that occurred during construction of seven case study nuclear plants were identified and used to forecast refurbishment-related impacts at the same seven plants. Differences between the construction and refurbishment periods in terms of key impact predictors such as work force size, population, and community infrastructure conditions were factored into the impact analysis. The analysis assumes that no other major construction projects will occur concurrently with plant refurbishment. If other large construction projects are ongoing during refurbishment, the socioeconomic impacts could be greater than those predicted. Because the case study plants (Figure 3.1) were representative of the range of U.S. nuclear plants in terms of a number of key factors (remoteness, population density, geographic region, age of plant), the impacts projected for the seven sites provide upper and lower bounds for the range of impacts that will occur at all plants.

Socioeconomic impacts are site-specific in nature. Therefore, simultaneous relicensing of several nuclear power plants will not have cumulative regional or national impacts. However, if two plants within 80 km (50 miles) of each other are refurbished simultaneously, worker in-migration and the related impacts might be larger. An overview of the socioeconomic research methods used is provided in Appendix C.

Socioeconomic impact analyses, particularly of resources affected by changes in population, are based on work force estimates presented in Chapter 2, Appendix B, and SEA (1995). The conservative scenario work force represents the upper bound of work force requirements for a typical plant. The primary socioeconomic impact analyses are based on the largest estimated work force (i.e., the PWR work force of 2273 persons).[1] This peak work force would occur during the 9-month major refurbishment outage immediately before the expiration of the initial operating license (see Appendix B).

After the refurbishment work force has peaked, refueling will be undertaken to prepare for continued plant operation during the license renewal term. Because of uncertainty surrounding the work force numbers, a sensitivity analysis was performed wherein socioeconomic impacts were predicted in response to a work force roughly 50 percent larger than the projected bounding case PWR refurbishment work force (i.e., 3400 workers). The discussion of conclusions for each socioeconomic topic states whether or not the category of impacts expected with the original estimate would change in response to the larger work force.

The estimates for the conservative case and typical case BWR peak work forces are 1500 and 1017, respectively.[2] The peak

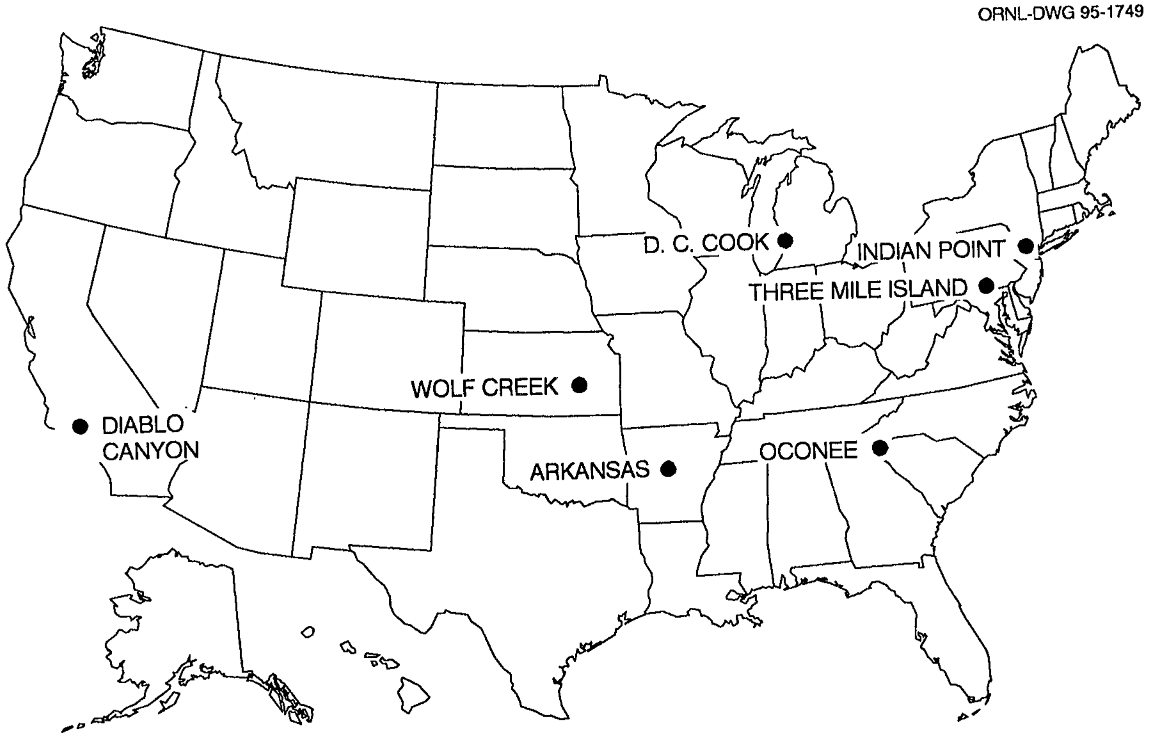

Figure 3.1 The seven case study nuclear plants.

on-site work force associated with the conservative BWR refurbishment scenario would occur during the current-term outages that will begin up to 10 years before the expiration of the original operating license. Because the current-term outages will last only 4 months, refueling and refurbishment workers will be on-site simultaneously. Both types of workers are included in the estimated peak work force of 1500. Under the BWR typical refurbishment scenario, the peak work force (1017) would occur during the final refurbishment period, projected to last 4 months. Because the outage would be brief, refueling workers will be on-site at the same time as refurbishment workers and are therefore included in the total work force estimate.

Limited additional analyses were conducted to determine if these smaller work forces would cause smaller impacts. These analyses were conducted only for resources found to be subject to potential moderate or large impacts with a work force of 2273 and known not to experience moderate or large impacts with smaller work forces (e.g., associated with refueling/maintenance activities). These analyses are discussed in the education and land use sections (i.e., those resources which, at certain case-study sites, fit the above description).

Population growth is important because it is one of the main drivers of socioeconomic impacts. The population increases resulting from construction-related in-migration at the seven case study plants varied (Table 3.1). Of all U.S. nuclear power plants, Indian Point has the highest combination of population density and proximity to urban centers, whereas Wolf Creek has one of the lowest combinations of the same variables. Consequently, Indian Point and Wolf Creek serve as the lower and upper bounds, respectively, of construction-related growth as a percentage of the case study areas' total populations.

Both the absolute and relative population growths associated with the refurbishment of the case study plants would be less than were experienced during original construction (see Table 3.1). The absolute growth would be smaller because the scale of refurbishment activities would be smaller than original construction. Relative growth would also be smaller because existing populations of the host communities are expected to be larger than during original construction (see Appendix C). The levels of refurbishment-related growth projected for the case study sites are expected to bound the levels of growth that would occur at all other plants.

Table 3.1 Past and projected population growth associated with the peak construction and refurbishment work forces at the seven case study nuclear power plants[a]

Plant	Past population growth caused by original plant construction	Past population growth as a percentage of study area's total population during peak construction years	Projected population growth caused by refurbishment	Projected population growth (refurbishment) as a percentage of study area's projected total population
Arkansas Nuclear One	2756	8.3	2355	3.7
D. C. Cook				
Bridgman—Lake Township	175	4.6	141	3.1
Berrien County	2193	1.3	1825	1.0
Diablo Canyon	3308	2.6	3631	0.8
Indian Point				
Dutchess County	390	0.2	367	0.1
	309	<0.1	290	<0.1
Oconee	701	1.7	496	0.7
Three Mile Island	301	2.2	189	1.0
Wolf Creek	2329	20.5	798	9.1

[a] Includes both direct and indirect workers and their families.
Source: The staff.

Refurbishment-related growth is expected to represent between less than 0.1 percent and 9.1 percent of the local areas' total populations for all plants (Table 3.1). As a result, for most U.S. nuclear power plants, refurbishment would result in only small population increases and correspondingly small population-driven impacts. Rural areas that are more than 80 km (50 miles) from an urban center (i.e., a population of at least 100,000) and that have low population densities would experience greater population-driven impacts.

3.7.2 Housing

The impacts on housing are considered to be of small significance when a small and not easily discernible change in housing availability occurs, generally as a result of a very small demand increase or a very large housing market. Increases in rental rates or housing values in these areas would be expected to equal or slightly exceed the statewide inflation rate. No extraordinary construction or conversion of housing would occur where small impacts are foreseen.

The impacts on housing are considered to be of moderate significance when there is a discernible but short-lived reduction in available housing units because of project-induced in-migration. Rental rates and housing values would rise slightly faster than the inflation rate, but prices should realign quickly once new housing units became available or once project-related demand diminished. The new housing units added to the market during construction are easily absorbed into the market once project-related demand diminishes. Minor or temporary conversions of nonliving space to living space, such as converting garages to apartments, may occur. Also, there may be a temporary addition of new mobile home parks or expansions of existing parks.

The impacts on housing are considered to be of large significance when project-related demand for housing units would result in very limited housing availability and would increase rental rates and housing values well above normal inflationary increases in the state. Such increases could make housing unavailable or less affordable to nonproject personnel. Substantial conversions of housing units, such as single-family houses to apartments, as well as substantial overbuilding so that these units cannot be absorbed into the housing market once project demand diminishes are also considered indicative of large impacts.

Housing impacts were evaluated by comparing refurbishment-related housing demand to the projected local housing market (number of units and vacancies). The housing impacts that occurred during original plant construction were considered, as were current housing characteristics (e.g., the existence of multifamily units in the local and neighboring housing markets) and the presence of any growth control measures that limit housing development. The size of the future housing market during the refurbishment period was estimated based on historical housing growth rates in the study areas. Housing demand unrelated to refurbishment was estimated based on the projected population at refurbishment time and the 1990 household size. A complete discussion of these assumptions is provided in Section C.4.1.2. Information concerning original construction-related housing impacts and current housing markets at the seven case study sites was obtained from site-specific NUREG reports, the U.S. Census Bureau, local housing authorities, and interviews with realtors and community development officials (see references in Appendix C).

Table 3.2 summarizes the housing impacts that resulted from original construction of the seven case study plants and lists construction-related housing demand relative to the local housing market, which is one of several factors that influence significance. In most cases, project-related housing demand was so small or the local and regional housing markets were so large that no large impacts resulted. The large housing impacts experienced at Wolf Creek were evidenced by (1) limited or no housing availability, (2) the occupation of previously abandoned housing units and of structures that were not originally intended for residential use, and (3) drastically increased rental costs. At this and other sites, local mobile home parks expanded to meet increased demand. None of the case study plant areas experienced substantial new construction of housing units that were built solely in response to project-related demand for housing. Construction of new housing units was noted at some sites during and before plant construction, but all new units were readily absorbed into the market once project-related demand diminished. The smallest work force that induced large impacts occurred with 640 on-site workers at Wolf Creek during operations-period refuelings (Section 4.7.2). Consequently, a work force as small as 640 may cause large impacts in low population areas but less significant impacts in higher population areas.

Potential refurbishment impacts on housing at each of the case study sites are summarized in Table 3.3. Table 3.3 also includes information about peak housing demand and housing demand relative to the projected number of housing units in each study area, although there is no simple direct relationship between these numbers and significance levels. Projected refurbishment impacts at the case study sites range from small to large. Declining economic conditions in the host communities would not increase the severity of the impact because public revenues are not used to build or maintain the dwellings that plant workers would occupy and because economic decline often is accompanied by a loss of population, which could increase the number of available housing units.

Moderate and large impacts are possible at sites located in rural and remote areas, at sites located in areas that have experienced extremely slow population growth (and thus slow or no growth in housing), or where growth control measures that limit housing development are in existence or have recently been lifted. Because impact significance depends on local conditions that cannot be predicted at this time, housing is a Category 2 issue.

3.7.3 Taxes

Plant-induced increases to local tax receipts are considered beneficial. The benefits of plant refurbishment to local tax structures were considered by examining the magnitude of potential new tax payments by the nuclear power plants in relation to total revenues in the host community. The new payments could be made directly to local government jurisdictions or indirectly to local government jurisdictions through state tax and revenue sharing programs. A more detailed discussion of the methods used to predict tax impacts is provided in Section C.4.1.3.

The benefits of taxes are considered to be small when new tax payments by the

Table 3.2 Summary of housing impacts during construction of seven nuclear power plants in case study

Site	Peak housing demand in study area	Housing demand as a percentage of the total number of housing units in the study area	Factors affecting housing impact	Impact on housing
Arkansas Nuclear One	858	6.25	Construction-related demand caused temporary housing shortages and increased rents, expansion of housing stock	Moderate
D. C. Cook				
Berrien County	902	1.8	Existing housing stock and housing growth adequate to meet demand	Small
Diablo Canyon	1297	2.7	Impact increased by rapidly increasing demand for housing unrelated to project	Moderate
Indian Point				
Westchester County	194	0.28	Very large housing market	Small
Dutchess County	143	0.04		Small
Oconee	167	1.2	Duke power provided on-site housing for 150 workers	Small
Three Mile Island	146	2.8	Substantial growth in housing stock occurred unrelated to project demand	Small
Wolf Creek	713	18	Low vacancy rate in a small housing market; very large construction-related demand	Large

Source: The staff.

Table 3.3 Projected housing impacts of refurbishment at the seven case study nuclear power plants

Plant	Peak housing demand in the study area	Housing demand as a percentage of housing units in the study area	Projected impacts
Arkansas Nuclear One	976	3.8[a]	Small
D. C. Cook			
Berrien C.	811	1.1	Small to moderate
Diablo Canyon	1388	0.9	Moderate to large[b]
Indian Point			
Dutchess County	158	0.1	Small
Westchester County	124	0.02	Small
Oconee	260	0.6	Small
Three Mile Island	124	1.7	Small
Wolf Creek	355	9.2	Large

[a] If the rapid growth in housing that occurred during 1986–1990 continues, demand as a percentage of total housing units would be 3.2 percent. The more conservative estimate is presented in this table and used to determine potential impacts.

[b] Because of current growth control measures, a slower growth scenario for San Luis Obispo County (see Appendix C) is used. If these growth control measures remain in effect, the impact to housing would be moderate to large. However, if these growth control measures were removed, impacts would be small.

Source: The staff.

nuclear plant constitute less than 10 percent of total revenues for local taxing jurisdictions. The additional revenues provided by direct and indirect plant payments on refurbishment-related improvements result in little or no change in local property tax rates and the provision of public services. The benefits of taxes are considered moderate when new tax payments by the nuclear plant constitute 10 to 20 percent of total revenues for local taxing jurisdictions. The additional revenues provided by direct and indirect plant payments on refurbishment-related improvements result in lower property tax levies and increased services by local municipalities. The benefits of taxes are considered to be large when new tax payments by the nuclear plant represent more than 20 percent of total revenues for local taxing jurisdictions. Local property tax levies can be lowered substantially, the payment of debt for any substantial infrastructure improvements made in the past can easily be made, and future improvements can continue.

Property taxes paid to the municipalities and taxing school districts surrounding the seven case study plants were very small at the start of original plant construction, and income and residential-related property taxes, although increasing rapidly throughout the construction period, were usually not large. Generally, as construction progressed, the assessed value of the nuclear plants increased dramatically; therefore, the property tax payments based on these assessments also increased greatly.

Capital improvements made to plants during the final refurbishment outage very likely would have no effect on taxes until they have been completed; thus, they should cause no tax impacts until the license renewal term. However, the assessed value of the plant is expected to increase before that time because of refurbishment-related capital improvements that occur during current-term outages.

Based on the benefits that occurred as a result of original plant construction, benefits resulting from the increase in direct and indirect tax payments to local jurisdictions during refurbishment would be small to moderate at the case study sites. The magnitude of current tax payments provides an indication of the magnitude of new tax payments. Where existing tax payments account for only a small or moderate share (< 20 percent) of total revenue (see Table 4.13), the new additional tax payments will have only small benefits, especially if the increase in assessed value from capital improvements is small. At sites where the plants currently contribute significantly (> 20 percent) to their respective local jurisdictions' total revenues (see Table 4.13) and where substantial capital improvements greatly increase the assessed value, the new benefits may be moderate.

3.7.4 Public Services

The projected impacts of refurbishment on public services were considered for education, transportation, public safety, social services, level of demand for public utilities, and tourism and recreation.

For most public services, future impacts were projected based on the estimated number of in-migrating workers and on the projected state of the local infrastructure. To predict impacts to local educational systems, the number of in-migrating workers accompanied by their families and their associated family sizes also are important. In the area of transportation, the total number of workers is important whether or not they are new to the host community, because they will use local roads to access the project site. Assumptions about the above-mentioned variables were based on patterns observed during original plant construction. Additional information on the calculation of public service impacts is provided in Sections C.1.5.3 and C.4.1.4. Information concerning construction-related public service impacts and current services at the case study sites was obtained from site-specific reports and interviews with local officials (see references in Appendix C).

Because projections of infrastructure capacity were based on current conditions, it is appropriate to ask whether future deterioration of host community infrastructure could invalidate the conclusions about impact significance presented below. Infrastructure deterioration is unlikely because these facilities and services generally have been maintained (and in many instances improved) during the period of plant operations. In addition, continued plant operations will ensure continued revenues for those local jurisdictions currently taxing the plant, providing a measure of protection for communities in which economic decline might otherwise result in infrastructure deterioration. Also, in communities where the quality and quantity of public services have declined, a population decrease has often occurred, reducing the demand for these services. Finally, the sensitivity analysis discussed in Section 3.7.1 revealed that local public services could accommodate the growth associated with a work force 50 percent larger than the bounding case refurbishment work force without increasing the significance level of the impacts. As a result, for those elements of the infrastructure projected to experience only small impacts, the capacity of the existing infrastructure in impact area communities could decline and still be adequate to support projected refurbishment-induced growth.

3.7.4.1 Education

Impact determinations depend on the baseline conditions of the potentially affected school system (e.g., whether it is below, at, or exceeding maximum allowed student/teacher ratio). In general, small impacts are associated with project-related enrollment increases of 3 percent or less. Impacts are considered small if there is no change in the school systems' abilities to provide educational services and if no additional teaching staff or classroom space is needed. Moderate impacts generally are associated with 4 to 8 percent increases in enrollment. Impacts are considered moderate if a school system must increase its teaching staff or classroom space even slightly to preserve its pre-project level of service. Any increase in teaching staff, however small (e.g., 0.5 full-time equivalent), that occurs from hiring additional personnel or changing the duties of existing personnel (e.g., a guidance counselor assuming classroom duties) may result in moderate impacts, particularly in small school systems. Large impacts are associated with project-related enrollment increases above 8 percent. Education impacts are considered large if current institutions are not adequate to accommodate the influx of students or if the project-related demand can be met only if additional resources (e.g., new teachers and/or classrooms) are acquired.

Impacts to education that resulted from plant construction depended upon the number of in-migrating workers (and, thus, school-aged dependents) and the size of the existing school system (and thus its ability to absorb additional students). School districts were affected for a short period of time, and disruption to existing institutions was small in most cases. However, some schools had to set up temporary classrooms to accommodate the influx of children. At the case-study sites, impacts to education during plant construction ranged from small to moderate (see Table 3.4). Once construction was well under way, positive monetary impacts began to be experienced by some school districts where plants were located.

Projected impacts to education during the refurbishment period would be potentially large at Wolf Creek where school enrollment is projected to increase 9 percent because of the in-migration of the refurbishment work force (see Table 3.5). At the Arkansas Nuclear One site, a projected 4 percent increase in

Table 3.4 Original construction-induced public service impacts at the seven case study nuclear power plant sites

Service	Arkansas Nuclear One	Diablo Canyon	D. C. Cook	Indian Point	Oconee	Three Mile Island	Wolf Creek
Education	Small	Small to moderate	Small	Small	Small	Small	Moderate
Transportation	Small	Small	Small to moderate	Small	Small	Moderate	Large
Public safety	Small	Small	Small	Small	Small	Small	Small
Social services	Small	Small	Small	Small	Small to moderate	Small	Small
Public utilities	Small to moderate	Small	Small	Small	Small	Small	Moderate
Tourism and recreation	Small	Small	Small	Small	Small	Small	Small to moderate

Source: The staff.

Table 3.5 Projected refurbishment-induced public service impacts at seven nuclear plant sites in case study

Service	Arkansas Nuclear One	D. C. Cook	Diablo Canyon	Indian Point	Oconee	Three Mile Island	Wolf Creek
Education	Moderate	Small	Small	Small	Small	Small	Moderate to large
Transportation	Small	Moderate	Small	Small	Small	Moderate	Large
Public safety	Small	Small	Small	Small	Small	Small	Small
Social services	Small	Small	Small	Small	Small	Small	Small
Public utilities	Small	Small	Small to moderate	Small	Small	Small	Small to moderate
Tourism and recreation	Small	Small	Small	Small	Small	Small	Small

Source: The staff.

enrollment could cause moderate impacts to education. At all other sites, impacts would be small.

Analyses of the smaller projected work forces associated with BWR conservative and BWR typical scenarios were conducted at case-study sites where impacts induced by the PWR conservative scenario work force were projected to be moderate or large. The analyses determine whether these smaller work forces would induce smaller impacts to education. At the most sparsely populated case study site (Wolf Creek), impacts to education would be moderate even with the smaller work forces. At the other site (Arkansas Nuclear One), impacts would be moderate with the 1500-person BWR bounding case work force but small with the 1017-person BWR typical case work force.

Based on the case-study analysis of the PWR bounding-case work force, refurbishment impacts on education at all plant sites would range from small to large, although most sites will experience only small new impacts to education. Analyses of the work forces associated with the BWR bounding- and typical-case scenarios conclude that moderate impacts to education could be induced by these smaller work forces but only at sites that are remotely located and sparsely populated. Because site-specific and project-specific factors determine the significance of impacts to education and the potential value of mitigation measures, this is a Category 2 issue.

3.7.4.2 Transportation

Significance levels of transportation impacts are related to the Transportation Research Board's level of service (LOS) definitions (Transportation Research Board 1985). LOS is a qualitative measure describing operational conditions within a traffic stream and their perception by motorists. LOS data, when available, can be obtained from local planners, county engineers, or local or state departments of transportation. Using LOS data describing existing conditions, the staff projected LOS conditions that would arise from the additional traffic associated with refurbishment (or continued operations). The LOS at each site was examined during shift change times when plant- and non-plant-related traffic is heaviest. A general definition of each LOS is provided below.

LOS A and B are associated with small impacts because the operation of individual users is not substantially affected by the presence of other users. At this level, no delays occur and no improvements are needed. LOS C and D are associated with moderate impacts because the operation of individual users begins to be severely restricted by other users and at level D small increases in traffic cause operational problems. Consequently, upgrading of roads or additional control systems may be required. LOS E and F are associated with large impacts because the use of the roadway is at or above capacity level, causing breakdowns in flow that result in long traffic delays and a potential increase in accident rates. Major renovations of existing roads or additional roads may be needed to accommodate the traffic flow.

Impacts to local transportation networks during construction of the case study plants were large only at Wolf Creek (Table 3.4) because of the inadequacy of the main local access roads to accommodate plant-related traffic. Large transportation impacts also are anticipated at Wolf Creek during refurbishment. In this case, current operations workers would contribute to the

Level of service	Conditions
A	Free flow of the traffic stream; users are unaffected by the presence of others.
B	Stable flow in which the freedom to select speed is unaffected but the freedom to maneuver is slightly diminished.
C	Stable flow that marks the beginning of the range of flow in which the operation of individual users is significantly affected by interactions with the traffic stream.
D	High-density, stable flow in which speed and freedom to maneuver are severely restricted; small increases in traffic will generally cause operational problems.
E	Operating conditions at or near capacity level causing low but uniform speeds and extremely difficult maneuvering that is accomplished by forcing another vehicle to give way; small increases in flow or minor perturbations will cause breakdowns.
F	Defines forced or breakdown flow that occurs wherever the amount of traffic approaching a point exceeds the amount which can traverse the point. This situation causes the formation of queues characterized by stop-and-go waves and extreme instability.

magnitude of those impacts. The magnitude of impacts experienced at this and the other case study sites depends primarily on the state of the existing road network rather than on the host area population density.

Refurbishment impacts to transportation would be small at most sites, but a few sites would experience moderate or large impacts. Because impacts are determined primarily by road conditions existing at the time of the project and cannot be easily forecast, a site-specific review will be necessary to determine whether impacts are likely to be moderate or large and whether mitigation measures may be warranted. Transportation is a Category 2 issue.

3.7.4.3 Public Safety

Impacts on public safety are considered small if there is little or no need for additional police or fire personnel. Impacts are considered moderate if some permanent additions to the police and fire protection forces or some new capital equipment purchases are needed. Impacts are considered to be large if there is a substantial increase in the permanent manpower of police and fire protection forces and in the need to purchase additional vehicles.

No serious disruption of public safety services occurred as a result of original construction at the seven case study sites (Table 3.4). Most communities showed a steady increase in expenditures connected with public safety departments. Tax contributions from the plant often enabled expansion of public safety services in the purchase of new buildings and equipment and the acquisition of additional staff.

Public safety services may experience some benefit from any increase in tax revenue generated by plant improvements during current term outages. Past adverse impacts at the case study sites were found to be small, and nothing in the literature review indicated reason to expect moderate or large impacts. Accordingly, any adverse public safety impacts associated with future plant refurbishment at case study sites would be small.

Based on the case-study analysis, it is determined that there would be little or no need for additional police or fire personnel. Therefore, adverse public safety impacts at all sites would be small. Sensitivity analysis indicated that this conclusion would be true even with a peak work force of 3400 workers. Some minor positive impacts might result because of increased tax payments. Because the impacts are small and the implementation of additional mitigation measures (e.g., additional personnel or capital equipment) would be costly, no mitigation measures beyond those implemented during the current term license would be warranted. Therefore, public safety is a Category 1 issue.

3.7.4.4 Social Services

The impacts on social services are considered small if no change in the current level of service occurs. Impacts are considered moderate if some additional personnel are needed to administer existing service programs. Impacts are considered large if new programs and additional personnel are required.

Impacts to local social services associated with the original construction of the case study plants generally were small (Table 3.4), but some areas did see a small increase in both the amount of dollars spent for new or existing programs and the demand for service during the construction period.

Based on original construction experience at case study plants, the staff anticipates that refurbishment-related population increases would lead to no change in the current levels of social service provided (Table 3.5). Consequently, the impacts of refurbishment on social services would be small at all sites. Because there would be no change in the levels of service and because mitigation measures (e.g., hiring additional social service personnel) beyond those implemented during the current term license would be costly, no mitigation measures would be warranted. This is a Category 1 issue. Sensitivity analysis indicates that this conclusion would be true even with a peak of 3400 workers.

3.7.4.5 Public Utilities

Impacts on public utility services are considered small if little or no change occurs in the ability to respond to the level of demand and thus there is no need to add to capital facilities. Impacts are considered moderate if overtaxing of facilities during peak demand periods occurs. Impacts are considered large if existing service levels (such as the quality of water and sewage treatment) are substantially degraded and additional capacity is needed to meet ongoing demands for services.

In general, small to moderate impacts to public utilities were observed as a result of the original construction of the case study plants (Table 3.4). While most locales experienced an increase in the level of demand for services, they were able to accommodate this demand without significant disruption. Water service seems to have been the most affected public utility.

Public utility impacts at the case study sites during refurbishment are projected to range from small to moderate. The potentially moderate impact at Diablo Canyon is related to water availability (not processing capacity) and would occur only if a water shortage occurs at refurbishment time.

Because the case studies indicate that some public utilities may be overtaxed during peak periods, the impacts to public utilities would be moderate in some cases, although most sites would experience only small impacts. This is a Category 2 issue.

3.7.4.6 Tourism and Recreation

Impacts on tourism and recreation are considered small if current facilities are adequate to handle local levels of demand. Impacts are considered moderate if facilities are overcrowded during peak demand times. Impacts are considered large if additional recreation areas are needed to meet ongoing demands.

In most of the case study areas, the original construction of a nuclear power plant had positive effects on tourism and recreation facilities. For example, some locales have been able to build new recreation facilities because of plant-related tax revenues. Some improvement to recreation facilities and programs may be possible if additional tax revenue is available as a result of current-term refurbishment at the plant. Increased demand associated with the refurbishment work force and in-migrating population is expected to cause only small impacts to recreation at the case-study sites.

Based on the case study analysis, the beneficial impacts of refurbishment would continue at most sites. Sensitivity analysis indicates that this conclusion would be true even with a peak work force of 3400 workers. Current facilities would continue to be adequate to handle local levels of demand at all sites, and developing additional facilities would be costly. Therefore, no mitigation measures (e.g., improving or expanding existing facilities) beyond those implemented during the current term license would be warranted. This is a Category 1 issue.

3.7.5 Off-Site Land Use

The issue evaluated in this section concerns refurbishment-induced changes to local land use and development patterns. Because the value attributed to land-use changes can vary for different individuals and groups, this analysis does not attempt to conclude whether such changes have positive or negative impacts. The methodology used to define impact significance and project impacts is discussed briefly in the introduction to Section 3.7 and is detailed in Section C.4.1.5.

The impacts to off-site land use are considered small if population growth results in very little new residential or commercial development compared with existing conditions and if the limited development results only in minimal changes in an area's basic land-use pattern.

Land-use impacts are considered to be moderate if plant-related population growth results in considerable new residential or commercial development and the development results in some changes to an area's basic land-use pattern. The impacts are considered to be large if population growth results in large-scale new residential or commercial development and the development results in major changes in an area's basic land-use pattern.

Although it is difficult to predict the exact nature of land-use impacts that will result from any nuclear plant's refurbishment, the original construction experience at the case study plants provides some key predictors of impacts. Generally, if plant-related population growth is less than 5 percent of the study area's total population, off-site land-use changes would be small, especially if the study area has established patterns of residential and commercial development, a population density of at least 60 persons per square mile (2.6 km^2), and at least one urban area with a population of 100,000 or more within 80 km (50 miles).

If refurbishment-related growth is between 5 and 20 percent of the study area's total population, moderate new land-use changes can be expected. Such impacts would most likely occur when the study area has established patterns of residential and commercial development, a population density of 30 to 60 persons per square mile (2.6 km^2), and one urban area within 80 km (50 miles).

Small, moderate, and large off-site land-use impacts resulted from the original construction at the study sites. Large impacts resulted during construction at the two sites where lakes were created. Because no major off-site land use conversion would be needed to support the refurbished plants, only small impacts of this sort are expected. Large impacts were not induced at any site by population growth (see Table 3.6 and Appendix C).

Because the residential settlement pattern of the refurbishment work force is expected to be comparable to that of the original construction work force at many nuclear plants, population-driven land-use impacts that have resulted from the original construction can be used to predict some of the off-site land-use impacts of refurbishment. Thus, the staff expects that refurbishment-related population increases will result in small to moderate new off-site land-use impacts for socioeconomic case study plants (see Table 3.6 and Appendix C).

For the case study site where the staff anticipates moderate land-use changes associated with population in-migration, the staff has conducted additional analyses to determine whether smaller work forces would induce smaller impacts. This analysis shows that at this case-study site moderate impacts are possible with the BWR conservative scenario construction work force (1500 persons), but only small impacts are anticipated with the BWR typical scenario construction work force (1017 persons).

Based on predictions for the case study sites, refurbishment at all nuclear plants is expected to induce small or moderate land-use changes. There will be new impacts; but for almost all plants, refurbishment-related population growth would typically represent a much smaller percentage of the local areas' total population than did original construction-related growth. Moderate land use changes are also possible under the BWR conservative scenario, but only small impacts would be

Table 3.6 Significance levels for original construction and refurbishment-related off-site land-use impacts at seven case study nuclear power plants

Plant	Construction	Refurbishment
Arkansas Nuclear One	Moderate	Small
D. C. Cook	Moderate	Small
Diablo Canyon	Small	Small
Indian Point	Moderate	Small
Oconee	Large[a]	Small
Three Mile Island	Small	Small
Wolf Creek	Large[a]	Moderate

[a] Large impact because lake construction was associated with site development, not because of population growth (see Appendix C).
Source: The staff.

associated with the BWR typical scenario. Because future impacts are expected to range from small to moderate, and because land-use changes could be considered beneficial by some community members and adverse by others, this is a Category 2 issue. A sensitivity analysis shows that large changes in land use would not occur even with a 3400-person work force.

3.7.6 Economic Structure

The issue evaluated in this section concerns the impact of plant refurbishment on local employment and income levels.

Economic effects are considered small if peak refurbishment-related employment accounts for less than 5 percent of total study area employment. Effects are considered moderate if peak refurbishment-related employment accounts for 5 to 10 percent of total study area employment. Effects are considered large if peak refurbishment-related employment accounts for more than 10 percent of total study area employment. In this context, "plant-related employment" refers to area residents employed at the nuclear power plant or at indirect jobs resulting from a nuclear plant's presence. Employees who live outside the study area and work at the plant are not included.

The study of economic structure examines employment because of its preeminent role in determining the economic well-being of an area. Economic impacts at the case study plants were predicted by comparing the number of direct and indirect jobs created by a plant's refurbishment with the total employment of the local study area at the time of refurbishment. These impacts are considered positive. The potential economic impacts of plant refurbishment at all sites were projected based on the seven case study plants.

During original construction, plant-related employment represented 0.3–25.6 percent of total employment in the communities near the case study plants. Table 3.7 shows the past effects associated with the construction work force and the projected effects of the refurbishment work force for all seven case study sites. The impacts to economic structure of both direct and indirect employment were included in this assessment.

Based on the findings at the case study sites, refurbishment-related economic effects would range from small benefits to moderate benefits at all nuclear plant sites. No adverse effects to economic structure would result from refurbishment-related employment. This conclusion would apply in the event of a much larger refurbishment work force because the associated impacts are beneficial.

3.7.7 Historic and Archaeological Resources

For this discussion and that in Section 4.7.7, historic resources are considered to be any prehistoric or historic archaeological site or historic property, district, site, or landscape in or eligible for inclusion in the *National Register of Historic Places* or having great local importance.

Sites are considered to have small impacts to historic and archaeological resources if (1) the State Historic Preservation Office (SHPO) identifies no significant resources on or near the site; or (2) the SHPO identifies (or has previously identified) significant historic resources but determines they would not be affected by plant refurbishment, transmission lines, and license-renewal-term operations and there are no complaints from the affected public about altered historic character; and (3) if the conditions associated with moderate impacts do not occur. Moderate impacts may result if historic resources, determined by the SHPO not to be eligible for the *National Register*, nonetheless are thought by the SHPO or local historians to have local historic value and to contribute substantially to an area's sense of historic character. Sites are considered to have large impacts to historic resources if resources determined by the SHPO to have significant historic or archaeological value would be disturbed or otherwise have their historic character altered through refurbishment activity, installation of new transmission lines, or any other construction (e.g., for a waste storage facility). Determinations of significance of impacts are made through consultation with the SHPO.

Any new construction activity, including building new waste storage facilities, new parking areas, new access roads to existing transmission lines, or new transmission lines, is particularly important to an analysis of impacts to historic and archaeological resources. Therefore, a refurbishment plan detailing areas of land disturbance is necessary to assess the potential impacts. Historic and archaeological resources vary widely from site to site; there is no generic way of determining their existence or significance. Also, additional resources (e.g., an archaeological site) may be identified before refurbishment begins or their historic significance may be newly established (e.g., a historic building). For these reasons, it is not possible to conclude that only small impacts would occur at the case study sties.

In addition, conclusions with respect to potential impacts to historic resources at the case study sites can be drawn only through consultation with the SHPO. The National Historic Preservation Act of 1966,

Table 3.7 Past construction-related and projected refurbishment-related employment effects at seven case study nuclear plants

	Construction			Refurbishment	
Nuclear plant	Plant-related employment[a]	Percentage of total study area employment	Magnitude of impact	Percentage of total study area employment in peak refurbishment year	Magnitude of impact
Arkansas Nuclear One	964	6.4	Moderate	5.8	Moderate
D. C. Cook					
Bridgman-Lake Township	140	8.8	Moderate	7.5	Moderate
Berrien County	2569	6.5	Small	3.3	Small
Diablo Canyon	3153	3.6	Moderate	1.8	Small
Indian Point					
Westchester County	966	0.3	Small	0.2	Small
Oconee	706	3.3	Small	1.9	Small
Three Mile Island	259	2.1	Small	6.0	Small
Wolf Creek	1361	25.6	Large	6.8	Small

[a] Includes both direct and indirect employment and income for study area residents.
Source: The staff.

especially Section 106, requires consultation with the SHPO and possibly the Advisory Council on Historic Preservation to determine whether historic and archaeological resources (either in or eligible for inclusion in the *National Register of Historic Places*) are located in the area and whether they will be affected by the proposed action.

It is unlikely that moderate or large impacts to historic resources occur at any site unless new facilities or service roads are constructed or new transmission lines are established. However, the identification of historic resources and determination of possible impact to them must be done on a site-specific basis through consultation with the SHPO. The site-specific nature of historic resources and the mandatory National Historic Preservation Act consultation process mean that the significance of impacts to historic resources and the appropriate mitigation measures to address those impacts cannot be determined generically. This is a Category 2 issue.

3.7.8 Aesthetic Resources

The issues evaluated in this section concern the impacts of construction and refurbishment activities on aesthetic resources at and around nuclear power plants. Primarily, aesthetic impacts would be temporary, would be limited both in terms of land disturbance and the duration of activity, and would have characteristics similar to those encountered during industrial construction: dust and mud around the construction site, traffic and noise of trucks, and construction disarray on the site itself. If severe, these effects could have implications for the economic and social institutions and functions of communities. Aesthetic resources are the physical elements that are pleasing sensory stimuli and include natural and manmade landscapes and the way the two are integrated. In this evaluation, the staff considers aesthetic resources to be primarily visual.

Levels of impacts for aesthetic resources are defined largely by the impact of the proposed changes as perceived by the public, not merely the magnitude of the changes themselves. The potential for significance arises with the introduction (or continued presence) of an intrusion into an environmental context resulting in measurable changes to the community (e.g., population declines, property value losses, increased political activism, tourism losses).

Sites are considered to have small impacts on their host communities' aesthetic resources if there are (1) no complaints from the affected public about a changed sense of place or a diminution in the enjoyment of the physical environment and (2) no measurable impact on socioeconomic institutions and processes. Sites are considered to have moderate impacts on their host communities' aesthetic resources if there are (1) some complaints from the affected public about a changed sense of place or a diminution in the enjoyment of the physical environment and (2) measurable impacts that do not alter the continued functioning of socioeconomic institutions and processes. A site is considered to have large impacts on its host community's aesthetic resources if there are (1) continuing and widely shared opposition to the plant's continued operation based solely on a perceived degradation of the area's sense of place or a diminution in the enjoyment of the physical environment and (2) measurable social impacts that perturb the continued functioning of community institutions and processes.

Because refurbishment would not result in substantial physical changes to existing plants and because the duration of these activities is expected to be short, new aesthetic impacts are expected to be limited to temporary effects. Based on projections for the case study sites, noticeable impacts on aesthetic resources from refurbishment activities could occur only at those sites where well-recognized aesthetic resources have been identified and protected by community organizations. Insignificant levels of impact on aesthetic resources are likely to be experienced in most host communities where (1) no scenic protection organizations are active, (2) active organizations view refurbishment activities as nonthreatening to such resources, or (3) either few or no distinctive aesthetic resources exist or refurbishment activities are not perceived to be threatening to local resources.

Refurbishment activities will be conducted on-site and primarily within existing buildings. Other than a possible increase in local traffic, due to refurbishment workers, refurbishment activities are not expected to be readily noticeable from off-site viewpoints at any plant. Thus, without a visual intrusion within the physical environment there is no stimulus that could lead to complaints from the public about a changed sense of place or a diminution in the enjoyment of the physical environment and measurable impact on socioeconomic institutions and processes. For these reasons, the impact on aesthetic resources is found to be small. Because there will be no readily noticeable visual intrusion, consideration of mitigation is not warranted. Aesthetic impacts of refurbishment is a Category 1 issue.

3.8 RADIOLOGICAL IMPACTS

Radiological impacts include off-site dose to members of the public and on-site dose to the work force. Each of these impacts is generic to all light-water reactors (LWRs). Section 2.6 and Appendix B identify the changing out of steam generators at PWRs and the replacement of recirculation piping at BWRs as the major anticipated refurbishment activities. Public radiation exposures and occupational radiation exposures from refurbishment activities for license renewal can be evaluated on the basis of information derived from past occurrences and projections for other repairs. Effluents anticipated during major refurbishment events were estimated on the basis of historical information derived for steam generator changeouts at PWRs and replacements of recirculation piping at BWRs, refurbishment tasks that have already taken place several times within the LWR power reactor industry. From these estimates, the maximum individual and average doses to members of the public were compared with the design objective of Appendix I to 10 CFR Part 50 and with baseline effluents produced during normal reactor operations. Occupational exposures were similarly estimated on the basis of detailed reports of major refurbishment or replacement actions. The radiological significance of the doses caused by refurbishment was compared with doses from normal operation, and risks from occupations not associated with ionizing radiation. Major historical refurbishment actions are referred to in Section 2.6 and are described in detail in Appendix B. Radiological impacts of transportation are discussed in Chapter 6.

A detailed discussion is provided in Chapter 6 of the radiological impacts of low-level waste, mixed waste, and spent fuel generated by power reactors during the renewal period; the impacts attributable to the uranium fuel cycle; and the impacts of the transportation of fuel and waste.

In response to comments on the draft generic environmental impact statement (GEIS) and the proposed rule, the standard defining a small radiological impact has changed from a comparison with background radiation to sustained compliance with the dose and release limits applicable to the activities being reviewed. This change is appropriate and strengthens the criterion used to define a small environmental impact for the reasons that follow. The Atomic Energy Act requires NRC to promulgate, inspect, and enforce standards that provide an adequate level of protection of the public health and safety and the environment. These responsibilities, singly and in the aggregate, provide a margin of safety. The definitions of the significance level of an environmental impact (small, moderate, or large) applied to most other issues addressed in this GEIS are based on an ecological model that is concerned with species preservation, ecological health, and the condition of the attributes of a resource valued by society. Generally, these definitions place little or no weight on the life or health of individual members of a population or an ecosystem. However, health impacts on individual humans are the focus of NRC regulations limiting radiological doses. A review of the regulatory requirements and the performance of facilities provides the bases to project continuation of performance within regulatory standards. For the purposes of assessing radiological impacts, the Commission has concluded that impacts are of small significance if doses and releases do not exceed permissible levels in the Commission's regulations. This definition of "small" applies to occupational doses as well as to doses to individual members of the public. Accidental releases or noncompliance with the standards could conceivably result in releases that would cause moderate or large radiological impacts. Such conditions are beyond the scope of regulations controlling normal operations and providing an adequate level of protection. Given current regulatory activities and past regulatory experience, the Commission has no reason to expect that such noncompliance will occur at a significant frequency. To the contrary, the Commission expects that future radiological impacts from the fuel cycle will represent releases and impacts within applicable regulatory limits.

3.8.1 Public Exposures

This section addresses the impacts on members of the public of radiation doses caused by refurbishment activities, including doses from effluents as well as from direct radiation. This issue is generic to all 118 nuclear power plants. To determine the relative significance of the estimated public dose for refurbishment, the staff compared dose projections for refurbishment with the historical (baseline) doses experienced at PWRs and BWRs. The dose estimates were based on reports evaluating effluent releases during refurbishment efforts (projected and measured).

Evaluating and analyzing public exposures to radioactive emissions associated with refurbishment was done in light of the regulatory requirements for nuclear power plants, methods for calculating doses from gaseous and liquid effluents, the levels of risk that authoritative agencies have determined to be associated with radiation exposure, and baseline radiation exposure data.

3.8.1.1 Regulatory Requirements

Nuclear power reactors in the United States must be licensed by the NRC and must comply with NRC regulations and conditions specified in the license in order to operate. NRC regulations in 10 CFR Part 20 include requirements that apply to all licenses such as individual nuclear power plants. In particular, maximum allowable concentrations of radionuclides in air and water above background at the boundary of unrestricted areas are specified to control radiation exposures of the public and releases of radioactivity. These concentrations are based on an annual total effective dose equivalent of 0.1 rem to individual members of the public. (A discussion of the International System of units used in measuring radioactivity and radiation dose is given in Appendix E, Section E.A.3.) In addition, design criteria and technical specifications concerning releases from the plant are required to minimize the radiological impacts associated with plant operations to levels as low as reasonably achievable (ALARA).

In 10 CFR Part 50.36a, conditions are imposed on licensees in the form of technical specifications on effluents from nuclear power reactors. These specifications are intended to keep releases of radioactive materials to unrestricted areas during normal operations, including expected operational occurrences, to ALARA levels. Appendix I to 10 CFR Part 50 provides numerical guidance on dose-design objectives and limiting conditions for operation of LWRs to meet the ALARA requirement. All licensees have provided reasonable assurance that the dose-design objectives are being met for all unrestricted areas. The design objective doses for Appendix I are summarized in Table 3.8.

In addition to NRC limitations, nuclear power plant releases to the environment must comply with EPA standards in 40 CFR Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operations." These standards specify limits on the annual dose equivalent from normal operations of uranium fuel-cycle facilities (except mining, waste disposal operations, transportation, and reuse of recovered special nuclear and byproduct materials). The standards are given in Table 3.8. Radon and its daughters are excluded from these standards.

EPA standards in 40 CFR Part 61, "National Emission Standards for Hazardous Air Pollutants; Regulation of Radionuclides," apply only to airborne releases. The EPA specified an annual effective dose equivalent limit of 10 mrem for airborne releases from nuclear power plants; however, no more than 3 mrem can be caused by any isotope of iodine. However, EPA has stayed the rule for NRC-licensed commercial nuclear power reactors based on its finding that NRC's program for power reactor air effluents protects and is likely to continue to protect the public health and safety with an ample margin of safety.

Experience with the design, construction, and operation of nuclear power reactors indicates that compliance with the design objectives of Appendix I to 10 CFR Part 50 will keep average annual releases of radioactive material in effluents at small percentages of the limits specified in 10 CFR Part 20 and 40 CFR Part 190. At the same time, the licensee is permitted the flexibility of operation, compatible with considerations of health and safety, to ensure that the public is provided a dependable source of power, even under unusual operating conditions that may temporarily result in releases higher than such small percentages but still well within the regulatory limits.

A major revision of 10 CFR Part 20 became effective in 1991. A significant change is the explicit requirement that the sum of the external and internal doses (total effective dose equivalent) for a member of the public may not exceed 100 mrem/year. This value is an annual limit and is not intended to be applied as a long-term average goal. Summations are to be performed using the methodology in International Commission on Radiological Protection (ICRP) Publication 26 (1977). The revised airborne effluent limits are based on 50 mrem/year. Therefore, with regard to radiation levels at any unrestricted area, the limit of 100 mrem in 7 consecutive days is eliminated, while the limit of 2 mrem in any 1 h is retained. Licensees may comply with the 100-mrem limit by demonstrating (1) by measurement or calculation that the individual likely to receive the highest dose from sources under the licensee's control does not

Table 3.8 Design objectives and annual limits on doses to the general public from nuclear power plants[a]

Tissue	Gaseous	Liquid
Design objectives, 10 CFR Part 50, Appendix I		
Total body, mrem	5[b]	3
Any organ (all pathways), mrem		10
Ground-level air dose[b], mrad	10 (gamma) 20 (beta)	
Any organ[c] (all pathways), mrem	15	
Skin, mrem	15	
Dose limits, 40 CFR Part 190, Subpart B		
Total body[d], mrem	25	
Thyroid[d], mrem	75	
Any other organ[d], mrem	25	

[a] Calculated doses.
[b] The ground-level air dose has always been limiting because an occupancy factor cannot be used. The 5-mrem total body objective could be limiting only in the case of high occupancy near the restricted area boundary.
[c] Particulates, radioiodines.
[d] All effluents and direct radiation except radon and its daughters.

exceed the limit or (2) that the concentrations of radioactive material released in gaseous and liquid effluents averaged over 1 year do not exceed the new levels at the unrestricted area boundary and that the dose in an unrestricted area exceeds neither 2 mrem in any given hour nor 100 mrem in 1 year. It is difficult to judge how federal regulations and industry standards will change between the present time and the license renewal period, which, for the newest reactors, may be 40 years from now. Some indications of future trends can be summarized, however. Two changes are discussed that could significantly affect radiation protection programs at the 118 power plants:

- New ICRP recommendations. ICRP-60 (1991) has recommended an occupational dose limit of 10-rem effective dose equivalent, accumulated over defined periods of 5 years. They have further specified that the effective dose should not exceed 5 rem in any single year. The NRC has carefully reviewed the recommendations of the ICRP and is reviewing the comments of the scientific community and others on these recommendations, and the ICRP response to inquiries. In addition, NRC staff will review the recommendations of other expert bodies, such as the National Council on Radiation Protection and Measurements (NCRP), and participate in the deliberations of the U.S. Committee on Radiation Research and Policy Coordination and any interagency task force convened by the EPA to consider revised federal radiation guidance. Any future reductions in the dose limits by NRC would be the subject of a future rulemaking proceeding.

- NCRP lifetime dose recommendation. NCRP has recommended that a worker's dose in rem should not exceed his age in years. The recommendation was not accepted for the 1991 revision of 10 CFR Part 20. NRC considers that if the magnitude of the annual dose is limited, there is a *de facto* limitation on the lifetime dose that can be received. The annual dose limit is preferable to an actual cumulative lifetime dose limit because the cumulative limit could act to limit employment, raising questions concerning the right of an individual to pursue employment in a chosen profession. Nonetheless, the Institute of Nuclear Power Operations has expressed considerable interest in the recommendation, and at many plants records are being examined to determine whether the more experienced workers meet this criterion. For those who do not, the utilities may face decisions involving worker protection and liability considerations from a viewpoint favoring restrictions and the need for skilled and experienced workers during the process leading up to and extending throughout the license renewal period.

3.8.1.2 Effluent Pathways for Calculations of Dose Commitment to the Public

When an individual is exposed to radioactive materials through air or water pathways, the dose is determined in part by the amount of time spent in the vicinity of the source or the amount of time the radionuclides inhaled or ingested are retained in the individual's body (exposure). The consequences associated with this exposure are evaluated by calculating the dose commitment. The total effective dose equivalent is the sum of the deep dose from external sources and the committed effective dose equivalent for internal exposures. This latter dose is that which would be received over a 50-year period following the intake of radioactive materials for 1 year under the conditions existing at the midlife of the station operation (typically 15 years).

Radioactive effluents can be divided into several groups based on physical characteristics. Among the airborne effluents, the radioisotopes of the noble gases krypton, xenon, and argon neither deposit on the ground nor are absorbed and accumulated within living organisms; therefore, the noble gas effluents act primarily as a source of direct external radiation emanating from the effluent plume. For these effluents, dose calculations are performed for the site boundary where the highest external-radiation doses to a member of the general public are estimated to occur.

A second group of airborne radioactive effluents—the fission-product radioiodines, as well as carbon-14 and tritium—are also gaseous but some can deposit on the ground or be inhaled during respiration. For this class of effluents, estimates are made of direct external radiation doses from ground deposits (as well as exposure to the plume). Estimates are also made of internal radiation doses to total body, thyroid, bone, and other organs from inhalation and from vegetable, milk, and meat consumption.

A third group of airborne effluents consists of particulates and includes fission products, such as cesium and strontium, and activated corrosion products, such as cobalt and chromium. These effluents contribute to direct external radiation doses and to internal radiation doses through the same pathways as described above for the radioiodine. Doses from the particulates are combined with those from the radioiodines, carbon-14, and tritium for comparison with one of the design objectives of Appendix I to 10 CFR Part 50.

The liquid effluent constituents could include fission products such as strontium and iodine; activation and corrosion products, such as sodium, iron, and cobalt; and tritiated water. These radionuclides contribute to the internal doses through pathways described above from fish consumption, water ingestion (as drinking water), and consumption of meat or vegetables raised near a nuclear plant and using irrigation water, as well as from any direct external radiation from recreational use of the water near the point of a plant's discharge.

The release of each radioisotope and the site-specific meteorological and hydrological data serve as input to radiation-dose models that estimate the maximum radiation dose that would be received outside the facility by way of a number of pathways for individual members of the public and for the general public as a whole. These models and the radiation-dose calculations are discussed in Revision 1 of Regulatory Guide 1.109, "Calculation and Annual Doses to Man from Routine Releases of Reactor Effluent for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I."

Doses from all airborne effluents except the noble gases are calculated for individuals at the location or source point (for example, the site boundary, garden, residence, milk cow or goat, and meat animal) where the highest radiation dose to a member of the public has been established from each applicable pathway (such as ground deposition, inhalation, vegetable consumption, milk consumption, or meat consumption). Only those pathways associated with airborne effluents that are known to exist at a single location are combined to calculate the total maximum exposure to an exposed individual. Pathway doses associated with liquid effluents are combined without regard to any single location but are assumed to be associated with maximum exposure of an individual.

A number of possible exposure pathways to humans are evaluated to determine the impact of routine releases from each nuclear facility on members of the general public living and working outside the site boundaries. A detailed listing of these exposure pathways would include external radiation exposure from the gaseous effluents, inhalation of iodines and particulate contaminants in the air, drinking milk from a cow or goat or eating meat from an animal that grazes on open pasture near the site on which iodines or particulates may be deposited, eating vegetables from a garden near the site (that may be contaminated by similar deposits), and drinking water or eating fish or invertebrates caught near the point of liquid effluent discharge. Other, less important exposure pathways may include external irradiation from surface deposition; eating of animals and crops grown near the site and irrigated with water contaminated by liquid effluents; shoreline, boating, and swimming activities; drinking potentially contaminated water; and direct irradiation from within the plant itself. Calculations for most pathways are limited to a radius of 80 km (50 miles). Beyond 80 km, the doses to individuals are smaller than 0.1 mrem/year, which is far below the average natural-background dose of 300 mrem/year.

For this study, effluent and population dose information was collected from a series of documents that have resulted from ongoing NRC programs. Source-term data (normal effluent releases from nuclear power plants) are assembled annually at Brookhaven National Laboratory (NUREG/CR-2907), and calculations of radiation dose to the public are performed at Pacific Northwest Laboratory. Documentation is given in a series of reports titled *Population Dose Commitments Due to Radioactive Releases from Nuclear Power Plant Sites* (NUREG/CR-2850). The source terms (measured in effluents) are used to estimate dose commitments to those persons assumed to be living in a region between 2 and 80 km (1.2 and 50 miles) from the reactor sites. Atmospheric transport factors (annual average dilution and annual average deposition) were calculated for the region around each site using appropriate meteorological data supplied by either the NRC or the utility. Site-specific parameters other than releases, meteorology, and population were obtained from environmental impact statements or updates in environmental monitoring reports. Parameter values include the total population drinking contaminated water, fish and invertebrate harvest for the region, and dilution factors. For those cases in which site-specific data were not readily available and the particular pathway was not expected to result in a large dose, assumptions intended to be conservative were used to estimate doses. The use of more realistic data should decrease dose estimates in most cases. To this end, each licensee has the opportunity to provide site-specific data. Doses were calculated using models approved by the NRC (NUREG/CR-2850).

3.8.1.3 Risk Estimates from Radiation Exposure

In estimating the health effects resulting from both off-site and occupational radiation exposures as a result of refurbishment of nuclear power facilities, the staff used normal probability coefficients for stochastic effects recommended by the ICRP (ICRP 1991). The coefficients consider the most recent radiobiological and epidemiological information available and are consistent with the United Nations Scientific Committee on the Effects of Atomic Radiation. The coefficients used in this GEIS (Table 3.9) are the same as those recently published by ICRP in connection with a revision of its recommendations (ICRP 1991). Excess hereditary effects are listed separately in this GEIS because radiation-induced effects of this type have not been observed in any human population, as opposed to excess malignancies that have been identified among populations receiving instantaneous and near-uniform exposures in excess of 10 rem. Details regarding the risk of radiation-induced health effects are provided in Appendix E.

Table 3.9 Nominal probability coefficients used in this generic environmental impact statement[a]

Health effect	Occupational	Public
Fatal cancer	4	5
Hereditary	0.6	1

[a]Estimated number of excess effects among 10,000 people receiving 10,000 person-rem. Coefficients are based on "central" or "best" estimates.
Source: ICRP 1991.

3.8.1.4 Baseline Gaseous and Liquid Effluents

Public radiation exposures from gaseous and liquid effluents resulting from refurbishment can be evaluated on the basis of effluent data from the replacement of steam generators and recirculation piping. The projections are based on large refurbishment efforts that have already been performed. Among the past refurbishment efforts, steam generator replacement has been the largest operation at U.S. PWRs. Replacement of the recirculating coolant piping probably represents the largest single effort at BWRs. During the replacement of steam generators and recirculation piping, releases of effluents have taken place under controlled conditions and in accordance with ALARA principles. Similar refurbishment efforts that may occur as part of the license renewal process would also take place under controlled conditions and in accordance with ALARA principles.

For the first several plants to replace steam generators, environmental reports were prepared that estimated amounts of radioactivity expected to occur in liquid and gaseous effluents as a result of the repair (NUREG/CR-3540). Actual effluent measurements were performed in several cases. The values are presented in Table 3.10, along with a summary of the same actual effluent types from BWRs and PWRs for 1986. It should be noted that steam generator repairs took less than a year, typically 6 to 9 months. The 1986 data are used because they represent a mid-level year between the early, post-Three Mile Island (TMI) backfitting and the more recent years that reflect a protracted emphasis on ALARA as well as the completion of the post-TMI backfits. The expected or measured releases from the refurbishments were also compared with (1) the normal operational effluents as predicted in the final environmental statements for the affected plants and (2) measured releases from the normal operation of these few reactors and for all reactors for 1986 as reported in NUREG/CR-2907. For each effluent type, when effluents associated with steam generator replacement are compared with those for normal operation as predicted in the final environmental statements, measured at the specific sites or measured at all LWR sites, they are found to be of the same order as or much less than effluents from normal operation for a year. The replacement of a steam generator

Table 3.10 Radioactive effluent source terms for steam generator replacements compared with typical 1986 effluent data for boiling-water reactors (BWRs) and pressurized-water reactors (PWRs)

Radioactive effluent	Surry[a] measurement (Ci)		Turkey Point[a] measurement (Ci)		Point Beach[b] estimate (Ci/unit)	H. B. Robinson [c] estimate (Ci/unit)	BWRs[d,e] (1986)	PWRs[e] (1986)	BWRs (1990)	PWRs (1990)
	Unit 1	Unit 2	Unit 3	Unit 4						
					Gaseous					
Noble gases	510	101	—	875	Negligible	140	53%, 1000[e]	57%, 1000	25%, 1000	23%, 1000
Iodine	0.0033	0.69	—	0.039	0.000007	0.00004	63%, 0.01	26%, 0.01	42%, 0.01[g]	49%, 0.01[g]
Particulates	0.0027	0.0013	0.00021	0.0012	0.00015	0.00009	63%, 0.01	26%, 0.01	—	—
Tritium	4.2	—	—	0.027	Negligible	0.7	—	—	—	—
					Liquid					
Mixed fission and activitation products (excluding tritium)	0.52	0.26	0.12	0.078	0.23	0.0013	50%, 0.1	30%, 1.0	47%, 0.1	39%, 1.0
Tritium	8.5[f]	—	—	47	125	14	26%, 10	85%, 100	37%, 100	90%, 100

[a] NUREG/CR-3540.
[b] NUREG-1011.
[c] NUREG-1003.
[d] Adapted from NUREG/CR-2907.
[e] Read as: 53% of the BWR nuclear power reactor sites released annually at least 1000 Ci of noble gases per reactor unit in 1986 (1 Ci = 3.7×10^{10} Bq).
[f] Estimated value from NUREG-0692.
[g] Data for the most recent years reported combine iodine and particulates.

does not change a plant's technical specifications relative to accident risk; thus, based on 10 CFR Part 50.59 an environmental assessment is not required. This point, coupled with past experience resulting in small environmental releases associated with steam generator changeouts, suggests that National Environmental Policy Act documents are not likely for future steam generator replacements.

Documents comparable to NUREG/CR-2907 estimating anticipated releases to the environment were not identified for BWR recirculation piping replacement, reflecting relatively less concern on the staff's part for effluents from recirculation piping replacement compared with initial concern for steam generator replacement. However, data of a similar nature are obtained from the two series of NRC summary documents, *Radioactive Materials Released from Nuclear Power Plants* (NUREG/CR-2907) and *Population Dose Commitments Due to Radioactive Releases from Nuclear Power Plant Sites* (NUREG/CR-2850). Annual release and dose commitment information for five reactor sites—Cooper, Monticello, Nine Mile Point-1, Peach Bottom-2, and Vermont Yankee—is presented in Table 3.11. Data presented in Table 3.11 demonstrate that releases of radioactive materials during recirculation piping replacement and consequent radiation doses to the public are similar to or less than those resulting from normal operation of the same plants. (Note that Peach Bottom Units 2 and 3 are reported together.) Releases from Peach Bottom Units 2 and 3 are typically larger than those at many other BWRs, although the releases still result in very small radiation doses to the public. This site has the largest releases during recirculation piping replacement. Given that data of Table 3.11 are representative of early technology for the recirculation piping replacement procedure, similar procedures during refurbishment of BWRs related to license renewal are not anticipated to result in significantly larger effluent releases or consequent radiation doses to the public.

Trends for dose reduction in the LWR industry (as seen in Table 4.6) suggest that dose reduction measures are working.

3.8.1.5 Dose to the Public from Radiological Effluents

Section 2.6 and Appendix B consider the scenario and types of potential refurbishment activities that may take place for license renewal. Only the period of major refurbishment is examined here because the potential for release of radioactive materials is greater for the single major refurbishment than for refurbishment in each of the four current term outages.

Detailed estimates of effluents associated with major refurbishment are not available at this time; however, there is a significant data base upon which to assess expected impacts. Major refurbishment efforts have taken place at PWRs and BWRs; associated data are presented in Tables 3.10 and 3.11. Within these tables, it is seen that effluents and dose impacts do not differ significantly from normal operation when a major refurbishment is performed. It is expected that, during the 9-month outage, a greater amount of work will be performed and some of the effluents, especially atmospheric particulates and possibly some liquid effluents associated with decontamination, may be slightly greater than were found during the steam

Table 3.11 Radioactive effluent releases and radiation doses to the public for boiling-water reactors (BWRs) that have had recirculation piping replaced

			Liquid releases			Air releases		
Year	Net electrical energy (10^6 MWh)	Total outage dates	Tritium (Ci)	Fission and activation products (Ci)	Population dose (person-rem)	I-131 and particulates (Ci)	Fission and activation products (Ci)	Population dose (person-rem)
				Cooper				
1979	5.0		6.6E	<2.5	0.01	<0.18	30000	0.3400
1980	3.8		8.8E	<11	0.02	<0.15	5000	0.0470
1981	3.9		<8.4E	<3.6	0.012	<0.011	2500	0.0540
1982	3.3		<9.1E	<5.4	0.03	<0.16	14000	0.1400
1983	5.3		<7.6E	<12	0.09	<0.023	1500	0.0100
1984	3.5	9/84	<7.2E	<6.3	0.06	<0.012	<1400	0.0100
1985	1.1	8/85	<5.1E	<13	0.06	<0.023	<1400	0.0100
1986	4.1		<5.6E	<7.4	0.03	<0.012	<1700	0.0100
1987	5.5		5.0E	<2.3	0.0081	0.027	1200	0.0003
1988	4.20		4.17	2.3	0.0068	0.0204	1810	0.0049
1989	4.79		5.45	2.19	0.007	0.00526	344	0.0014
1990	5.11		5.07	2.04	0.0029	0.000353	187	0.0012
				Monticello				
1979	4.4		ND[a]	ND	0	0.034	4000	0.1400
1980	3.5		ND	ND	0	0.028	3800	0.1600
1981	3.3		0.0042	0.0000031	0	0.035	3700	0.1800
1982	2.4		0.000027	0.00000058	0	0.089	7200	0.1900
1983	4.2		ND	ND	0	0.041	3200	0.1000
1984	2.6	2/84	ND	ND	0	0.029	520	0.0500
1985	4.3	1/85	ND	ND	0	0.10	2700	0.1400
1986	3.4		ND	ND	0	0.069	2500	0.1000
1987	3.5		ND	ND	0	0.17	4000	0.1700
1988	4.57		ND	ND	0	0.079	5880	0.18
1989	2.65		ND	ND	0	0.114	3980	0.21
1990	4.51		ND	ND	0	0.0434	2960	0.20
				Nine Mile Point 1				
1979	3.0		6.8	1.9	140	0.047	1000	0.0800
1980	4.5		ND	ND	0	0.026	590	0.0400
1981	3.3		5.1	5.4	4.9	0.015	610	0.2500
1982	1.1	8/82	5.8	0.0025	0.01	0.027	51	0.0100
1983	2.8	7/83	7.9	0.011	0.01	0.011	270	0.0400
1984	3.6		ND	ND	0	0.018	1000	0.0300
1985	4.9		ND					

Table 3.11 (continued)

			Liquid releases			Air releases		
Year	Net electrical energy (10^6 MWh)	Total outage dates	Tritium (Ci)	Fission and activation products (Ci)	Population dose (person-rem)	I-131 and particulates (Ci)	Fission and activation products (Ci)	Population dose (person-rem)
1986	3.2		2.2	<6.7E-4	0.0013	0.018	490	0.0200
1987	4.6		ND	ND	0.49[b]	0.016	200	0.0160
1988	0.0		ND	ND	0.21	0.00189	18	0.0044
1989	0.0		ND	ND	0.026	0.00302	0.000152	0.0067
1990	1.28		1.41	1.95E-3	0.007	0.00272	ND	0.016
				Peach Bottom 2[c]				
1979	15		43.0	2.0E1	16	0.26	190000	14.0000
1980	4.3		37.0	1.9E0	3	0.029	15000	1.7000
1981	6.6		37.0	2.0E0	0.84	<0.042	16000	1.9000
1982	4.8		24.0	9.3E0	3.1	0.039	13000	2.2000
1983	4.5		20.0	2.2E0	1.1	0.046	35000	8.6000
1984	2.4	4/84	36.0	6.2E0	1.1	0.10	81000	8.5000
1985	2.3	6/85	50.0	2.2E0	1.2	0.069	130000	15.0000
1986	6.9		45.0	4.6E-1	0.61	0.052	28000	4.1000
1987	1.6		46.0	3.3E-1	0.47	0.020	12000	1.6000
1988	0.0		9.69	2.02E-1	0.32	0.00150	0.0019	0.014
1989	4.05		20.0	1.13E-1	0.2	0.00345	2640	0.13
1990	14.2		23.5	1.36E-2	0.076	0.0182	11200	0.77
				Vermont Yankee				
1979	3.5		4.0	2.4E-4	0.0021	0.44	<8100	0.4600
1980	3.0		ND	ND	0	0.017	1600	0.0600
1981	3.6		37.0	1.0E-2	0.49	0.0045	<3200	0.1100
1982	4.2		ND	ND	0	0.0015	<3100	0.0600
1983	2.9		ND	ND	0	0.0041	<3100	0.1100
1984	3.3		ND	ND	0	0.0069	<3200	0.1000
1985	3.0	9/85	ND	ND	0	<0.0059	<3400	0.1000
1986	2.1	5/86	ND	ND	0	<0.0013	<1600	0.1200
1987	3.5		ND	ND	0	0.013	ND	0.0160
1988	4.11		ND	ND	0	0.00658	ND	0.059
1989	3.61		ND	ND	0	0.00892	10300	0.69
1990	3.62		ND	ND	0	0.0724	50700	0.16

[a] ND—not detected.

[b] Nine Mile Point—2 began operation in 1987. Radioactive releases are reported separately for units 1 and 2 in NUREG/CR-2907; doses reported are combined for units 1 and 2 in NUREG/CR-2850.

[c] Data for Peach Bottom includes units 2 and 3.

Sources: NUREG/CR-4494; NUREG/CR-2907-V8; NUREG/CR-2850.

generator changeouts or recirculation piping replacements. However, because of their origins (other effluents, for example), the noble gases and tritium gaseous emissions, which constitute the largest proportion of the total body dose from gaseous effluents to the maximally exposed individual, are not expected to increase beyond levels experienced for the already performed major refurbishments.

The resultant potential impacts on members of the public can be gauged with respect to impacts already experienced. Data tabulated in Appendix E on the maximally exposed individual from routine airborne emissions suggest that from 1985 through 1987, approximately 5 percent of the 47 plants for which data have been tabulated caused in any year annual total body doses of 1 mrem or greater, and approximately 10 percent caused thyroid doses of 1 mrem or greater. Because effluents and doses during periods of accomplished major refurbishment (Tables 3.10 and 3.11) have not been seen to differ significantly from normal operation, gaseous effluents and liquid discharges occurring during the 9-month refurbishment are not expected to result in maximum individual doses exceeding the design objectives of Appendix I to 10 CFR Part 50 or the allowable EPA limits of 40 CFR Part 190.

Within an 80-km (50-mile) radius, the average individual dose, considering all licensed LWRs, for 1985 to 1987 was between 0.001 and 0.002 mrem. If these values were increased a few percent, they would still be small. The average collective dose within an 80-km (50-mile) radius is between 1.0 and 2.0 person-rem (NUREG/CR-2850). For the assumed 9-month period of major refurbishment, these values might be raised slightly. In order to provide a point of comparison, the NCRP estimates that the effective dose equivalent from natural background sources to an individual in the United States is approximately 300 mrem annually. Typically, about 1 million persons are within an 80-km (50-mile) radius of a nuclear facility; this population will annually collect approximately 300,000 person-rem from natural background radiation.

Radiobiologists and epidemiologists generally agree that the collective dose to a population would have to be much larger than current doses from nuclear power plants before health effects would become a realistic concern. In its 1988 report (paragraph 251), the United Nations Scientific Committee on the Effects of Atomic Radiation stated:

> The product of risk coefficients appropriate for individual risk and the relevant collective dose will give the expected number of cancer deaths in the exposed population, provided that the collective dose is at least of the order of 100 man-Sv (10,000 person-rem). If the collective dose is only a few man-Sv, the most likely outcome is zero deaths.

In BEIR-V (1990) (p. 181), the National Academy of Sciences' Advisory Committee on the Biological Effects of Ionizing Radiation stated:

> Moreover, epidemiologic data cannot rigorously exclude the existence of the threshold in the millisievert [1 mSv is equivalent to 100 mrem] dose range. Thus, the possibility that there may be no risks from exposures comparable to external natural background radiation cannot be ruled out. At such low doses and dose

> rates, it must be acknowledged that the lower limit on the range of uncertainty in the risk estimates extends to zero.

In the event that small annual radiation doses (i.e., 0.001 mrem/year) contribute to cancer risks, the "best estimate" of cancer risk would be 5×10^{-10}/year. EPA considers that a risk level of 1×10^{-6} to the public provides an ample margin of safety and is an acceptable risk.

3.8.1.6 Dose to the Public from On-Site Storage of Radioactive Materials

Steam generator assemblies, recirculation piping, and other large assemblies may be stored on- site in shielded buildings. Potential doses from such storage can be estimated from information gained by previous experience with steam generators. Each steam generator will contain approximately 300 Ci of fixed gamma emitters at the time it is removed from the containment (NUREG-1003). In past steam generator replacements, storage buildings that housed the removed steam generators and associated equipment provided sufficient shielding to limit the dose rate to less than 1 mrem/h outside the building. Shielding of a similar nature for buildings that may contain more than one steam generator or recirculation piping is anticipated for future refurbishment efforts because of the need to minimize occupational doses. If one of these buildings were 275 m (1500 ft), a typical distance, from the nearest site boundary, the estimated additional dose rate at the site boundary would be less than 0.00001 mrem/h from on-site storage of the steam generators and other equipment. An individual who lived at this location for 1 year would receive less than 0.1 mrem from this source. This dose rate would decrease rapidly during the first 2 years of storage because short-lived radionuclides would decay; thereafter, the dose would decrease by a factor of two every 5 years as the remaining ^{60}Co decayed. The staff concludes that radiation doses to the public from on-site storage of steam generators, recirculation piping, and other assemblies removed during refurbishment would be very small and insignificant.

3.8.1.7 Cumulative Impacts

A perspective on the addition of a radiation burden to members of the U.S. population can be gained from the data presented in Table 3.12. A total average annual effective dose equivalent of 360 mrem/year to members of the U.S. population is contributed by two primary sources: naturally occurring radiation and artificial sources (including human enhancement of natural sources) of radiation. Natural radiation sources other than radon result in 27 percent of the typical radiation dose received. The larger source of radiation dose (55 percent) is from radon, particularly because of homes and other buildings that entrap radon and significantly enhance its dose contribution over open-air living. The remaining 18 percent of the average annual effective dose equivalent consists of radiation from medical procedures (x-ray diagnosis, 11 percent, and nuclear medicine, 4 percent) and from consumer products (3 percent). For consumer products, the chief contributor is radon in domestic water supplies, building materials, mining, and agricultural products, as well as coal burning. (Smokers are additionally exposed to the natural radionuclide ^{210}Po in tobacco, resulting in the irradiation of a small region of the bronchial epithelium to up to 16,000 mrem/year. Tobacco products are the dominant contributor to individual

Table 3.12. Average annual effective dose equivalent of ionizing radiations to a member of the U.S. population

Source	Effective dose equivalent	
	mrem	Percent of total
Natural		
Cosmic	27	8.0
Terrestrial	28	8.0
Internal	39	11
Total natural	94	27
Artificial		
Radon (human enhanced)	200	55
Medical		
X-ray diagnosis	39	11
Nuclear medicine	14	4
Consumer products	11	3
Other		
Occupational	0.9	< 0.3
Nuclear fuel cycle	< 1.0	< 0.03
Fallout	< 1.0	< 0.03
Miscellaneous	< 1.0	< 0.03
Total artificial	266	73
Total natural and artificial	360	100

Source: Adapted from NCRP (1987).

body organ doses, but the conversion of the organ dose to effective dose equivalent is too uncertain for NCRP to include it in its tables. However, NCRP used a weighting factor of 0.08 and estimated effective dose equivalents to an average smoker of 1,300 mrem/year and to an average member of the U.S. population of 280 mrem/year (NCRP, Report No. 95, 1987). Radiation exposures from occupational activities, nuclear fuel cycle, and miscellaneous environmental sources (including nuclear weapons testing fallout) contribute very insignificantly to the total average effective dose equivalent.

Activities at nuclear power stations can be considered to contribute to the cumulative radiation burden. During the major period of refurbishment, radiation dose to members of the public within a 50-mile radius are not expected to change significantly from the current-term conditions which were between 0.001 and 0.002 mrem/year during 1985–1987, and even lower in the most recent reporting year. In 1990, the average dose was 0.0005 mrem/year. During refurbishment, the average dose to the public will remain very small, probably unchanged from current operation which, according to the most recent year analyzed, is less than 0.001 mrem/year. Therefore, cumulative impacts of radiation dose to members of the public should remain a very small part (less than 0.0003 percent) of the ionizing radiation dose to an average member of the U.S. population.

3.8.1.8 Mitigation

Radiation exposures to the public have been examined for potential mitigation, based on findings of impacts during the refurbishment effort. Adequate mitigation is already in place and properly functioning: the preceding sections demonstrate that public radiation doses have been steadily decreasing over nearly two decades.

The basis for current mitigation is found in the Code of Federal Regulations governing nuclear power plants. For example, in 10 CFR Part 20.1101 (radiation protection programs), specific requirements are detailed:

(a) Each licensee shall develop, document, and implement a radiation protection program commensurate with the scope and extent of licensed activities and sufficient to ensure compliance with the provisions of this part (see Section 20.2102 for recordkeeping requirements relating to these programs).
(b) The licensee shall use, to the extent practicable, procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are ALARA.
(c) The licensee shall periodically (at least annually) review the radiation protection program content and implementation.

Regulations under which licensees of nuclear power plants operate explicitly require that attention be made to reducing public radiation exposures. Evidence is provided in Tables 3.10 and 3.11 as well as in the text of Sections 2 and 3 and in Appendices B and E to demonstrate that major refurbishment efforts taken during the current term of operation have operated under ALARA principles. Refurbishment activities that will take place in anticipation of license renewal can also be expected to comply with federal regulations in minimizing radiation dose.

Because of the existing federal regulations requiring operation under ALARA principles, and the historical record demonstrating that the regulations are being followed and are effective, ample evidence is provided that adequate mitigation for radiation exposure is already in place for major refurbishment activities and additional mitigation requirements are not warranted.

3.8.1.9 Conclusions

Off-site doses to the public attributable to refurbishment have been examined for both the maximally exposed individual and the typical or average individual. Because the focus of the analysis is on annual dose, only the results based on the assumed 9-month refurbishment outage were examined. In each instance, impacts were found to be small. To date, effluents and doses during periods of major refurbishments have not been seen to differ significantly from normal operation. Consequently, gaseous effluents and liquid discharges occurring during the 9-month refurbishment are not expected to result in maximum individual doses exceeding the design objectives of Appendix I to 10 CFR Part 50 or the allowable EPA limits of 40

CFR Part 190. Both the average individual dose and the 80-km (50-mile) radius collective doses will remain approximately 100,000 times less than the dose from natural background radiation. The evaluation of off-site radiation doses attributable to refurbishment determined that their significance is small for all nuclear plants. Radiation impacts to the public are considered to be of small significance because public exposures are within regulatory limits. It should also be noted that the estimated cancer risk is to the average member of the public is much less than 1×10^{-6}. Because current mitigation practices are properly functioning, cumulative impacts would not be significantly increased by refurbishment. Because current mitigation practices have resulted in declining public radiation doses for nearly two decades, additional mitigation is not warranted. The impact on human health is a Category 1 issue.

3.8.2 Occupational Dose

To determine the significance of the estimated occupational dose for refurbishment, the staff has compared dose projections for refurbishment with the historical (baseline) doses experienced at PWRs and BWRs. The dose estimates are based on detailed investigations of major refurbishment or replacement activities. Projected doses were used as the basis for estimates of cancer and genetic risk. Finally, the staff has compared the estimated risk to nuclear power plant workers with the risks to those workers from exposure to naturally occurring radiation and with published risks for other occupations. For the purpose of assessing radiological impacts to workers, the Commission has concluded that impacts are of small significance if doses and releases do not exceed permissible levels in the Commission's regulations. The standards for acceptable dose limits are given in 10 CFR Part 20.

Throughout the nuclear power industry, construction-type activities have continued at each operating plant but at greatly reduced levels compared with the original plant construction. These construction activities have included a broad range of plant modifications and additions made in response to a number of NRC requirements and industry initiatives, including post-TMI upgrades, radioactive waste system modifications, and spent fuel storage upgrades. In addition, several nuclear power plants have experienced major refurbishment efforts such as PWR steam generator replacement and the replacement of coolant recirculation piping in BWRs. These activities had significant potential for occupational exposure. Thus, occupational exposure histories accumulated to date are reflective of normal operation plus modifications and additions to existing systems. This information forms the basis for the evaluation of occupational doses resulting from refurbishment associated with license renewal.

3.8.2.1 Baseline Occupational Exposure

Table 3.13 shows the occupational dose history for PWRs and BWRs. Average collective occupational dose information and average annual individual worker doses are presented for those plants operating between 1974 and 1992. The year 1974 was chosen as a starting date because the dose data for years before 1974 are primarily from reactors with average rated capacities below 500 MW(e). Since the early 1980s, when the majority of post-TMI plant modifications were completed, there has been a decreasing trend in the average

Table 3.13 Annual average occupational dose for U.S. licensed light-water reactors

	Reported collective occupational dose (person-rem)						Annual average whole-body dose (rem)	
	BWR[a]			PWR[b]				
Year	Low	Average	High	Low	Average	High	BWR	PWR
1974	139	507	1430	18	345	1225	0.81	0.70
1975	114	701	2022	21	318	1142	0.86	0.76
1976	105	559	2468	58	460	1583	0.74	0.79
1977	198	828	3142	87	396	1153	0.89	0.65
1978	158	611	1327	48	424	1621	0.75	0.64
1979	157	733	1793	30	516	1792	0.73	0.56
1980	218	1136	3626	154	578	2387	0.87	0.52
1981	123	980	1836	58	652	3223	0.73	0.61
1982	205	940	1896	101	578	1426	0.76	0.53
1983	121	1056	2257	68	592	1881	0.82	0.56
1984	155	1004	4082	49	552	2880	0.66	0.49
1985	119	709	1677	36	424	1581	0.54	0.41
1986	84	645	2436	23	384	1567	0.51	0.37
1987	103	622	1579	47	370	1217	0.40	0.38
1988	53	529	1504	27	335	917	0.45	0.36
1989	177	432	910	18	287	1436	0.35	0.32
1990	83	426	884	13	285	1678	0.38	0.31
1991	103	324	1185	21	223	1468	0.31	0.27
1992	81	360	710	19	219	1280	0.32	0.26

[a] BWR = boiling-water reactor.
[b] PWR = pressurized-water reactor.
Source: NUREG-0713.

collective occupational dose. The average collective doses, however, are based on widely varying yearly doses. For example, between 1974 and 1992, annual collective doses for operating PWRs have ranged from 13 to 3223 person-rem; for operating BWRs, the figures range from 53 to 4083 person-rem. A decreasing trend in the highest annual collective dose is somewhat apparent, as is that for the average collective dose. In addition to decreases in collective dose, the average annual dose per nuclear plant worker has been reduced during this period from somewhat more than 0.8 rem to about 0.3 rem for BWRs and from around 0.7 rem to less than 0.3 rem for PWRs. A breakdown of the number of individual workers receiving doses in different ranges for 1992 is provided in Table E.8. These data demonstrate that 94 percent of plant radiation workers received less than 1 rem, and no worker received more than 4 rem. Overall data presented in Table 3.13 and in Appendix E provide ample evidence that doses to nearly all radiation workers are far below the worker dose limit established by 10 CFR Part 20 and that the continuing efforts to maintain doses at ALARA levels have been successful. A portion of the total work force can be defined as "transient." These individuals are usually employed for special functions and may be employed at multiple reactor sites during a given year. Data for individual reactors described earlier include these people, but only for each power plant. Thus some people are counted more than once and some people receive greater annual doses than are reported by individual plants. In 1993 there were approximately 13,000 of these people (NUREG-0713 1995). Over the years, doses to transient workers have been decreasing in the same way as doses to more permanent workers at nuclear power plants, going from an average of 1.04 rem in 1984 to 0.49 rem in 1993 (NUREG-0713 1995). In 1993 four transient workers received whole body doses between 4 and 5 rem, and no individuals received more than 5 rem (NUREG-0713 1995).

The wide range of annual collective doses experienced at LWRs in the United States results from a number of factors such as the reactor design, the amount of required maintenance, and the amount of reactor operations and in-plant surveillance. Because these factors can vary widely and unpredictably, it is impossible to determine in advance a specific year-to-year annual occupational radiation dose for a particular plant throughout its operating lifetime. On occasion, there may be a need for relatively high collective occupational doses compared with the average annual collective dose, even at plants with radiation protection programs designed to ensure that occupational doses will be kept to ALARA levels.

3.8.2.2 Projected Doses During Refurbishment

Many nuclear power plant operators have accrued considerable experience with the types of refurbishment activities that will be associated with license renewal. On the average, utilities have spent approximately $140 million per plant in modifications, and experience in retrofitting and modifying operating reactors has been gained. The level of effort required to support large construction activities such as a steam generator replacement has involved, for example, from 200,000 to 900,000 person-hours. The duration of shutdown has lasted from about 8 months to 2 years. Less complex modifications have required fewer person-hours and less plant downtime. Personnel who perform the modifications have often worked in relatively high radiation fields. Component surface exposure rates range from a few hundred mrem per hour to several rem per hour. The resulting cumulative radiation exposure to the work force has ranged from about 300 to 3500 person-rem for large, complex modifications and from 2 to 100 person-rem for smaller ones.

Throughout the process of plant modifications, it has been routine industrial practice to conduct ALARA reviews and studies on projects that may involve significant personnel exposures. Such evaluations are intended to assist the engineering of systems or implement radiological work practices that will reduce personnel exposures. Nonetheless, it is anticipated that each refurbishment program will result in occupational radiation doses in addition to those expected from normal operation during that time period.

Two scenarios were developed to estimate the occupational radiation doses caused by refurbishment activities: (1) a typical scenario that is expected in most situations and (2) a conservative scenario that is intended to capture additional work that might occur for those outlier plants whose impacts will be considerably greater than what is typical of the reactor population as a whole (see Section 2.6 and Appendix B). Care was taken to ensure that the dose estimates were conservative. The scenarios include work done in support of refurbishment during four current-term outages plus a single period of major refurbishment. Dose estimates for activities during each of the four current-term refurbishment outages are 11 and 10 person-rem for PWRs and BWRs respectively for the typical case and 200 and 191 person-rem respectively for the conservative case (see Tables 2.8 and 2.11). Dose estimates for the assumed single periods of major refurbishment are 79 and 153 person-rem for PWRs and BWRs respectively for the typical case and 1380 and 1561 for person-rem respectively for the conservative case.

3.8.2.3 Analysis of Occupational Exposures

According to the scenario developed in Appendix B, refurbishment efforts expended during the current licensing term are to take place during four outages plus a single large outage devoted to major items. Doses to power plant workers will, accordingly, take place during five time periods. Under the conservative scenario, the projected 200 to 191 person-rem for each of the four current term outages could increase the average annual collective dose during that period (based on 1992 numbers; see Table 3.13) from the range of 219 to 360 person-rem to the range of 419 to 551 person-rem for PWRs and BWRs respectively. These doses are similar to the average collective dose that was experienced by all LWRs during the second half of the 1980s. Under the typical scenario, the occupational doses would increase by less than 5 percent for both reactor types.

The single large outage effort in the conservative refurbishment scenario is estimated to result in a single-year increase in collective occupational dose (based on 1992 numbers) from 219 to 1599 person-rem for PWRs and from 360 to 1921 person-rem for BWRs. These levels are above the average of all reactors for any given year during the 1980s but are well below the levels for the highest single years for most BWRs and some PWRs (NUREG-0713). Thus the anticipated collective occupational doses attributable to refurbishment under the conservative scenario are in the range of doses already experienced by a large portion of the nuclear power plant industry. Under the typical scenario, the single large outage would add less than 7 percent to the current annual occupational doses.

During the large refurbishment outage, even in the conservative case, it is anticipated that average individual occupational doses will be maintained at acceptable levels. Experience during the early 1980s, when considerable backfitting was being performed within the industry, has shown that average worker doses could be kept to about 0.8 rem (NUREG-0713). Average worker doses are now in the 0.3–0.4 rem range. Because many activities in the 1980s were the same or similar to those expected to be performed in the refurbishment related to license renewal, it is estimated that such work can be performed while maintaining radiation protection to the degree achieved during the 1980s. On that basis, the NRC staff has compared the risks associated with the range of 0.4–0.8 rem to published risks associated with other occupations (Table 3.14). In this table, only nuclear plant workers are given the added chronic risk resulting from occupational exposures. Thus the risk for this category of workers is inflated by the theoretical calculations. There are three entries in Table 3.14 for nuclear power plant workers: using an annual average dose of 0.8 rem in conjunction with the "best estimate" cancer risk estimator; using an annual average dose of 0.4 rem in conjunction with the "best estimate" cancer risk estimator; and using the lower limit risk cancer estimator for both 0.8 and 0.4 rem.

During the 1980s, the average annual worker doses were reduced by a factor of two, from 0.8 to 0.4 rem (Table 3.13). Part of the reduction has resulted from the completion of backfitting work and part has resulted from improvements in radiation protection (ALARA) programs. The precise average annual worker doses that will accompany refurbishment are not known at present but are anticipated to be between 0.8 and 0.4 rem. This dose range puts nuclear power plant workers in the mid-range of job-related mortality incidence (Table 3.14). The actual cancer incidence as a result of radiation exposures at such low rates (i.e., two to three times natural background radiation) may be zero (NAS 1990). As a consequence, the actual occupational risk for nuclear plant workers may be in the lower part of the mortality incidence table. On the basis of these comparisons, the staff concludes that the risk to nuclear plant workers from refurbishment efforts associated with license renewal is comparable to the risks associated with other occupations.

The staff has examined the cumulative effects of occupational exposures during refurbishment activities under the conservative scenario. These effects are based on the dose estimate for BWRs (Appendix B) as an upper bound. A total of 2000–4000 persons are expected to compose the refurbishment work force if average annual individual doses are maintained at 0.4 to 0.8 rem. The risk of potentially fatal cancers in the exposed refurbishment work force population at a typical site and the risk of potential genetic disorders in all future generations of this refurbishment work force are estimated as follows: multiplying the estimated cumulative dose of 2325 person-rem (4 × 191 person-rem + 1561 person-rem) by the limit of the risk coefficients described earlier (Section 3.8.1.3 and Table 3.9), the staff estimates that between zero and one additional cancer death could occur in the total exposed refurbishment population for a given power plant. The magnitude of this risk estimate can be understood by comparing it with the current incidence of cancer deaths. Multiplying the estimated exposed worker population of 2000 to 4000 persons by the current incidence of actual cancer fatalities (20 percent), about 400 to 800 cancer deaths are expected in this population from causes other than occupational radiation exposure (American Cancer Society 1994).

The risk estimate of 0.1 genetic disorder to the progeny of the exposed refurbishment work-force population is roughly 5 million times less than the risk estimates of natural incidence of actual genetic ill health of about 500,000 expected for the same progeny. Because the risk is borne by the progeny of the entire population, it is thus properly considered as part of the risk to the general public. BEIR-III (1980) indicates that the mean persistence of the

Table 3.14 Incidence of job-related mortalities[a]

Occupational group	Mortality rates (premature deaths per 10^5 person-years)
Underground metal miners[b]	~1300
Uranium workers[b]	420
Smelter workers[b]	190
Nuclear-plant workers (early 1980s)[d]	44
Agriculture, forestry, and fisheries[c]	35
Mining, quarrying[c]	33
Nuclear-plant workers (1992)[e]	24
Construction[c]	22
Transportation and public utilities[c]	20
Nuclear-plant workers[f]	12
Government[c]	11
Wholesale and retail trade[c]	5
Manufacturing[c]	4
Services[c]	3

[a] Mortality incidences in this table do not include occupational diseases except for the hypothetical cancer incidence in nuclear plant workers.

[b] U.S. Department of Health, Education, and Welfare 1972.

[c] *Accident Facts* 1994 Edition, National Safety Council.

[d] The nuclear-plant worker's risk is equal to the sum of the radiation-related risk and the non-radiation-related risk. The estimated occupational risk associated with an average radiation dose of 0.8 rem is about 32 potential premature deaths per 10^5 person-years resulting from cancer, based on the ICRP 60 "best estimate" risk estimator of 4×10^{-4}/rem (ICRP 1991). The average non-radiation-related risk for seven U.S. electrical utilities during the 1970–79 period was about 12 actual premature deaths per 10^5 person-years, as shown in Figure 5 of Wilson and Koehl. (Note that the estimate of 32 radiation-related premature cancer deaths describes potential risk rather than an observed statistic. The lower confidence limit is zero.)

[e] The average worker dose in 1992 was approximately 0.3 rem. Using the "best estimate" risk estimator, about 12 premature deaths per 10^5 person-years are expected. Also, 12 actual premature deaths are caused by nonradiological causes typical of electrical utilities (see footnote *c*). The lower confidence limit is zero.

[f] Using the lower confidence limit for the risk estimate, no deaths from occupational radiation exposures are anticipated and the mortality incidence results totally from nonradiological causes typical of electrical utilities.

Source: Adapted from Wilson and Koehl (1980).

two major types of genetic disorders are about five generations and ten generations respectively. The risk of potential genetic disorders from refurbishment is conservatively compared with the risk of actual genetic ill health in the first five generations, rather than the first ten generations. Multiplying an assumed population of 1 million persons in the vicinity of the plant by the current incidence of actual genetic ill health in each generation (11 percent) yields an estimate that about 500,000 genetic abnormalities are expected in the first five generations of this population.

3.8.2.4 Cumulative Impacts

Currently, occupational radiation doses are on the order of 0.4 rem/year in addition to the 0.36 rem/year received by the typical U.S. resident. The cumulative impact of the estimated exposures due to refurbishment would be to increase average occupational radiation exposures for those involved from 0.76 rem to 0.79 rem for the year that includes the 9-month refurbishment period.

3.8.2.5 Conclusions

Occupational doses from refurbishment activities associated with license renewal (including current-term outages and the assumed single large outage) are estimated to be less than 1 percent of regulatory dose limits. The average individual exposures for refurbishment are expected to remain roughly the same as they have been during the last decade, within the middle zone of the occupations examined. The "best estimate" cancer risk due to refurbishment, 1×10^{-5}, is less than 10 percent of the ongoing annual occupational risk of 1.6×10^{-4} and less than 1 percent of the lifetime accumulation of occupational risk of 4.8×10^{-3}. Occupational radiation exposure during refurbishment meets the standard of small significance. Because the ALARA program continues to reduce occupational doses, no additional mitigation program is warranted. This is a Category 1 issue.

3.9 THREATENED AND ENDANGERED SPECIES

Potential impacts of refurbishment on federal- or state-listed threatened and endangered species, and species proposed to be listed as threatened or endangered, cannot be assessed generically because the status of many species is being reviewed and it is impossible to know what species that are threatened with extinction may be identified that could be affected by refurbishment activities. In accordance with the Endangered Species Act of 1973 (Pub. L. 93-205), the appropriate federal agency (either the U.S. Fish and Wildlife Service or the National Marine Fisheries Service) must be consulted about the presence of threatened or endangered species. At that time, it will be determined whether such species could be affected by refurbishment activities and whether formal consultation will be required to address the impacts. Each state should be consulted about its own procedures for considering impacts to state-listed species. Because compliance with the Endangered Species Act cannot be assessed without site-specific consideration of potential effects on threatened and endangered species, it is not possible to determine generically the significance of potential impacts to threatened and endangered species. This is a Category 2 issue.

3.10 SUMMARY OF IMPACTS OF REFURBISHMENT

The following conclusions have been drawn with regard to the impacts of refurbishment.

On-Site Land Use

- On-site land use impacts are expected to be of small significance at all sites. Temporary disturbance of land may be mitigated by restoration to its original condition after refurbishment. This is a Category 1 issue.

Air Quality

- Nuclear power plant atmospheric emissions would either remain constant during refurbishment or decrease if the plant were partially or totally shut down. Small quantities of fugitive dust and gaseous exhaust emissions from motorized equipment operation during construction and refurbishment would temporarily increase ambient concentrations of particulate matter and gaseous pollutants in the vicinity of the activity but would not be expected to measurably affect ambient concentrations of regulated pollutants off-site. Additional exhaust emissions from the vehicles of up to 2300 personnel could be cause for some concern in geographical areas of poor or marginal air quality, but a general conclusion about the significance of the potential impact cannot be drawn without considering the compliance status of each site and the numbers of workers to be employed during the outage. This is a Category 2 issue.

Surface Water Quality and Use

- Proven erosion control measures such as best management practices are expected to be implemented at all plants and to minimize impacts to local water quality from runoff in disturbed areas. Consequently, impacts of refurbishment on surface water quality are expected to be of small significance at all plants. Because the effects of refurbishment are considered to be of small significance and potential mitigation measures are likely to be costly, the staff does not consider implementation of mitigation measures beyond best management practices to be warranted. This is a Category 1 issue.

- Additional water requirements during construction and refurbishment would be a small fraction of cooling water requirements of the operating power plant. If the plant is partially or totally shut down, cooling water use would decline. Water use during refurbishment is expected to have impacts of small significance on the local water supply. The only potential mitigation for any increase in water consumption would be to acquire the additional water from some other source. However, because this approach would provide very little, if any, environmental benefit and would be costly, the staff does not consider implementation of additional mitigation to be warranted. This is a Category 1 issue.

Groundwater

- Deep excavations and site dewatering would not be required during refurbishment. Consequently, the impacts of refurbishment on groundwater would be of small significance at all sites. No additional mitigation measures would be warranted because there would be no adverse impacts to mitigate. This is a Category 1 issue.

Aquatic Ecology

- Effluent discharges from the cooling system of a nuclear power plant would either remain constant during refurbishment or decrease if the plant were partially or totally shut down. Effects of changes in water withdrawals and discharges during refurbishment would be of small significance. No additional mitigation measures beyond those implemented during the current license term would be warranted because there would be no adverse impacts to mitigate. This is a Category 1 issue.

Terrestrial Ecology

- The small on-site change in land use associated with refurbishment and construction could disturb or eliminate a small area of terrestrial habitat [up to 4 ha (10 acres)]. The significance of the loss of habitat depends on the importance of the plant or animal species that are displaced and on the availability of nearby replacement habitat. Impacts would be potentially significant only if they involved wetlands, staging or resting areas for large numbers of waterfowl, rookeries, restricted wintering areas for wildlife, communal roost sites, strutting or breeding grounds for gallinaceous birds, or rare plant community types. Because ecological impacts cannot be determined without considering site- and project-specific details, the potential significance of those impacts cannot be determined generically. This is a Category 2 issue.

Socioeconomics

- Because of refurbishment-related population increases, impacts on housing could be of moderate or large significance at sites located in rural and remote areas, at sites located in areas that have experienced extremely slow population growth (and thus slow or no growth in housing), or where growth control measures that limit housing development are in existence of have recently been lifted. This is a Category 2 issue.

- Tax impacts, which involve small to moderate increases in the direct and indirect tax revenues paid to local jurisdictions, are considered beneficial in all cases.

- In the area of public services, in-migrating workers could induce impacts of small to large significance to education, with the larger impacts expected to occur in sparsely populated areas. Impacts of small to moderate significance may occur to public utilities at some sites. Transportation impacts could be of large significance at some sites. These socioeconomic issues are Category 2.

- The impacts of refurbishment on other public services (public safety, social services, and tourism and recreation) are expected to be of small significance at all sites. No additional mitigation measures beyond those implemented during the current license term would be warranted because mitigation would be costly and the benefits would be small. These are Category 1 issues.

- In-migrating workers could induce impacts of small to moderate significance to off-site land use, and the larger impacts are expected to occur in sparsely populated areas. This is a Category 2 issue.

- Based on the findings at the case study sites, refurbishment-related economic effects would range from small benefits to moderate benefits at all nuclear power plant sites. No adverse effects to economic structure would result from refurbishment-related employment.

- Site-specific identification of historic and archaeological resources and determination of impacts to them must occur during the consultation process with the SHPO as mandated by the National Historic Preservation Act. Impacts to historic resources could be large if the SHPO determines that significant historic resources would be disturbed or their historic character would be altered by plant refurbishment activities. The significance of potential impacts to historic and archaeological resources cannot be determined generically. This is a Category 2 issue.

- The impact on aesthetic resources is found to be of small significance at all sites. Because there will be no readily noticeable visual intrusion, consideration of mitigation is not warranted. This is a Category 1 issue.

Radiological Impacts

- Radiation impacts to the public are considered to be of small significance because public exposures are within regulatory limits. Also, the estimated cancer risk to the average member of the public is much less than 1×10^{-6}. Because current mitigation practices have resulted in declining public radiation doses for nearly two decades, additional mitigation is not warranted. The impact on human health is a Category 1 issue.

- Occupational radiation exposure during refurbishment meets the standard of small significance. Because the ALARA program continues to reduce occupational doses, no additional mitigation program is warranted. This is a Category 1 issue.

Threatened and Endangered Species

- The significance of potential impacts to threatened and endangered species cannot be determined generically because compliance with the Endangered Species Act cannot be assessed without site-specific consideration of potential effects on threatened and endangered species. This is a Category 2 issue.

3.11 ENDNOTES

1. The PWR conservative work force number used in this analysis is taken from a work force estimate provided by Science and Engineering Associates, Inc. (SEA), that differs slightly from SEA's work force estimate discussed in Chapter 2 and Appendix B. The slight difference would not affect the conclusions.
2. The BWR conservative and typical work force numbers used in this analysis are taken from a work force

estimate provided by Science and Engineering Associates, Inc. (SEA), that differs slightly from SEA's work force estimate discussed in Chapter 2 and Appendix B. The slight difference would not affect the conclusions.

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4. ENVIRONMENTAL IMPACTS OF OPERATION

4.1 INTRODUCTION

Nuclear power plant operations during the license renewal term will result in a continuation of most of the impacts that were occurring prior to license renewal. Some operational procedures will change, however, in response to efficiency, reliability, and safety goals. These new procedures may result in a new baseline of plant-induced impacts that will continue throughout the license renewal term. In addition, the environmental receptors such as air, water, population, and biotic communities may be changing. These receptor changes in turn will influence the significance of any plant-induced impacts. Therefore, this chapter defines the prelicense-renewal baseline for plant-induced impacts and additional impacts due to a changing environment, refurbishment, and changes in plant operation.

It is the intent of this chapter to discuss all substantive issues of concern that were identified in the scoping process (Section 1.3). This chapter is organized according to the major modes by which nuclear power plants affect the environment. Because the cooling system is a major mode of interaction with the environment and because the three types of cooling systems have substantially different effects, the first three sections address the impacts of operation for each of the three cooling system types. Transmission lines have distinctly different effects from cooling systems, so they are discussed separately in Section 4.5. Operation of nuclear power plants also has potential human health, socioeconomic, and groundwater effects that are not closely related to either the cooling system or the transmission lines. These effects are discussed in Sections 4.6, 4.7, and 4.8.

The issue of impacts to threatened or endangered species is potentially relevant to all cooling system types and to transmission lines. Review of power plant operations has shown that neither current cooling system operations nor electric power transmission lines associated with nuclear power plants are having significant adverse impacts on any threatened or endangered species. However, widespread conversion of natural habitats and other human activities continues to cause the decline of native plants and animals. As biologists review the status of species, additional species threatened with extinction are being identified; consequently, it is not possible to ensure that future power plant operations will not be found to adversely affect some currently unrecognized threatened or endangered species. In addition, future endangered species recovery efforts may require modifications of power plant operations. Similarly, operations-related land-disturbing activities (e.g., spent fuel and low-level waste storage facilities) could affect endangered species. As noted in Section 3.2, without site-specific and project-specific information, the magnitude or significance of impacts on threatened and endangered species cannot be assessed. For these reasons, the nature and significance of nuclear power plant operations on as yet unrecognized endangered species cannot be predicted; and no generic conclusion on the significance of potential impacts on endangered species can be reached. The impact on threatened and endangered species, therefore, is a Category 2 issue and will not be discussed further in this chapter.

4.2 ONCE-THROUGH COOLING SYSTEMS

A once-through cooling system can affect the environment by withdrawing a large amount of water, heating it, adding biocides, and discharging it back to the receiving body. The main issues associated with plants using such a system are (1) effects on aquatic organisms due to changes in water quality, entrainment, and impingement; (2) water-use conflicts; and (3) effects on groundwater quality, hydrology, and use. These issues as they relate to license renewal are addressed in this section.

The following sections discuss the potential effects of operation of once-through condenser cooling systems on surface water quality, hydrology, and use (Section 4.2.1) and aquatic ecology (Section 4.2.2). Section 4.2.2.2 summarizes the conclusions for each of these issues.

4.2.1 Surface Water Quality, Hydrology, and Use

This section considers how once-through cooling systems may alter surface water quality, hydrology, and quantity; the consequent biological effects of such changes and the methodology used to arrive at conclusions are described in Section 4.2.2. Each issue is described and, as appropriate, illustrated with examples from operating nuclear power plants. Any ongoing effects will probably continue into the license renewal term, assuming that the cooling system design and operation will not change for any plant under the requirements for license renewal. Judgments about the significance of these issues during the license renewal term are based on published information, agency consultation, and information provided by the utilities (Appendix F) on every nuclear power plant in the United States. The conclusions reached in Section 4.2.1 apply to all nuclear power plants with once-through cooling systems.

Seventy nuclear power plants have a once-through cooling system (see Table 2.2). The operation of once-through cooling systems alters water quality primarily through the discharge of heat and chemicals to a receiving body of water. The largest volumes of discharge are associated with the main condenser cooling system, but there are other sources of liquid effluents (e.g., the service water system and sanitary wastes). Because the volumes of water discharged from other systems are relatively small compared with those of the once-through condenser cooling system (typically around 10 percent), concern about water quality impacts of discharges has generally focused on the condenser cooling system. The amounts of heated effluent from such a system can be large; a nuclear power plant with once-through cooling discharges water at about 46 m^3/s (736,000 gal/min) per 1000 MW(e) with a temperature increase of 10°C (18°F).

4.2.1.1 Regulation of Condenser Cooling System Effluents

The U.S. Nuclear Regulatory Commission (NRC) considered the costs and benefits of alternative condenser cooling systems (including potential impacts on water quality and aquatic ecology) in the environmental statements associated with issuance of construction permits and operating licenses. Once a plant is operating, however, the continuing regulation of nonradiological impacts on water quality and aquatic ecology is primarily the responsibility of the U.S. Environmental Protection Agency (EPA) or the applicable state permitting agency. This section describes the environmental statutes that underlie the regulation of impacts on aquatic resources from operating nuclear power plants. An understanding of the requirements of these statutes and the procedures under which aquatic resources effects are controlled by the permitting agencies is important to the interpretation of the issue categories.

As with other industries, discharges from steam-electric power plants are regulated under the Clean Water Act (CWA). Because power plants discharge wastewater into surface bodies of water, they must obtain a National Pollutant Discharge Elimination System (NPDES) permit under Section 402 of the CWA (33 USC 1342). The NPDES permit specifies the discharge standards and monitoring requirements that the facility must achieve for each point of discharge or outfall. NPDES permits must be renewed every 5 years, and during the renewal process, the plant must certify that no changes have been made to the facility that would alter aquatic impacts and no significant adverse impacts on aquatic resources have been observed. An NPDES permit is issued by EPA or, more commonly, a designated state water quality agency.

Under Section 316(a) of the CWA [33 U.S.C. 1326(a)], state-established thermal effluent limitations in the NPDES permit may be modified to a less stringent level if it can be shown that the less stringent level (i.e., higher temperatures) is sufficient to "ensure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife" (Bugbee 1978). The regulatory agency's decision to allow alternative thermal discharge limitations is based on the utility's 316(a) demonstration, which may present considerable information about the actual or projected thermal impacts of the power plant discharge. Like the NPDES permit, the 316(a) "variance" must be renewed every 5 years, and the applicant must provide evidence to the permitting agency as to why the variance is still appropriate. A 316(a) determination is not necessary for those power plants that are able to meet state water temperature standards; this is the case for many nuclear power plants that use closed-cycle cooling systems (Appendix F). However, a biological assessment/study, similar to that which would be required by 316(a), may be required to ensure that the mixing zone meets water quality standards [Charles H. Kaplan, letter to G. F. Cada, Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee November 19, 1990].

Section 316(b) of the CWA [33 USC 1326(b)] requires that "the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact." Like NPDES permits and 316(a) determinations, 316(b) determinations are made by EPA or a state permitting agency based on data supplied in the applicant's 316(b) demonstration. The 316(b) determination need not be separated from the NPDES process. Although 316(b) determinations are usually one-time judgments that are not periodically reconsidered, a determination under CWA Section 316(b) is not permanently binding. Where circumstances have changed (e.g., fish population has changed, the initial determination was deemed inappropriate, or some adjustment in the operation of the intake structure is warranted), a full 316(b) demonstration could again be required by EPA during the license period.

The 316(a) and (b) demonstrations provide EPA (or a designated state permitting agency) a means for considering condenser cooling system effects on aquatic biota, not just on water quality per se. Other federal and state agencies with responsibilities for aquatic resources [e.g., the U.S. Fish and Wildlife Service (FWS), the National Marine Fisheries Service (NMFS), state fish and wildlife agencies] do not issue permits but are consulted in the development of NPDES permits and Section 316 determinations.

Under Section 401 of the CWA (33 USC 1341), an applicant for a federal license or permit (the utility in this case) must obtain a state water quality certification (i.e., the state must certify that the applicant's discharges will comply with state water quality standards). This requirement would apply, for example, to U.S. Army Corps of Engineers Section 404 permits for the disposal of dredged and fill material and to EPA-issued NPDES permits. Of course, issuance of an NPDES permit by a state water quality agency implies certification under Section 401.

Any pesticide must be registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (7 USC 136 et seq.); this includes the various chlorine compounds, bromine compounds, and molluscicides used to control biofouling in power plants. Registration requires development of toxicity data. Under FIFRA, no one can use a biocide except in accordance with labeled instructions. Information about toxicity developed by the biocide manufacturer as a FIFRA requirement may be used to determine permissible power plant discharge concentrations for the NPDES permit.

Other potential aquatic resource issues are the subjects of particular legislation or executive orders (EOs) with specific requirements that cannot be limited or eliminated. For example, potential effects of plant modifications on floodplains and wetlands must be considered under EOs 11988 and 11990, respectively. Modifications that entail disposal of dredged material may require a permit from the U.S. Army Corps of Engineers under Section 404 of CWA (Pub. L. 92-500). Because the impacts could range from small to large depending on the details of the site and the proposed construction, the potential effect on floodplains or wetlands is a Category 2 issue.

4.2.1.2 Water Quality/Hydrology

The continued operation of once-through condenser cooling systems will allow continuation of associated hydrologic changes, including altered current patterns at intake and discharge structures, altered salinity gradients, and altered thermal stratification of lakes. Water quality effects considered in this section include temperature effects on sediment transport capacity, scouring, eutrophication, and the discharge of biocides, sanitary wastes, and heavy metals.

4.2.1.2.1 Current Patterns

Operation of the cooling system usually causes changes in water currents in the immediate vicinity of both the intake and the outfall. The extent of the changes depends on the design and siting of the intake and discharge and the nature of the body of water (Langford 1983). Because many nuclear plants are located on large rivers, lakes, reservoirs or on the seacoast, such localized altered current patterns are minor. However, plants sited near small bodies of water may have marked effects on current patterns. Operation of the cooling water system of Oyster Creek Nuclear Generating Station (NGS) changed the flows of the lower portions of Oyster Creek and South Branch Forked River from alternating flows typical of estuarine streams to unidirectional flows with constant salinity. The South Branch Forked River became an intake canal, with salt water continuously moving upstream toward the power plant. Oyster Creek, on the other hand, became a discharge canal, with heated salt water moving continuously away from the plant. Although substantial changes to the hydrology and water quality of these small streams have been documented, there have been only minor effects on nearby Barnegat Bay (Kennish et al. 1984). Changes to current patterns are of small significance if they are localized near the intake and discharge of the power plant and do not alter water use or hydrology in the wider area. Because once-through power plants are located near substantial bodies of water that are not subject to extreme changes in volume or flow rate, cooling water withdrawals and discharges do not have major effects on the hydrology of these large bodies of water. Impacts during the license renewal period are expected to be of small significance for all plants. Localized effects on current patterns would have been manifested during the initial stages of plant operation and would have been mitigated if necessary at that time. Based on a review of the published literature and operational monitoring reports, operation of the cooling system is expected to cause only small, localized changes to current patterns near the power plant and would not contribute to the cumulative impacts. Further, consultation with the utilities and regulatory agencies during preparation of the draft GEIS, as well as their comments on the draft GEIS, revealed no concerns about the individual or cumulative impacts of cooling system operations on current patterns. The impacts of altered current patterns will continue to be localized and of small significance. No change in operation of the cooling system is expected during the license renewal term, so no change in effects on current patterns is anticipated. The effects on current patterns could be reduced by changing to a closed-cycle cooling system or by reducing the plants' generation rate. However, these measures would be costly and are not reasonable in light of the small benefits that might be gained from their implementation. Hence, no additional mitigation measures to reduce the impact of cooling system operations on current patterns are necessary in the renewal period. For these reasons, the effect of once-through cooling system operation on current patterns is a Category 1 issue.

4.2.1.2.2 Salinity Gradients

Power plants operating near estuaries can also alter salinity gradients. As noted, the Oyster Creek NGS cooling system converted two brackish creeks to canals with unidirectional flows and increased salinity to an average of 17 parts per thousand, similar to Barnegat Bay (Tatham et al. 1978). The two creeks have become hydrologic extensions of the bay because of operation of the power plant, causing significant changes in the original water quality and aquatic communities in the creeks because water quality is now essentially the same as that of the bay

(Chizmadia et al. 1984). Effects do not appear to extend beyond these creeks, which are also affected by dredging and thermal and chemical discharges.

Chesapeake Bay has a large number of power plants (mostly fossil-fueled) within the mesohaline (estuarine) zone. The fact that power plant discharges can alter salinity regimes, which in turn can change the type and abundance of aquatic organisms at the discharge site, is considered in the development of NPDES permits for Maryland power plants (MDNR 1988). Although natural salinity patterns have been altered by the discharge of Chalk Point (a large fossil-fueled power plant) into a shallow mesohaline area of Chesapeake Bay, other plants in the area, including the Calvert Cliffs Nuclear Power Plant, have not had consistent discharge effects on salinity (MDNR 1988). Any localized effects on biota near these Maryland power plants are attributed to thermal and habitat changes, rather than to salinity. Changes to salinity gradients are of small significance if they are localized near the intake and discharge of the power plant and are within the normal tidal or seasonal movements of salinity gradients that characterize estuaries. Based on a review of the published literature and operational monitoring reports, operation of the cooling system is expected to cause only small, localized changes to salinity gradients near the power plant. Further, consultation with the utilities and regulatory agencies during preparation of the draft GEIS, as well as their comments on the draft GEIS, revealed no concerns about the individual or cumulative impacts of cooling system operations on salinity gradients. These organizations did not identify a need for additional mitigation of impacts associated with this issue. For example, operation of numerous once-through power plants in the Chesapeake Bay estuary has not caused significant changes in salinity gradients. The effects on salinity gradients could be reduced by changing to a closed-cycle cooling system or by reducing the plants' generation rate. However, these measures would be costly and are not reasonable in light of the small benefits that might be gained from their implementation. Hence, no additional mitigation measures to reduce the impact of cooling system operations on salinity gradients are necessary in the renewal period. For these reasons, the effects of once-through cooling system operation on salinity gradients are a Category 1 issue.

4.2.1.2.3 Thermal Effects

Discharges of heated effluents have the potential to affect water quality in five ways: (1) water temperature increases, including altered thermal stratification of lakes, (2) temperature effects on sediment transport capacity, (3) scouring, (4) lowered dissolved oxygen concentrations, and (5) eutrophication. Heated water discharges tend to remain at (or move toward) the surface of lakes and rivers. These discharges form a plume of warm water that dissipates with distance from the source by rejecting heat to the atmosphere or mixing with cooler ambient waters. Mixing tends to occur more rapidly in rivers than in lakes because of increased turbulence. Also because of turbulence, rivers do not naturally thermally stratify; as a result, alteration of temperature stratification in rivers by nuclear power plants is not an issue. Impacts of thermal discharges to water quality are of small significance if discharges are within thermal effluent limitations designed to ensure protection of water quality and if ongoing discharges have not resulted in adverse effects on the five attributes of water quality identified above.

Temperature-induced density stratification of lakes and reservoirs is a principal regulator of water quality and organism distribution in deep waters. Thermal stratification can be changed in two general ways by once-through cooling of power plants: by the discharge of heated water and by the altered circulation patterns generated by pumping cooling water into and out of the power station (Coutant 1981). Temperature elevation can intensify stratification (through surface discharge of heated water), whereas enhanced circulation may break down stratification. The relative importance of these two counteracting processes depends on the characteristics of the site and cooling system.

Destratification can increase dissolved oxygen concentrations in deeper waters and decrease the solubility of phosphorus (which contributes to eutrophication), and may be a net benefit to warm-water fisheries by expanding available habitat. For example, Larimore and McNurney compared two nearby lakes in Illinois—Lake Shelbyville, an unheated flood control reservoir, and Lake Sangchris, a cooling lake for a coal-fired power plant. In contrast with the unheated lake, Lake Sangchris did not stratify in the summer. Furthermore, largemouth bass had a longer growing season and greater annual growth in the cooling lake.

On the other hand, Coutant (1981) noted that the common practice of using cool hypolimnetic water from deep intakes for power station cooling, with surface discharge, may increase the size of the warm epilimnion and decrease the amount of habitat available to cool-water fish. For example, thermal discharges from the Oconee Nuclear Station have increased the annual heat load of Keowee Reservoir by one-third and lowered the thermocline (boundary between warm surface waters and cool bottom waters) from between 5 and 15 m to as low as 27 m (Oliver and Hudson 1987), although neither specified thermal limits nor lethal temperatures were exceeded [Oliver and Hudson 1987; Duke Power Company response to NUMARC survey (NUMARC 1990)].

The McGuire Nuclear Station withdraws cool hypolimnetic water from Lake Norman and discharges the heated water at the surface. As with Oconee, this has the effect of increasing the size of the upper layer of warm water and decreasing the habitat available for cool-water fishes (e.g., striped bass) in the hypolimnion of Lake Norman. Temperature modeling indicated that increasing the maximum upper discharge temperature from 95 to 99°F during July, August, and September would conserve cool-water fish habitat in the lake by allowing smaller withdrawal rates of hypolimnetic waters and would lower the average heat content of the lake by allowing more heat to be dissipated to the atmosphere from the warmer localized area (Duke Power Company 1988; Lewis 1990). The increased thermal limit is not expected to substantially affect water quality or aquatic biota in the mixing zone. Following consultation with the North Carolina Department of Health and Natural Resources, the NPDES permit has been modified to allow the higher temperatures [Duke Power Company response to NUMARC survey (NUMARC 1990)]. Modeling reservoir heat budgets allows effects of thermal discharges on stratification to be predicted and used by utilities and regulatory agencies to develop the best heat dissipation scheme. Altered thermal stratification has never been a problem at most plants. At other plants (i.e., McGuire and Oconee), the issue has been periodically re-examined during the initial license period and mitigated as needed by adjusting thermal discharges.

The effects of altered thermal stratification on water quality and distribution of aquatic organisms are monitored during plant operation and are mitigated if necessary through the NPDES permit renewal process. Based on a review of the published literature and operational monitoring reports, operation of the cooling system has not altered thermal stratification at most power plants with once-through cooling systems. At the small number of plants where changes in thermal stratification have occurred, monitoring and modeling studies have been used to adjust the thermal discharges, thereby mitigating adverse impacts. As appropriate, these models take into account other thermal inputs to the receiving waterbody and therefore consider cumulative as well as individual plant effects. Consultation with the utilities and regulatory agencies during preparation of the draft GEIS, as well as their comments on the draft GEIS, revealed no concerns about the individual or cumulative impacts of cooling system operations on thermal stratification. The impacts of altered thermal stratification will continue to be of small significance. No change in operation of the cooling system is expected during the license renewal term, so no change in effects on thermal stratification is anticipated. The effects of thermal stratification could be reduced by changing to a closed-cycle cooling system or by reducing the plants' generation rate. However, these measures would be costly and are not reasonable in light of the small benefits that might be gained from their implementation. Hence, no additional mitigation measures to reduce the impact of cooling system operations on thermal stratification are necessary in the renewal period. For these reasons, the effects of once-through cooling system operation on thermal stratification are a Category 1 issue.

Increased temperature and the resulting decreased viscosity have been hypothesized to change the sediment transport capacity of water, leading to potential sedimentation problems, altered turbidity of rivers, and changes in riverbed configuration. Coutant (1981) discussed the theoretical basis for such possible changes, as well as relevant field investigations, and concluded that there is no indication that this is a significant problem at operating power stations. Examples of altered sediment characteristics are more likely the result of power plant structures (e.g., jetties or canals) or current patterns near intakes and discharges; such alterations are readily mitigated.

Based on review of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, there is no evidence that temperature effects on sediment transport capacity have caused adverse environmental effects at any existing nuclear power plant. Regulatory agencies have expressed no concerns regarding the cumulative impacts of temperature effects on sediment transport capacity. Furthermore, because of the small area near the plant affected by increased water temperature, it is not expected that plant operations would have a significant contribution to cumulative impacts. Effects are considered to be of small significance for all plants. No change in the operation of the cooling system is expected during the license renewal term so no change in effects on sediment transport capacity is anticipated. Effects on sediment transport could be reduced by changing to a closed-cycle cooling system or by reducing the plants' generation rate. However, because the effects on sediment transport capacity are considered to be impacts of small significance and because these measures would be costly, the staff does not consider the implementation of these potential mitigation measures to be warranted. This is a Category 1 issue.

Cooling water discharges have the potential for scouring sediments, especially near high-velocity discharge structures, and for changing patterns of sediment deposition. Changes in sediment composition have been observed near operating power plants; for example, the Calvert Cliffs Nuclear Power Plant (MDNR), the Haddam Neck (Connecticut Yankee) Plant (Merriman and Thorpe), and the San Onofre Nuclear Generating Station (MRC). Fine-grained materials near the power plant discharge structure may become suspended by the discharge plume, resulting in localized increases in turbidity and a coarser-grained composition of sediments near the discharge. Depending on site-specific circumstances, changes in sediment composition near the power plant discharge may be regarded as adverse (shading of kelp beds; MRC), beneficial (enhancement of the productivity of benthic animals; MDNR), or inconsequential (Merriman and Thorpe). In all cases, sediment changes are localized.

Review of literature and operational monitoring reports, consultation with utilities and regulatory agencies, and comments on the draft GEIS confirm that sediment scouring has not been a problem at most power plants and has caused only minor localized effects at three plants. The impacts of sediment scouring will continue to be localized and of small significance. Contributions to cumulative impacts are not expected because of the small area near the power plant affected by higher velocity cooling water discharges, and no concerns about cumulative impacts were expressed by the regulatory agencies. The effects of sediment scouring could be reduced by changing to a closed-cycle cooling system or by reducing the plants' generation rate. However, these measures would be costly and are not reasonable in light of the small benefits that might be gained from their implementation. Hence, no additional mitigation measures to reduce sediment scouring effects are necessary in the renewal period. Sediment scouring due to discharge of condenser cooling water is a Category 1 issue.

An early concern about thermal discharges from power plants was that the heat would stimulate biological productivity and speed the process of eutrophication of natural waters. Coutant (1981) examined the evidence for such changes and concluded that, because enhanced mineralization of organic matter by bacteria would offset any thermally induced increases in organic production, significant eutrophication from direct thermal effects at most plants was unlikely. On the other hand, Coutant (1981) hypothesized that power plants that withdraw hypolimnetic water from stratified reservoirs and discharge heated effluents at the surface may (1) lengthen the growing season and (2) transfer previously unavailable nutrients from bottom waters to the surface. A longer growing season and more nutrients in the surface layer could result in more biological production and more organic matter that would settle into the hypolimnion and thus decay and consume oxygen; all of these are symptoms of eutrophication. This chain of events is most likely to be seen in small lakes that were oligotrophic (relatively unproductive) and supported hypolimnetic fisheries. Long-term monitoring of the McGuire Nuclear Station on such a reservoir indicates that operations have not resulted in increased eutrophication (NPDES No. NC0024392, 1988; NPDES No. NC0024392, 1990). Similarly, the operation of Oconee Nuclear Station does not appear to be causing eutrophication in Lake Keowee; long-term studies indicate that nutrient levels in the lake are low and appear to be declining [Duke Power Company, response to NUMARC survey (NUMARC 1990)]. Review of literature and operational monitoring reports, consultation with utilities and regulatory agencies, and review of comments on the draft GEIS indicate that power-plant-induced eutrophication has not been a problem at any existing nuclear power plant. Monitoring studies have not revealed cumulative impacts, and no concerns about nuclear power plants contributing to eutrophication in a cumulative way were expressed by the regulatory agencies. Effects are considered to be of small significance for all plants. No change in operation of the cooling system is expected during the license renewal term, so no change in the effects on eutrophification is anticipated. The eutrophication effects could be reduced by changing to a closed-cycle cooling system or by reducing the plants' generation rate. However, these measures would be costly and are not reasonable in light of the small benefits that might be gained from their implementation. Hence, no additional mitigation measures to reduce eutrophication effects are necessary in the renewal period. Accelerated eutrophication due to discharge of condenser cooling water is a Category 1 issue.

4.2.1.2.4 Chemical Effects

Some of the water quality issues that have been raised are potential chemical effects resulting from discharges of chlorine or other biocides, small-volume discharges of sanitary and other liquid wastes (Chapter 2), chemical spills, and heavy metals leached from cooling system piping and condenser tubing. Impacts of chemical discharges to water quality are considered to be of small significance if discharges are within effluent limitations designed to ensure protection of water quality and if ongoing discharges have not resulted in adverse effects on aquatic biota.

The discharged chemicals, including chlorine and other biocides, are regulated by the NPDES permit of each nuclear power plant. Regulatory concern about toxic effects of chlorine and its combination products, as well as operating experience with control of biofouling, has led many plants to eliminate the use of chlorine or reduce the amount used below those levels that were originally anticipated in the environmental statements associated with issuing the construction permit and operating license. Some power plants use mechanical cleaning methods or, because of the abrasive properties of particulates in the intake water, do not have to clean the condenser cooling system at all. Other plants chlorinate the condenser cooling or service water systems but can isolate certain portions for treatment (e.g., a single unit of a multi-unit plant), thereby allowing dilution to reduce the concentration of chlorine in the discharge. Because of these refinements and the process for modifying NPDES permit conditions as needed, water quality degradation from existing biocide usage at once-through nuclear power plants is not a concern among the regulatory and resource agencies consulted for this GEIS. Based on review of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, water quality effects of discharge of chlorine and other biocides are considered to be of small significance for all plants. Small quantities of biocides are readily dissipated and/or chemically altered in the receiving waterbody so that significant cumulative impacts to water quality would not be expected. No change in operation of the cooling system is expected during the license renewal term, so no change in the effects of biocide discharges on receiving water quality is anticipated. Effects of biocide discharges could be reduced by increasing the degree of discharge water treatment, reducing the concentration of biocides, or by treating only a portion of the plants' cooling and service water systems at one time. However, because the effects of biocide discharges on water quality are considered to be impacts of small significance, the staff does not consider the implementation of these potential mitigation measures to be warranted. Discharge of chlorine and other biocides is a Category 1 issue. Discharges of sanitary wastes are regulated by NPDES permit, and discharges that do not violate the permit limits are of small significance.

Minor chemical spills or temporary off-specification discharges from sanitary waste treatment systems and other low-volume effluents (e.g., excessive coliform counts or total suspended solids levels, pH outside of permitted range) were cited as common NPDES permit violations in the utility responses to the NUMARC survey (NUMARC 1990). Such NPDES noncompliances have been variable, random in occurrence, and readily amenable to correction. These minor discharges or spills do not constitute widespread, consistent water quality impacts. Water quality effects of minor chemical discharges and spills are of small significance and do not have significant effects on aquatic biota for all plants and have been mitigated as needed. Significant cumulative impacts to water quality would not be expected because the small amounts of chemicals released by these minor discharges or spills are readily dissipated in the receiving waterbody. Spills and off-specification discharges occur seldom enough that regulatory agencies express no concern about them for operating nuclear power plants. While there may be additional management practices or discharge control devices that could further reduce the frequency of accidental spills and off-specification discharges, they are not warranted because impacts are already small and occur at low frequency and because such mitigation would be costly. The water quality impacts of permitted sanitary waste water and minor, nonradiological chemical discharges and spills are a Category 1 issue.

Heavy metals (e.g., copper, zinc, chromium) may be leached from condenser tubing and other heat exchangers and discharged by power plants as small-volume waste streams or corrosion products. Although all are found in small quantities in natural waters (and many are essential micronutrients), concentrations in the power plant discharge are controlled in the NPDES permit because excessive concentrations of heavy metals can be toxic to aquatic organisms. Discharge of metals and other toxic contaminants may also be subject to individual control strategies developed by the states to control toxic pollutants under the 1987 Amendments to the CWA. These strategies for point source discharges of toxic pollutants are implemented through the NPDES permit program. Langford reviewed the literature concerning heavy metal discharges from power plants and concluded that, during normal operations, concentrations generally are below the levels of detection. However, plant shutdowns for testing and refueling keep stagnant water in contact with condenser tubes and other metal structures for extended periods and could allow abnormally large amounts of metals to be leached. For example, Harrison et al. (DOE/ER-0317) detected elevated copper concentrations in the discharge during startup of Diablo Canyon Nuclear Power Station. Abalone deaths in the discharge area of the Diablo Canyon were attributed to high copper concentrations in the effluent following a shutdown period (Martin et al. 1977).

The ability of aquatic organisms to bioaccumulate heavy metals even at low concentrations has led to concerns about toxicity both to the biota and to humans that consume contaminated fish and shellfish. For example, bioconcentration of copper discharged from the Chalk Point Plant (a fossil-fuel power plant on Chesapeake Bay) resulted in oyster "greening" (Roosenburg 1969). Bioaccumulation of copper released from the H. B. Robinson Plant resulted in malformations and decreased reproductive capacity among bluegill in the cooling reservoir (ASTM STP 854); see Section 4.4.3. In all three of these examples of excessive accumulation of copper (Diablo Canyon, Chalk Point, and H. B. Robinson), replacement of the copper alloy condenser tubes with another material (e.g., titanium) eliminated the problem.

Concentrations of heavy metals in the discharges of once-through nuclear power plants are normally within NPDES permit limits and are quickly diluted or flushed from the area by the large volumes of the receiving water. Discharge of metals and other toxic contaminants may also be subject to individual control strategies developed by the states to control toxic pollutants under the 1987 Amendments to the CWA. These strategies for point source discharges of toxic pollutants are implemented through the NPDES permit program. Excessive discharges of metals have been corrected at the two nuclear power plants (Diablo Canyon and H. B. Robinson) that experienced problems during the original license period. Impacts of heavy metal discharges are considered to be of small significance if water quality criteria (e.g., NPDES permits) are not violated and if aquatic organisms in the vicinity of the plant are not bioaccumulating the metals. Based on review of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, discharge of heavy metals leached from the condenser cooling system has been a problem at only Diablo Canyon and H. B.Robinson nuclear power plants, and mitigation was effective in both cases. Although cumulative impacts could result from the long-term accumulation and bioaccumulation of heavy metals, mitigation for individual plant effects has also reduced the potential for contributions to cumulative effects. Monitoring has not revealed a continuing problem with accumulation of heavy metals. No change in operation of the cooling system is expected during the license renewal term, so no change in metal concentrations in the cooling water discharge is anticipated. Effects of elevted metal concentrations could be reduced by replacing condenser tubes with alloys that are less likely to corrode. However, because the effects of metal concentrations on cooling water discharges are considered to be impacts of small significance and because the potential mitigation measures would be costly, the staff does not consider the implementation of these potential mitigation measures to be warranted. Elevated heavy metal concentrations in the condenser cooling water discharge is a Category 1 issue.

4.2.1.3 Water Use/Water Availability

Water use in the United States, as measured by freshwater withdrawals in 1985, averaged 15 million m^3/s (338 billion gal/day) (Carr et al. 1990). Four million m^3/s (ninety-two billion gal/day), or 27 percent of the water withdrawn, was consumed (e.g., by evaporation) and thus was not directly returned to the body of water. The remainder of the withdrawals (73 percent) was return flow available for reuse. In 1985, freshwater withdrawals by steam-electric power plants were approximately 5.7 million m^3/s (132 billion gal/day), which was 39 percent of the total freshwater withdrawals for all uses (Carr et al. 1990). About 2.4 million m^3/s (56 billion gal/day) of saline water was used for cooling by thermoelectric plants in coastal areas. Nuclear power plants accounted for 22 percent of the total thermoelectric withdrawals and fossil-fueled plants for 78 percent.

Consumptive uses remove the water from a stream or river and may or may not impact in-stream and off-stream beneficial uses. Return flows that are discharged to a stream are available to other users; freshwater withdrawals discharged to an estuary are effectively lost to further freshwater use (Carr et al. 1990). On the average, out of 0.4 m^3 (100 gal) withdrawn from surface waters for cooling of steam electric utilities, over 0.37 m^3 (98 gal) is returned almost immediately to the source body of water; less than 0.008 m^3 (2 gal) is consumed through evaporation (Solley et al. 1983). The consumptive loss for once-through cooling systems [0.5 m^3/s (18 ft^3/s) per 1000 MW(e)] is somewhat smaller than that attributed to cooling tower evaporation, which has been estimated to average 0.9 m^3/s (30 ft^3/second) per 1000 MW(e) (Giusti and Meyer 1978).

In those areas experiencing water availability problems, nuclear plant consumption may conflict with either existing or potential downstream municipal water use as well as with in-stream water uses. A shift in human population distribution and associated changes in demand for water could have important implications for the continued supply of cooling water for power generating facilities.

Impacts of power plant water use are considered to be of small significance since conflicts with other offstream or instream water users have not occurred and are not anticipated. The nuclear power plants that use once-through condenser cooling systems are located on large lakes, reservoirs, estuaries, oceans, and rivers, and—except possibly during extended periods of drought—are unlikely to experience problems with the water supply. Because net water consumption by facilities using once-through cooling is negligible compared with the size of the body of water, such plants should have only a limited potential for impacts on water availability for downstream use. Should water-use conflicts arise during operation of existing power plants, local officials who are responsible for allocating water resources would have to weigh the use of water for power generation. Based on review of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, water use conflicts are found to be of small significance for all plants and cumulative impacts are not of concern. Net water consumption by facilities using once-through cooling is negligible compared with the size of the body of water. Because of abundant water supply, consumptive water use will have impacts of only small significance on riparian plant and animal communities at sites that use once-through cooling systems. No change in operation of the cooling system is expected during the license renewal term, so no change in effects on consumptive water use or riparian communities is anticipated. Effects on consumptive water use and riparian communities could be reduced by changing to a closed cycle cooling system or by reducing the plant's generation rate. However, because such changes would be costly, and because the effects on consumptive water use and riparian communities are of small significance, the staff does not consider the implementation of these potential mitigation measures to be warranted in light of the small benefit that might be gained. Both of these are Category 1 issues.

4.2.2 Aquatic Ecology

As noted in Section 4.2.1, large amounts of water are withdrawn by once-through cooling systems, passed through the condenser tubes, and discharged back to the body of water with an added load of heat and chemical contaminants. A total of 70 nuclear plants use once-through cooling (see Table 2.2). Initial concerns about effects of thermal effluents on aquatic biota (e.g., Krenkel and Parker 1969) were soon accompanied by concerns about impacts of biocide discharges and losses due to intake effects (i.e., impingement and entrainment). All of these issues have received considerable attention and study from utility and regulatory agency scientists in the past two decades, as exemplified by the numerous books and symposia devoted to resolving them (CONF-750425; Saila 1975; Schubel and Marcy 1978; Jensen 1978, 1981; Barnthouse and Van Winkle 1988). The aquatic resources issues that are considered in this section are entrainment (of fish, shellfish, phytoplankton, and zooplankton), impingement of fish and shellfish, thermal effects (heat shock, cold shock, thermal plume barrier to migratory fish, premature emergence of aquatic insects, enhanced susceptibility to parasitism and disease, stimulation of nuisance organisms, gas bubble disease, lower dissolved oxygen), and chemical effects (biocides and accumulation of contaminants in biota).

The following sections review the past and ongoing impacts on aquatic biota of operation of once-through condenser cooling systems. Any ongoing impacts will probably continue throughout the license renewal term because the cooling system design and operation is not expected to change for most plants. Judgments about the significance of these issues during the license renewal term are based on published information, agency consultation, and information provided by the utilities (Appendix F). These sources represent every nuclear power plant in the United States. In addition, seven case studies (Arkansas, McGuire, Cook, San Onofre, Crystal River, and combined effects of power plants on Lake Michigan and the Hudson River) were evaluated in greater detail. These case studies are examples of large once-through condenser cooling systems that affect a variety of aquatic environments (i.e., large lakes and reservoirs, oceans, and estuaries). Published information about these plants was reviewed to determine whether operation has resulted in demonstrable entrainment, impingement, or thermal impacts. For some of the case studies in Appendix F, cumulative effects of the operation of nuclear power plants in conjunction with other sources of stress to aquatic resources are considered.

4.2.2.1 Analysis of Issues

4.2.2.1.1 Entrainment of Phytoplankton and Zooplankton

As discussed in Section 2.3.5, water that is withdrawn for power plant cooling carries with it a variety of aquatic organisms. Those organisms that are small enough to pass through the debris screens in the intake pass through the entire cooling system and are exposed to heat, mechanical and pressure stresses, and possibly biocides before being discharged to the receiving water. This process, called entrainment, may affect phytoplankton, zooplankton, planktonic larval stages of benthic organisms such as shellfish (i.e., meroplankton), and fish eggs and larvae (ichthyoplankton). Most nuclear power plants have been required to monitor for entrainment effects during the initial years of operation. Entrainment impacts to phytoplankton and zooplankton are considered to be of small significance if there is no evidence of reductions of populations of phytoplankton or zooplankton.

Studies of the effects of entrainment at several nuclear power plants are reviewed in Appendix F. None of the agencies consulted expressed concern about entrainment of phytoplankton or zooplankton (Appendix F). Because of large numbers and short regeneration times of phytoplankton and zooplankton, impacts of entrainment on these organisms have rarely been documented outside the immediate vicinity of the plant and are considered to be of little consequence (Schubel and Marcy 1978; Hesse et al. 1982; Kennish et al. 1984; MDNR 1988; MRC 1989; EPRI EA-1038).

The effects of entrainment at nuclear plants are not expected to cause or contribute to cumulative impacts to populations of zooplankton or phytoplankton. The effects of phytoplankton and zooplankton entrainment are localized (i.e., the affected areas are smaller than the distances between power plants) and are not expected to contribute to cumulative impacts because generation times of plankton are rapid. Review of the literature and operational monitoring reports did not reveal evidence of cumulative impacts from entrainment of phytoplankton and zooplankton. Further, consultation with utilities and agencies during preparation of the draft GEIS, as well as their comments on the draft GEIS (NUREG-1529), revealed no concerns about cumulative impacts of phytoplankton and zooplankton entrainment.

Reviews of the literature, monitoring reports, and consultation with agencies and utilities did not reveal any evidence of mitigation measures that had been required to correct problems with entrainment of phytoplankton and zooplankton. Because cooling system operations are not expected to change during the license renewal term, additional mitigation is not expected to be warranted.

Entrainment of phytoplankton and zooplankton is expected to have a small impact on populations of these organisms in the source body of water at any plant. No change in operation of the cooling system is expected during the license renewal term, so no change in effects on entrainment of phytoplankton and zooplankton is anticipated. Effects on entrainment of phytoplankton and zooplankton could be reduced by changing to a closed cycle cooling system or by reducing the plant's generation rate. However, because the effects on entrainment of phytoplankton and zooplankton are considered to be impacts of small significance and because they would be costly to implement, the staff does not consider the implementation of these potential mitigation measures to be warranted. This is a Category 1 issue.

4.2.2.1.2 Entrainment of Fish and Shellfish

The effects of entrainment on aquatic resources were considered by NRC at the time of original licensing and are periodically reconsidered by EPA or state water quality permitting agencies in the development of NPDES permits and 316(b) demonstrations (Section 4.2.1.1.2). Although significant adverse entrainment effects have not been demonstrated at most facilities, the entrainment of fish and shellfish in early life stages remains an issue at some nuclear power plants with once-through cooling systems. Agencies consulted for this GEIS expressed concerns about the impacts of entrainment at Zion, Salem, Oyster Creek, Indian Point, Calvert Cliffs, Millstone, Yankee Rowe, and Surry. Several licensed nuclear power plants (e.g., Indian Point, Oyster Creek, Comanche Peak, Salem, and Zion) have unresolved 316(b) determinations. At some power plants, fish populations have been restored in the years since issuance of the original license and, as a result, more fish are now susceptible to entrainment. At other nuclear power plants (Beaver Valley, Susquehanna, Three Mile Island, and Peach Bottom), an agency expressed concern about future entrainment during the license renewal period as restoration efforts continue to increase fish populations (James Gillett, Deputy Regional Director, U.S. Fish and Wildlife Service, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, July 27, 1990).

The impacts of fish and shellfish entrainment are small at many plants, but they may be moderate or even large at a few plants with once-through cooling systems. Further, ongoing restoration efforts may increase the numbers of fish susceptible to intake effects during the license renewal period, so that entrainment studies conducted in support of the original license may no longer be valid. For these reasons, the entrainment of fish and shellfish is a Category 2 issue for plants with once-through cooling systems.

4.2.2.1.3 Impingement of Fish and Shellfish

Aquatic organisms that are drawn into the intake with the cooling water and are too large to pass through the debris screens may be impinged against the screens. Mortality of fish that are impinged is high at many plants because impinged organisms are eventually suffocated by being held against the screen mesh or are abraded, which can result in fatal infection. Impingement can affect large numbers of fish and invertebrates (crabs, shrimp, jellyfish, etc.). As with entrainment, operational monitoring and mitigative measures have allayed concerns about population-level effects at most plants, but impingement mortality continues to be an issue at others. Consultation with resource agencies (Appendix F) revealed that impingement is a frequent concern at once-through power plants, particularly where restoration of anadromous fish may be affected. In several cases, such as Oyster Creek, Salem, Surry, and Prairie Island, significant modifications were made to the intake structure to substantially reduce mortality due to impingement. Impingement is an intake-related effect that is considered by EPA or state water quality permitting agencies in the development of NPDES permits and 316(b) determinations. Appendix F examines studies of the effects of impingement of fish at several nuclear power plants. The impacts of impingement are small at many plants but may be moderate or even large at a few plants with once-through cooling systems. For this reason, the impingement of fish and shellfish is a Category 2 issue.

4.2.2.1.4 Thermal Discharge Effects

The heated effluents of steam-electric power plants can cause mortality among fish and other aquatic organisms from either thermal discharge effects or cold shock. Temperatures high enough to kill organisms are found in the cooling water systems, often in the area nearest the effluent discharge structure. Because thermal effects were among the earliest potential impacts identified for power plant operation, a great deal of research and regulatory effort has been aimed at understanding and controlling thermal discharges. Upper lethal temperatures (and various other expressions of temperature tolerance) have been determined for many important species and life stages. As a result, conditions that can lead to thermal discharge effects are relatively predictable. Mitigative measures have been employed at many power plants to reduce the potential for thermal discharge effects. They can be minimized by lowering effluent temperature before discharge to natural waters (e.g., with cooling ponds) or by enhancing rapid mixing and heat dissipation (through high-velocity jet diffusers).

Each permitting state has developed mixing zone criteria and thermal discharge limits for steam-electric power plants. If the plant meets these criteria, no 316(a) determination is required. If the facility fails to meet the state temperature limits, the facility must submit data demonstrating that the discharge will ensure the protection and propagation of a balanced indigenous population of shellfish, fish, and wildlife [i.e., a 316(a) demonstration]. For plants within the state limits, the implicit assumption is made that a balanced indigenous population is ensured. The NPDES permit required for each power plant contains discharge temperature limits that are based on either state standards or site-specific studies of thermal effects [i.e., 316(a) demonstrations]. Nevertheless, thermal discharges continue to be an issue at some once-through nuclear power plants (see agency consultation, Appendix F). In some cases, the facility is being extensively modified to minimize thermal-discharge-related effects (e.g., installation of cooling towers at Crystal River). In others, the 316(a) determination has not been approved and is now under review. Studies of thermal discharge effects at selected nuclear power plants that employ once-through cooling systems are described in Appendix F.

Based on the research literature, monitoring reports, and agency consultations, the potential for thermal discharges to cause thermal discharge effect mortalities is considered small for most plants. However, impacts may be moderate or even large at a few plants with once-through cooling systems. For example, thermal discharges at the Crystal River Nuclear Plant are considered by the agencies to have damaged the benthic invertebrate and seagrass communities in the effluent mixing zone around the discharge canal; as a result, helper cooling towers have been installed to reduce the discharge temperatures (Appendix F.4.7). Conversely, at other plants it may become advantageous to increase the temperature of the discharge in order to reduce the volume of water pumped through the plants and thereby reduce entrainment and impingement effects (see discussion of San Onofre Nuclear Generating Station in Appendix F.4.6). Because of continuing concerns about thermal discharge effects and the possible need to modify thermal discharges in the future in response to changing environmental conditions, this is a Category 2 issue for plants with once-through cooling systems.

4.2.2.1.5 Cold Shock

Cold shock occurs when organisms that have been acclimated to warm water (e.g., in a discharge canal in winter) are exposed to sudden temperature decreases when artificial heating ceases. Such situations may occur when a single-unit power plant suddenly shuts down in winter (Coutant 1977) or when winds or currents shift a thermal plume that was occupied by fish or benthic invertebrates seeking warm water. As with heat effects, the conditions that can lead to cold shock are relatively well understood—it is a function of acclimation temperature, final (cold ambient) temperature, and exposure times—and therefore can be mitigated if needed. Cold shock mortalities have occurred, for example, at the Haddam Neck (Connecticut Yankee) plant (S. W. Gorski, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, July 18, 1990) and at the Prairie Island and Monticello nuclear generating plants (P. M. Bailey, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, July 3, 1990). Cold-shock mortalities are relatively rare and usually involve small numbers of fish. Population-level effects have not been demonstrated. Where necessary, the discharge structure or the plant operating procedures have been modified to reduce cold-shock effects. Structural modifications could include constructing a barrier to prevent fish from residing in the discharge canal or designing a high-velocity discharge to encourage rapid mixing and to discourage residence in the plume. Operational measures that could be used to reduce the risk of cold shock by gradually reducing the amount of warm water discharged in winter include gradual shutdowns or shutdowns of only one unit of a multi-unit power plant at a time.

Impacts of cold shock are considered to be of small significance if populations of aquatic organisms in the vicinity of the plant are not reduced. Based on review of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, cold-shock-related mortalities of aquatic organisms have been a problem at few existing nuclear power plants. Operational and structural mitigation measures have been effective at the plants that experienced cold shock mortalities. Because mitigation has been effective in those few cases where cold shock has been a problem, effects are considered to be of small significance for all plants. Cold shock is not expected to contribute to cumulative impacts because the potential area of impact is so small and because mitigation to prevent cold shock mortalities at individual power plants also reduces the likelihood that thermal discharges would contribute to cumulative effects. No change in operation of the cooling system is expected during the license renewal term, so no change in potential for cold shock is anticipated. Effects of cold shock could be reduced by changing to a closed cycle cooling system or by reducing the plant's generation rate. However, because the effects of cold shock are considered to be impacts of small significance and these changes would be costly, the staff does not consider the implementation of these potential mitigation measures to be warranted. Cold shock is a Category 1 issue.

4.2.2.1.6 Effects of Movements and Distribution of Aquatic Organisms

Heated effluents can affect aquatic populations in more subtle ways by altering their distribution, growth, or movements. Changes in benthic community composition such as losses of seagrass or other macrophytes can alter the habitat available to aquatic animals. Warm water can increase the metabolic rates of aquatic biota, a method often used in aquaculture to achieve high growth and production rates. However, in the absence of adequate food supplies, elevated metabolic rates can lead to a poor condition of the fish inhabiting heated areas.

It had been suggested that thermal plumes could constitute a barrier to migrating fish if the mixing zone covered a substantial area and exceeded the fish avoidance temperatures. However, studies of effects of heated effluents on Columbia River salmon (Nakatani 1969) and anadromous fish in the Chesapeake Bay (e.g, shad and striped bass) (MDNR 1988) have concluded that fish migration routes were not blocked. Most migrating adult American shad move in the lower half of the water column (Witherell and Kynard 1990) and are therefore unlikely to be deterred by a thermal plume at the surface.

Impacts from potential thermal plume barriers are considered to be of small significance if fish migrations are not blocked and populations of aquatic organisms in the vicinity of the plant are not reduced. Based on review of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, thermal plume barriers have not been a problem at any existing nuclear power plants. Heat is rapidly dissipated from power plant discharge plumes, so that effects would only be localized and therefore of small significance for all plants. These effects are not expected to contribute to cumulative impacts. No regulatory agency expressed concerns about cumulative impacts to migrations of aquatic organisms. No change in operation of the cooling system is expected during the license reneqal term, so no change in the potential for a thermal plume barrier to migrating fish is anticipated. Effects of a thermal plume barrier to migrating fish could be reduced by changing to a closed cycle cooling system or by reducing the plant's generation rate. However, because the effects of a thermal plume barrier to migrating fish are considered to be impacts of small significance and because the changes would be costly to implement, the staff does not consider the implementation of these potential mitigation measures to be warranted. Thus thermal plume barriers to migrating fish are a Category 1 issue.

The temperature regime of a body of water is an important component of habitat available to aquatic organisms. By altering the temperature regime, heated effluents can increase or decrease the amount of available habitat. For example, the abundance of coldwater species may be constrained near the southern limits of their distribution by thermal power plant effluents because the heated water exceeds the temperature tolerance of the species. By the same token, heated effluents can extend the northern range of warmwater species by providing thermal refuges during the winter. For example, Stauffer et al. found that blue tilapia, a tropical exotic fish species from Africa and southern Asia, were able to survive low winter water temperatures in the Susquehanna River, Pennsylvania, by congregating in thermal effluents. On a larger scale, the effects of global warming on water temperatures and on the distribution and productivity of aquatic organisms is being studied (Regier et al. 1990). At present, heated discharges from power plants influence a relatively small area of the affected bodies of water so that significant changes to the geographic distribution of a species are unlikely.

Impacts of thermal discharges on geographic distribution of aquatic organisms are considered to be of small significance if populations in the overall region are not reduced. Based on review of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, thermal discharges have not been shown to constrain the regional geographic distribution of aquatic organisms at any existing nuclear power plants. Localized reductions in coldwater species or increases in warmwater species are possible, but the effects are limited to small areas and have not altered larger geographic distributions. Effects are considered to be of small significance for all plants. Heat is rapidly dissipated from power plant discharge plumes, and heated plumes are small relative to the size of the waterbody. Consequently, effects would only be localized, and cumulative impacts on geographic distribution would not be expected. No regulatory agency expressed concerns about cumulative impacts on geographic distribution of aquatic organisms. No change in operation of the cooling system is expected during the license renewal term, so no change in effects on geographic distribution of aquatic organisms is anticipated. Effects on geographic distribution of aquatic organisms could be reduced by changing to a closed cycle cooling system or by reducing the plant's generation rate. However, because the effects on geographic distribution of aquatic organisms are considered to be impacts of small significance and because these changes would be costly, the staff does not consider the implementation of these potential mitigation measures to be warranted. Effects of localized thermal discharges on geographic distribution of aquatic organisms are a Category 1 issue.

4.2.2.1.7 Premature Emergence of Aquatic Insects

Heated discharges from power plants can impact aquatic insects that inhabit the bottom areas influenced by the thermal plume. Impacts can range from direct mortality (e.g., when lethal temperatures are exceeded) to sublethal effects (e.g., increases in growth rates; decreases in development times; changes in body size and fecundity). Different species have different tolerances for altered temperature regimes, so that the benthic invertebrate community in the discharge area is rarely eliminated; but it may become dominated by a reduced number of taxa that are tolerant of higher temperatures. Because thermal plumes tend to be buoyant, often the bottom area of the receiving body of water that is affected by elevated temperatures is relatively small, and the effects on the benthic invertebrate community are localized.

Premature emergence of aquatic insects can result from heated effluents coming in contact with benthic habitats (e.g., in the discharge canal or along the shoreline near the discharge) and accelerating the development of immature forms. Adult insects emerge from the water before the normal seasonal cycle and may be unable to reproduce. Although this phenomenon has been observed near power plants, the area likely to be affected by thermal effluents would be a small part of the total lake or river bottom area available for production of aquatic insects. In addition, most aquatic insects have adult upstream migration flights that compensate for normal downstream drift of immature stages (Hynes), so that such localized effects on reproduction through this mechanism are inconsequential (Coutant 1981).

Effects of thermal discharges on premature emergence of aquatic insects are considered to be of small significance if changes are localized and populations in the receiving waterbody are not reduced. Based on reviews of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, thermal discharges have not been shown to cause reductions in the overall populations of aquatic insects near any existing nuclear power plants. Localized mortalities among heat-intolerant insect species occur in the thermal mixing zone, but the effects are limited to small areas and do not alter insect communities in larger geographic areas. Because heat in the discharged water is readily dissipated to the atmosphere, effects from this and other heated effluents would not be expected to contribute to cumulative impacts. Effects are considered to be of small significance for all plants. No change in operation of the cooling system is expected during the license renewal term, so no change in effects on emergence of aquatic insects is anticipated. Effects on emergence of aquatic insects could be reduced by changing to a closed cycle cooling system or by reducing the plant's generation rate. However, because the effects on emergence of aquatic insects are considered to be impacts of small significance and because these changes would be costly, the staff does not consider the implementation of these potential mitigation measures to be warranted. Effects of thermal discharges on premature emergence of aquatic insects is a Category 1 issue.

4.2.2.1.8 Gas Bubble Disease

Rapid heating of water in the condenser cooling system decreases the solubility and increases saturation levels of dissolved gases. The supersaturation of nitrogen gas has led to incidents of "gas bubble disease" (GBD) in the discharge areas of steam-electric power plants. The mechanisms by which gas supersaturation and GBD occur at steam-electric power plants (as well as under other conditions such as in the tailwaters of hydroelectric power plants) have been described by Wolke et al. Discharge configurations that do not allow rapid mixing of the effluent with the receiving waters may allow organisms to reside in the supersaturated effluent for long periods (Coutant 1981). As a result of equilibrating with the effluent, the tissues of aquatic organisms become supersaturated as well. Eventually, this unstable condition breaks down, and bubbles form inside the animal, most obviously in the fins and the eyeball (Wolke et al.). Fish mortalities generally occur at gas supersaturation levels above 110 to 115 percent (EPA 440/5-86-001).

GBD in the discharge of a steam-electric power plant (the Marshall Steam Station on Lake Norman) was first reported by DeMont and Miller and has been observed at other power plants since that time. GBD at the Pilgrim Nuclear Power Station caused a loss of 43,000 Atlantic menhaden in 1973, and another 5,000 in 1976 [Boston Edison Company, response to NUMARC survey (NUMARC 1990)]. The problem appears to be greatest at power plants that have discharge canals where fish may reside for extended periods of time (i.e., long enough to equilibrate with supersaturated effluents). The reported incidences of GBD at the Waukegan Generating Station (a coal-fired plant on Lake Michigan; Otto), the Marshall Steam Station (a coal-fired plant on Lake Norman; DeMont and Miller), and the Pilgrim Nuclear Power Station all involved fish residing in discharge canals. Ensuring the rapid mixing of effluents with receiving waters (e.g., with a jet diffuser system) appears to prevent GBD mortalities by inhibiting residence in the thermal plume (Lee 1984). Alternatively, measures to prevent residence of fish in discharge canals may be effective. Emplacement of a barrier net to exclude fishes from the Pilgrim discharge canal has prevented GBD mortalities at that plant since 1976 [Boston Edison Company, response to NUMARC survey (NUMARC 1990)]. The GBD problem has been mitigated at the one nuclear power plant where large numbers of fish were affected.

Impacts of GBD are considered to be of small significance if populations of aquatic organisms in the vicinity of the plant are not reduced. Based on review of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, GBD-related mortalities of aquatic organisms have not been a problem at most existing nuclear power plants; and operational and structural mitigation measures have been effective at those plants that experienced GBD mortalities during the initial license period. Effects are considered to be of small significance for all plants. Mitigation to prevent GBD mortalities at individual power plants also reduces the likelihood that thermal discharges would contribute to cumulative effects; no regulatory agency expressed concerns about the contribution of existing nuclear plants to cumulative impacts of GBD. No change in operation of the cooling system is expected during the license renewal term, so no change in effects on GBD is anticipated. Effects on GBD could be reduced by changing to a closed cycle cooling system or by reducing the plant's generation rate. However, because the effects on GBD are considered to be impacts of small significance and because such charges would be costly, the staff does not consider the implementation of these potential mitigation measures to be warranted. Gas bubble disease is a Category 1 issue.

4.2.2.1.9 Low Dissolved Oxygen in the Discharge

A power plant may aggravate the biological effects of low dissolved oxygen (DO) concentrations in the source water by adding a heat load to water with preexisting low DO levels. Aquatic biota below the discharge are then stressed by both higher temperatures (which increase the metabolic rate and the need for oxygen) and preexisting suboptimal oxygen levels. Concern about the effects of low DO concentrations in the heated discharge of the Sequoyah Nuclear Plant on downstream mussel beds and sauger reproduction has been expressed by the Tennessee Division of Water Pollution Control (Ann McGregor, Tennessee Division of Water Pollution Control, telephone interview with G. F. Cada, ORNL, Oak Ridge, Tennessee, May 30, 1990). Cool, hypolimnetic water released from Watts Bar reservoir, upstream from the Sequoyah Nuclear Plant, often had low DO concentrations. The temperature of the condenser cooling water rises approximately 14°C when both units are operating without cooling towers. As a result, a mean net decrease of 0.8 mg/L of DO concentration was measured in the cooling water, which under extreme low flow conditions could reduce the mean water column DO concentration in the Chickamauga reservoir near the Sequoyah Nuclear Plant by approximately 0.5 mg/L (TVA 1990). Water quality modeling indicated that increasing the DO of Watts Bar Dam releases by 2 mg/L would improve DO concentrations through Chickamauga Reservoir by about 1 mg/L. Recent changes in the release schedule of Watts Bar Dam appear to have reduced the stagnation of water near the Sequoyah Nuclear Plant and alleviated concern about low DO effects (Tom Roehm, Tennessee Division of Water Pollution Control, telephone interview with G. F. Cada, ORNL, Oak Ridge, Tennessee, November 16, 1992).

Impacts of low DO concentrations in the discharge are considered to be of small significance if populations of aquatic organisms in the vicinity of the plant are not reduced. Based on review of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, low DO concentrations have not been a problem at most existing nuclear power plants, and operational mitigation measures have been effective at the one plant that experienced problems during the initial license period. Effects of low DO concentrations are considered to be of small significance for all plants. Water will be reaerated by turbulent diffusion and/or photosynthesis, so far-field effects are not expected. Mitigation to prevent low DO concentrations in the vicinity of the power plant will also reduce the likelihood of significant cumulative impacts; none of the resource agencies expressed an ongoing concern about the contribution of existing power plants to cumulative impacts of low DO concentrations. No change in operation of the cooling system is expected during the license renewal term, so no change in effects of low DO concentrations is anticipated. Effects of low DO concentrations could be reduced by changing to a closed cycle cooling system or by reducing the plant's generation rate. However, because the effects of low DO concentrations are considered to be impacts of small significance and because these changes would be costly, the staff does not consider the implementation of these potential mitigation measures to be warranted. Low DO concentrations in the thermal discharge are a Category 1 issue.

4.2.2.1.10 Losses from Parasitism, Predation, and Disease

Sublethal power plant stresses may alter predator-prey interactions in the receiving body of water. Aquatic organisms that are stunned but not killed by entrainment, impingement, or thermal effects may still suffer "indirect" mortality through increased susceptibility to predators. Numerous laboratory studies have been carried out to evaluate the level of indirect mortality that might occur following heat and cold shocks or entrainment (reviews in ORNL/TM-7801; Coutant 1981). These studies have commonly demonstrated increased susceptibility to predation, but field evidence of such effects is often limited to anecdotal information such as observations of enhanced feeding activity of seagulls and predatory fish near power plant outfalls. For example, Barkley and Perrin (1971), and CONF-730505 reported increased concentrations of predators feeding on forage fish attracted to thermal plumes. Neither quantification of the levels of stress needed to increase predation rates, nor prediction of the subsequent population- and community-level effects of such changes can be made easily in the field. It is likely that operation of once-through cooling systems will cause some changes in predator-prey relationships, but the best evidence for impacts (or lack of impacts) may come from long-term monitoring of fish populations. Neither the literature reviews nor consultations with agencies and utilities (Appendix F) have revealed studies that demonstrate population- or community-level effects from power-plant-induced alterations of predator-prey relationships.

Elevated water temperatures in power plant discharges have been hypothesized to increase the susceptibility of fish to diseases and parasites. Langford cites a number of factors that could contribute to such an effect, including the tendency for fish to congregate in the heated discharge area in greater than normal concentrations, increased stresses on fish in warmer water that makes them more prone to infection, and the ability of some diseases and parasites to develop faster at higher temperatures. Additionally, it has been suggested that stress and injury from entrainment and impingement contribute to increased susceptibility of fish to disease, parasites, and predation. Coutant (1981) noted that although some studies of increased disease and parasitism in heated waters have found localized effects, most were not adequately designed to determine the significance of the effects to the overall population. The greatest risks appear to be associated with changes in animal concentrations; crowding can occur among fish that are attracted to heated effluents in the winter or that avoid heated water in the summer by occupying limited cool-water refugia. Crowding increases the chances of exposure to infectious diseases and may also lead to other stresses (decreased food supply or reduced oxygen concentrations) that increase susceptibility to disease (Coutant 1987). Despite limited laboratory studies that confirm this phenomenon, population-level effects in the vicinity of plants have not been observed.

Effects of sublethal stresses on the susceptibility of aquatic organisms to predation, parasitism, and disease are considered to be of small significance if changes are localized and populations in the receiving waterbody are not reduced. Based on reviews of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, these forms of indirect, power plant-induced mortality have not been shown to cause reductions in the overall populations near any existing nuclear power plants. Effects are considered to be of small significance for all plants. Although sublethal power plant stresses could contribute to cumulative impacts experienced by aquatic biota, monitoring has revealed no evidence for significant effects; the regulatory and resource agencies consulted in the preparation of this GEIS did not express concerns about the contribution of sublethal power plant stresses to cumulative impacts. No change in operation of the cooling system is expected during the license renewal term, so no change in effects of sublethal stresses is anticipated. Effects of sublethal stresses could be reduced by changing to a closed cycle cooling system or by reducing the plant's generation rate. However, because the effects of sublethal stresses are considered to be impacts of small significance and because the changes would be costly, the staff does not consider the implementation of these potential mitigation measures to be warranted. This is a Category 1 issue.

4.2.2.1.11 Stimulation of Nuisance Organisms

A variety of nuisance organisms or nonnative species may become established or proliferate as a result of power plant operations, including fouling organisms such as the Asiatic clam (*Corbicula* sp.) and the recently introduced zebra mussel, *Dreissena polymorpha*. Aspects of the operation of the power plants (e.g., warm temperatures or high flow rates that bring food to filter-feeding organisms) may be conducive to the growth and development of these organisms. *Corbicula* sp. and zebra mussels may become so abundant as to cause operational difficulties for the power plant and may out-compete native clams and mussels in thermally enriched waters. A population of tropical, non-native blue tilapia became established in the Susquehanna River in Pennsylvania by congregating in thermal effluents during the winter. Exposure to rapid temperature decreases (cold shock) killed these fish and eradicated the population from the vicinity of a steam-electric power plant (Stauffer et al.).

Langford (1983) reports a number of instances in which wood-boring crustaceans and mollusks, notably "shipworms," have caused concern in British waters. Although increased abundance of shipworms in the area influenced by heated power plant effluents caused substantial damage to wooden structures, replacement of old wood with concrete or metal structures eliminated the problem. Langford concluded that increased temperatures could enhance the activity and reproduction of wood-boring organisms in enclosed or limited areas but that elevated temperature patterns were not sufficiently stable to cause widespread effects.

In the United States, the influence of the operation of Oyster Creek Nuclear Generating Station on shipworm abundance and distribution has been extensively studied (see summary in Richards et al. 1984). Although numerous studies have varied somewhat in their conclusions, there is agreement that heated effluents from the plant increased the distribution and abundance of the nonnative, tropical-subtropical wood-boring species *Teredo bartschi* (Kennish et al. 1984). This species has not been found in Oyster Creek or Barnegat Bay since 1982, perhaps because of low water temperatures in Oyster Creek during a station outage in the winter of 1981–82 and the pathological effects of a parasite [GPU Nuclear Corporation response to NUMARC survey (NUMARC 1990)]. In addition, the removal of substantial amounts of driftwood and the replacement of untreated structural wood is thought to have contributed to reducing the populations of wood-boring organisms in Oyster Creek. No other concerns about nuisance organisms were cited by the regulatory or resource agencies contacted for this GEIS (Appendix F). Measures taken by licensees to control nuisance species (e.g., increased chlorination or use of molluskicides) may result in impacts on other species. This impact is addressed in Section 4.2.1 and is also controlled by the NPDES permitting procedures.

The effects of stimulating the growth of nuisance organisms are considered to be of small significance to aquatic resources if these organisms are restricted to the condenser cooling system (e.g., Asiatic clam; zebra mussel) or do not proliferate beyond the immediate vicinity of the plant. Based on review of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, nuisance organisms such as Asiatic clam may be an operational problem, but they have not impacted aquatic resources near most existing nuclear power plants. Mitigation measures were effective at the one plant that experienced problems with nuisance organisms (shipworms). Effects are considered to be of small significance for all plants. The regulatory and resource agencies consulted in the preparation of this GEIS did not express concerns about the contribution of power plant operations to other activities that might encourage the growth of nuisance organisms (i.e., cumulative effects). No change in operation of the cooling system is expected during the license renewal term, so no change in the growth or distribution of nuisance organisms is anticipated. Effects on nuisance organisms could be reduced by changing to a closed cycle cooling system or by reducing the plant's generation rate. However, because the effects on the growth of nuisance organisms are considered to be impacts of small significance and because such changes would be costly, the staff does not consider the implementation of these potential mitigation measures to be warranted. The stimulation of nuisance aquatic organisms by operation of existing power plants is a Category 1 issue.

4.2.2.2 Summary

The issues and the need for these issues to be addressed in license renewal applications of existing nuclear power plants with once-through cooling systems are summarized in Table 4.1. The operational experience of existing nuclear power plants indicates that many early aquatic resource concerns have not materialized as problems at any facility. Neither the published literature nor the responses of regulatory and resource agencies have revealed concerns about such early issues as phytoplankton and zooplankton entrainment and premature emergence of aquatic insects living in thermal discharges. Although statistically significant localized effects of these stresses have occasionally been demonstrated, long-term or far-field impacts have not been documented. Other issues (e.g., lowered DO concentrations, discharge of heavy metals, cold shock, and stimulation of nuisance organisms) were problems at a few nuclear power plants with once-through cooling systems but have since been mitigated.

Table 4.1 Significance of aquatic resources impacts for license renewal of existing nuclear power plants that use once-through cooling systems

Issue	Impact significance[a]
Water quality, hydrology, and use issues	
Water use conflicts	1
Altered current patterns at intake and discharge structures	1
Altered salinity gradients	1
Temperature effects on sediment transport capacity	1
Altered thermal stratification of lakes	1
Scouring from discharged cooling water	1
Eutrophication	1
Discharge of chlorine or other biocides	1
Discharge of metals in waste water	1
Discharge of sanitary wastes and minor chemical spills	1
Effects of consumptive water use on riparian communities	1
Aquatic ecology	
Impingement of fish and shellfish	2
Entrainment of fish and shellfish early life stages	2
Entrainment of phytoplankton and zooplankton	1
Thermal discharge effects	2
Cold shock	1
Thermal plume barrier to migrating fish	1
Distribution of aquatic organisms	1
Premature emergence of aquatic insects	1
Stimulation of nuisance organisms (e.g., shipworms)	1
Losses from predation, parasitism, and disease among organisms exposed to sublethal stresses	1
Gas supersaturation (gas bubble disease)	1
Low dissolved oxygen in the discharge	1
Accumulation of contaminants in sediments or biota (Section 4.2.1 and 4.2.4)	1

[a] A 1 means impact significance expected to be small at all sites. A 2 means that the impact may be of moderate or large significance at some sites.

Some aquatic resource issues warrant further monitoring and, in some cases, mitigative measures to define and correct adverse impacts. The entrainment and impingement of fish and the discharge of large volumes of heated effluents into small or warm ambient waters were a source of concern at some nuclear power plants. Such issues were examined and resolved through either the NEPA process during the licensing of the facility or the mechanisms of NPDES permitting and associated 316(a) and (b) determinations. They either were found acceptable or mitigated. For some plants with once-through cooling systems, the large volumes of water withdrawn, heated, and discharged back to the receiving water may cause adverse effects to fish and shellfish populations during the license renewal term. Because impacts of entrainment of fish and shellfish, impingement, and thermal discharge effects could be small, moderate, or large, depending on the plant, these are Category 2 issues for plants with once-through cooling systems. These issues will need to be analyzed in the supplemental NEPA document at the time of license renewal.

4.3 COOLING TOWERS

This section introduces cooling towers and their emissions (Section 4.3.1) and then evaluates the impacts of the emissions on surface water and groundwater (Section 4.3.2), aquatic ecology (Section 4.3.3), agricultural crops (Section 4.3.4), terrestrial ecology (Section 4.3.5, which also includes bird collisions with cooling towers), and human health (Section 4.3.6). Impacts of cooling-tower noise are also addressed (Section 4.3.7). Each section that evaluates impacts (Sections 4.3.2–4.3.7) provides a conclusion that defines the significance of the impacts. These conclusions are based on reviews of cooling-tower data available for towers at specific nuclear plants as well as for other cooling towers (e.g., those at coal-fired plants).

4.3.1 Introduction

Mechanical- and natural-draft wet cooling towers transfer waste heat to the atmosphere primarily by evaporating water. Natural-draft towers are generally up to 160 m (520 ft) in height, whereas mechanical-draft towers are generally less than 30 m (100 ft) tall (Roffman and Van Vleck 1974). Because of the large cooling capacity of natural-draft towers, only one such tower is required for each reactor unit; but two or more mechanical-draft towers are required for equivalent cooling.

Most of the water lost from a cooling tower escapes to the atmosphere as water vapor in the exhaust flow. About 10 percent of the vapor recondenses after release, forming the visible part of the plume leaving the tower (Golay et al. 1986). Drift droplets of cooling water are also entrained in the air stream inside the tower and escape directly into the atmosphere. A particulate solid drift material remains after droplet evaporation. The drift contains varying amounts of salts, biocides, and microorganisms.

Natural-draft towers release drift and moisture high into the atmosphere where they are dispersed over long distances. Local impacts are more likely to occur with mechanical-draft towers because the plume is not dispersed over as great an area. The visible moisture plume from a natural-draft cooling tower may be 20 to 30 percent longer than that from comparable mechanical-draft towers (Roffman and Van Vleck 1974). Icing of vegetation and roads can occur near mechanical draft towers when fog is present and temperatures are below freezing. Much of the drift eventually deposits on the earth. The atmospheric transport of drift and the amount of deposition to the earth has been estimated for most nuclear plants through the use of computer models. Actual measurements of drift deposition have been collected at only a few nuclear plants. These measurements indicate that, beyond about 1.5 km (1 mile) from nuclear plant cooling towers, salt deposition is not significantly above natural background levels.

4.3.2 Surface Water Quality and Use

Sections 4.3.2 and 4.3.3 review the past and ongoing impacts on aquatic resources caused by the operation of nuclear power plants with cooling towers. Any ongoing impacts will probably continue into the license renewal term because the cooling system design and operation will not change as a result of license renewal. Judgments about the significance of these issues during the license renewal terms are based on published information, agency consultation, and information provided by the utilities (Appendix F) applicable to every nuclear power plant in the United States. The conclusions drawn in Sections 4.3.2 and 4.3.3 apply to all nuclear power plants with cooling towers.

4.3.2.1 Water Use

Two factors may cause water-use and water-availability issues to become important for some nuclear power plants that use cooling towers. First, the relatively small rates of cooling water withdrawal and discharge allowed some power plants with cooling towers to be located on small bodies of water that are susceptible to droughts or competing water uses. Second, closed-cycle cooling systems evaporate cooling water, and consumptive water losses may represent a substantial proportion of the flows in small rivers. Loss of a substantial portion of flow from a small stream as a result of evaporative losses from a cooling tower will reduce the amount of habitat for fish and aquatic invertebrates. Off-stream water uses, such as power plant consumption, must be regulated to ensure that important in-stream uses, such as habitat for aquatic organisms, boating, angling, and waste assimilation, are not compromised.

Consumptive water use can adversely impact riparian vegetation and associated animal communities by reducing the amount of water in the stream that is available for plant growth, maintenance, and reproduction. Riparian vegetation is defined as streamside vegetation that is structurally and floristically distinct from adjacent upland plant communities (Taylor 1982). Riparian vegetation has important ecological functions; and its importance as a resource has been widely recognized and reviewed (e.g., Brinson et al. 1981; Johnson et al. 1985). Briefly, riparian vegetation stabilizes stream channels and floodplains. It influences biogeochemical cycles, water temperature and quality, and the duration and magnitude of flooding. Riparian vegetation also provides diverse cover, food, water, reproductive habitat, and migration corridors for many aquatic and terrestrial animals. As a result, riparian zones often support a wide variety and high density of wildlife (deer, small mammals, songbirds, raptors, reptiles, and amphibians), especially in arid or urbanized areas. Riparian vegetation may be adversely affected by dewatering in a number of ways (Taylor 1982), including decreases in the width of the riparian corridor, changes in species and community diversity, increased susceptibility to flooding, changes in tree canopy cover, lower tree basal area, and lower seedling densities. Impacts to wildlife occur as a direct or indirect result of degradation of riparian habitats. Such dewatering effects are most apparent in the arid and semi-arid West; in the eastern United States, dewatering effects generally involve more subtle changes in community composition because of the higher precipitation, humidity, and soil moisture and the lower water stress conditions that prevail.

Limerick Generating Station, located on the Schuylkill River at Pottstown, Pennsylvania, is an example of a plant with a closed-cycle cooling system that is subject to water availability constraints because of in-stream-flow requirements in a smaller river, controversy over water use related to interbasin transfer, competing water uses, and water-related agreements between utilities. Aquatic resource issues identified include (1) water quality and low-flow problems in the Schuylkill River; (2) water availability conflicts with downstream water users; (3) increased in-stream flow requirements, particularly with respect to continuing efforts to improve the water quality of the Schuylkill River and to reintroduce American shad into the river; and (4) concerns over saltwater movement upstream in the Delaware River as the result of upstream water use (Margaret A. Reilly, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee May 24, 1990; D. T. Guise, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, July 3, 1990).

Limerick is in one of the fastest growing regions in Pennsylvania, which is experiencing heavy residential development and water demands for domestic, existing industrial, and developing industrial uses (Joseph Hoffman, letter to V. R. Tolbert, ORNL, Oak Ridge, Tennessee, August 27, 1990). Limerick is permitted to withdraw up to 13 percent of the minimum flow of the Schuylkill River and a major portion of the flow of Perkiomen Creek for cooling tower makeup. Only 5 percent of the 1.8–2.0 m^3/s (65–70 ft^3/s) withdrawn from the Schuylkill River when the flow is greater than 15 m^3/s (530 ft^3/s) is returned to the river. This loss of in-stream flow is viewed as a significant contribution to the water quality and low-flow problems in the Schuylkill River (Dennis T. Guise, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, July 3, 1990). This water-use issue may be exacerbated as efforts to reintroduce the American shad into the Schuylkill River continue. In addition to the water use from the Schuylkill River, 2 m^3/s (71 ft^3/s) of water is diverted from the Delaware River to the East Branch of Perkiomen Creek via the Point Pleasant Diversion at a rate of 2 m^3/s (71 ft^3/s); this interbasin transfer affects the achievement of the 85 m^3/s (3000 ft^3/s) minimum flow objective in the Delaware River at Trenton. The effects of the diversion are being debated through an NPDES permit appeal before the Pennsylvania Environmental Hearing Board (Dennis T. Guise, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, July 3, 1990).

The Palo Verde NGS offers another example of competing water uses that may affect continued operation of nuclear facilities that use cooling towers. Palo Verde currently uses treated effluent from the cities of Phoenix and Tolleson for cooling tower makeup water. The blowdown from the cooling towers discharges to on-site lined evaporation ponds [Arizona Public Service Company response to NUMARC survey (NUMARC 1990)]. In the absence of the power plant, part of the municipal effluent would be used for commercial purposes and the remainder discharged to the Gila River, where it would be used for groundwater recharge, irrigation, and support of riparian habitat (Jack Bale, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, May 31, 1990). According to the Arizona Game and Fish Department (Donald Turner, Arizona Game and Fish Department letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, June 29, 1990), if Palo Verde uses all of its allocation, the flow from the Gila River downstream to Gillespie Dam will be reduced, the water tables will drop significantly, and aquatic habitat and riparian vegetation will be destroyed. Sixty-nine percent of the water flowing in the Gila and Salt rivers downstream from the Ninety-First Avenue treatment plant is discharged by the treatment plant. Most if not all of the water produced by the treatment plant is committed to Palo Verde. When all three units of the plant were operating, flow in the river was significantly reduced, pools and ponds dried up, and numerous fish die-offs occurred (Donald Turner, Arizona Game and Fish Department, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, June 29, 1990).

Nuclear facilities on small bodies of water may experience water-use constraints related to availability. For example, during temporary drought periods, power plants with cooling towers may have to curtail operations if evaporative water losses exceed the capacity of small, multiple-use source bodies of water. Byron Station in Illinois withdraws water from the Rock River to supply natural-draft cooling towers. By agreement with the Illinois Department of Conservation, the withdrawal for makeup is limited to 3.5 m^3/s (125 ft^3/s) and net water consumption is limited to no more than 9 percent of the flow below 19 m^3/s (679 ft^3/s) [Commonwealth Edison Company response to NUMARC survey (NUMARC 1990)]. Duane Arnold Energy Center on the Cedar River in Iowa uses mechanical-draft cooling towers for condenser cooling and could also experience water availability constraints. The state of Iowa Department of Natural Resources currently has no water-use concerns with operation of Duane Arnold (Larry J. Wilson, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, May 22, 1990); however, the plant may possibly experience future constraints on the availability of water for consumptive use, because the surface water withdrawals within the state are projected to increase by 19 percent from 1985 to 2005 (Thamke 1990). Within Linn County, where Duane Arnold is located, water use is also projected to increase (Brian Tormee, telephone interview with V. R. Tolbert, ORNL, Oak Ridge, Tennessee, September 4, 1990).

Consultations with regulatory and resources agencies indicate that water use conflicts are already a concern at two closed-cycle nuclear power plants (Limerick and Palo Verde) and may be a problem in the future at Byron Station and the Duane Arnold Energy Center. Because water use conflicts may be small or moderate during the license renewal period, this is a Category 2 issue for nuclear plants with closed-cycle cooling systems. Related to this, the effects of consumptive water use on in-stream and riparian communities could also be small or moderate, depending on the plant, and is also a Category 2 issue.

4.3.2.2 Water Quality

Although cooling towers are considered to be closed-cycle cooling systems, concentration of dissolved salts in the makeup water—which results from evaporative water loss—requires the discharge of a certain percentage of the mineral-rich stream (blowdown) and its replacement with fresh water (makeup). The quantities of blowdown are relatively small compared with the discharges from once-through systems, typically on the order of 10 percent. Water quality impacts could occur from the elevated temperatures of the blowdown or from the concentration and discharge of chemicals added to the recirculating cooling water (to prevent corrosion and biofouling, regulate pH, etc.). A unit of water may reside in the cooling circuit for 3 to 20 cycles before being lost to evaporation or released in the blowdown stream (Coutant 1981). The concentration of total dissolved solids in the cooling tower blowdown averages 500 percent of that in the makeup water, a concentration factor that can be tolerated by most freshwater biota (ORNL/NUREG/TM-226). Dilution of the low-volume blowdown by the receiving water also reduces water quality impacts of heat and contaminants discharged from closed-cycle cooling systems.

Because of strict regulation of chemical discharges from steam-electric power plants (e.g., EPA regulations per 40 CFR Part 423), water treatment systems for cooling tower blowdown have been developed. Many of these systems recapture chemical additives for recycling in the cooling system (Coutant 1981). As noted in Section 4.2, all nuclear power plants are required to obtain an NPDES permit to discharge effluents. These permits are renewed every 5 years by the regulatory agency, either EPA or, more commonly, the state's water quality permitting agency. The periodic NPDES permit renewals provide the opportunity to require modification of power plant discharges or to alter discharge monitoring in response to water quality concerns. Utility responses to the NUMARC survey (Table F.2) indicate that such changes have been made during the plants' operation to correct water quality problems.

Impacts of cooling tower discharges are considered to be of small significance if water quality criteria (e.g., NPDES permits) are not consistently violated. In considering the effects of closed-cycle cooling systems on water quality, the staff evaluated the same issues that were evaluated for open-cycle systems (Table 4.1): altered current patterns, altered salinity gradients, temperature effects on sediment transport capacity, altered thermal stratification of lakes, scouring from discharged cooling water, eutrophication, discharge of chlorine and other biocides, discharge of other chemical contaminants, and discharge of sanitary wastes. Based on review of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, discharge of cooling tower effluents has not been a problem at existing nuclear plants. Although occasional violations of NPDES permits have occurred at many plants (e.g., minor spills), water quality impacts have been localized and temporary. Effects are considered to be of small significance for all plants. Cumulative impacts to water quality would not be expected because the small amounts of chemicals released by these low-volume discharges are readily dissipated in the receiving waterbody. No change in operation of the cooling system is expected during the license renewal term, so no change in effects of cooling towers discharges on receiving water quality is anticipated. Effects of cooling tower discharges could be reduced by operating additional wastewater treatment systems, or by reducing the plant's generation rate. However, because the effects of cooling tower discharges on water quality are considered to be impacts of small significance and because the changes would be costly, the staff does not consider the implementation of these potential mitigation measures to be warranted. Effects of cooling tower discharges on water quality are all Category 1 issues.

4.3.3 Aquatic Ecology

Cooling towers have been suggested as mitigative measures to reduce known or predicted entrainment and impingement losses (see, for example, Barnthouse and Van Winkle 1988). The relatively small volumes of makeup and blowdown water needed for closed-cycle cooling systems result in concomitantly low entrainment, impingement, and discharge effects (see Section 4.2.2 for a more complete discussion of these effects regarding once-through cooling systems). Studies of intake and discharge effects of closed-cycle cooling systems have generally judged the impacts to be insignificant (NUREG/0720; NUREG/CR-2337). None of the resource agencies consulted for this GEIS (Appendix F) expressed concerns about the impacts of closed-cycle cooling towers on aquatic resources.

However, even low rates of entrainment and impingement at a closed-cycle cooling system can be a concern when an unusually important resource is affected. Such aquatic resources would include threatened or endangered species or anadromous fish that are undergoing restoration. For example, concern about potential impacts of the Washington Nuclear Project (WNP-2) on chinook salmon has been raised by the Washington Department of Fisheries (Cynthia A. Wilson, Washington Department of Fisheries, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, July 5, 1990). Although entrainment, impingement, and thermal discharges are not believed to be a problem at WNP-2, the importance of the Columbia River salmon stocks are such that the resource agency feels that monitoring should continue. Similarly, the Pennsylvania Fish Commission has expressed concern about future entrainment and impingement of American shad by the Limerick Generating Station, the Susquehanna Steam Electric Station, Three Mile Island Nuclear Station, and Peach Bottom Atomic Power Station (Dennis T. Guise, Pennsylvania Fish Commission, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, July 3, 1990). In all cases, losses of American shad at these power plants are minimal or nonexistent, but periodic monitoring has been recommended to ensure that no future problems occur as the anadromous fish restoration efforts continue.

It is unlikely that the small volumes of water withdrawn and discharged by closed-cycle cooling systems would interfere with the future restoration of aquatic biota or their habitats. Effects of operation of closed-cycle cooling systems on aquatic organisms are considered to be of small significance if changes are localized and populations in the receiving waterbody are not reduced. In considering the effects of closed-cycle cooling systems on aquatic ecology, the staff evaluated the same issues that were evaluated for open-cycle systems (Table 4.1): impingement of fish and shellfish, entrainment of fish and shellfish early life stages, entrainment of phytoplankton and zooplankton, thermal discharge effects, cold shock, effects on movement and distribution of aquatic biota, premature emergency of aquatic insects, stimulation of nuisance organisms, losses from predation, parasitism, and disease, gas supersaturation of low dissolved oxygen in the discharge, and accumulation of contaminants in sediments or biota. Based on reviews of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, these potential effects have not been shown to cause reductions in the aquatic populations near any existing nuclear power plants. None of the regulatory and resource agencies expressed concerns about the cumulative effects on aquatic resources of closed cycle cooling system operations at this time, although some recommended continued monitoring in view of efforts to restore fish populations. Effects of all of these issues are considered to be of small significance for all plants. No change in operation of the cooling system is expected during the license renewal term, so no change in effects of cooling towers on aquatic biota is anticipated. Effects of entrainment, impingement, and discharges from closed-cycle cooling systems could be reduced by reducing the plant's generation rate, or by operating additional wastewater treatment systems. However, because the effects of cooling tower withdrawals and discharges on aquatic organisms are considered to be impacts of small significance and because the changes would be costly, the staff does not consider the implementation of these potential mitigation measures to be warranted. The effects of closed-cycle cooling system operation on aquatic biota are all Category 1 issues.

4.3.4 Agricultural Crops and Ornamental Vegetation

The issue addressed by this section is the extent to which the productivity of agricultural crops near nuclear plants may be reduced by exposure to salts or other effects (e.g., icing, increased humidity) resulting from cooling-tower operation. The approach to evaluating this issue was as follows: first, based on a literature review, potential impacts of salts in general (whether from cooling towers or other sources such as wind-blown salts near seashores) are described according to the rate of salt deposition to earth and the relative sensitivity of different types of crops (Section 4.3.4.1); then, the data generated by monitoring programs at a representative subset of specific nuclear plants were reviewed (Section 4.3.4.2). The subset includes 10 of the 11 nuclear power plants with mechanical-draft cooling towers. Mechanical-draft towers are the focus of this section because impacts of drift deposition and icing are more likely to occur near these towers than at natural-draft towers. Drift from natural-draft towers is released at greater heights, disperses more widely, and therefore deposits on earth at lower rates or concentrations. Data were also found and reviewed for 8 of the 17 plants with natural-draft cooling towers (Table 4.1). The coal-fired Chalk Point Plant was also included in the analysis because extensive monitoring of cooling-tower-drift effects has been conducted there and because this plant uses brackish water for cooling and represents a case with comparatively high potential for drift impacts from natural-draft towers. The only nuclear plant that has a natural-draft tower and uses brackish water for cooling is Hope Creek in New Jersey. It is included among the plants that were reviewed.

The following standard of significance is applied to the effects of cooling tower operation on agricultural crops and ornamental vegetation. The impact is of small significance if under expected operational conditions measurable productivity losses (either quantity or quality of yield) do not occur for agricultural crops; and measurable damage (either visual or to plant function) does not occur for ornamental vegetation.

4.3.4.1 Overview of Impacts

4.3.4.1.1 Ambient Salts and Cooling-Tower Drift

Agricultural crops can be affected by chemical salts and biocides in cooling tower drift and drift-induced or plume-induced ice formation. Increased fogging, cloud cover, and relative humidity resulting from cooling-tower operation have little potential to affect crops, and adverse effects have not been reported. Generally, drift from cooling towers using fresh water has low salt concentrations and, in the case of mechanical draft towers, falls mostly within the immediate vicinity of the towers (ANL/ES-53), representing little hazard to vegetation off-site. Typical amounts of salt or total dissolved solids in freshwater environments are around 1000 ppm (ANL/ES-53). In arid environments, competition for water resources can result in the use of relatively low-quality or saline water for cooling, and the potential for drift-induced damage to surrounding vegetation may be greater (McBrayer and Oakes 1982). For example, source water for cooling at Palo Verde in Arizona is withdrawn from an onsite reservoir containing treated sewage effluent of relatively high salinity. As a result, cooling tower basin water also had high salinity levels including 10,000 to 26,000 ppm total dissolved solids, 3,400 to 7,000 ppm Cl^-, and 2,700 to 8,600 ppm Na^+ (NUS-5241). High salt levels also occur at plants on the coasts or coastal bays. Brackish cooling water used by the Chalk Point coal-fired plant in Maryland contained 11,000 to 26,000 ppm total soluble salts and 6,600 to 18,000 ppm Cl^- (Mulchi and Armbruster 1983). Nuclear plants with cooling towers use fresh water, except for the Hope Creek Plant in New Jersey, which uses saline water. At the Crystal River Plant, Florida, which currently uses brackish water in once-through cooling, a helper cooling tower has been constructed to cool water in a canal that receives discharge from five fossil and one nuclear units.

Talbot (1979) has concluded that adequate estimates of natural background levels of atmospheric salt loading (naturally occurring drift) and rates of deposition thereof are not available for points remote from oceans. In field measurements at a wet cooling tower, A. Backhaus et al. (1988) estimated that up to 60 percent of the chemical contents in the sample came from atmospheric aerosols and not from the tower. Therefore, observed deposition is not all drift from cooling towers (Talbot 1979). Recent work (ORNL/TM-11121) has quantified background aerosol deposition for a dozen sites throughout the country, but deposition for most locations remains poorly known.

Salts from cooling towers are deposited on vegetation by (1) wind-driven impaction, (2) droplet and particulate fallout, and (3) rainfall (Talbot 1979; CONF-740302, 1975b). In high-salt environments such as a windy seashore, impaction is usually the most important process, delivering 10 times more salt to vegetation than does fallout. Increasing wind speeds and salt concentrations increase impaction, hence increasing vegetation injury (Talbot 1979). In most humid environments, rainwater will wash off salts deposited on vegetation (ANL/ES-53), but exposure can be significant during periods between rainfalls.

4.3.4.1.2 Effects of Salt Drift

Plants damaged by salt drift may have acute symptoms, including necrotic or discolored tissue, stunted growth, or deformities (Talbot 1979; Hoffman et al. 1987). Chronic effects are less obvious but may include some degree of chlorosis and reduced growth (Talbot 1979) or increased susceptibility to disease and insect damage (Hosker and Lindberg 1982).

Climatic conditions affect plants' ability to tolerate salt (Talbot 1979; Maas 1985). The degree of injury is related to the salt content in the leaves, but hot or dry weather conditions and water stress are critical in inducing injury (most crops can tolerate greater salt stress during relatively cool and humid weather) (Maas 1985).

Among the factors that affect the plant's foliar accumulation of salt are physical characteristics of the leaves (Maas 1985; CONF-740302, 1975d; Taylor 1980), type and concentration of salt, ambient temperature and humidity, and length of time the leaf remains wet (Maas 1985). Because salt on foliage is apparently absorbed from solution, high humidity, which retards evaporation, enhances salt uptake (CONF-740302, 1975d; McCune et al. 1977; Talbot 1979; Grattan et al. 1981). Because precipitation and dew affect salt deposition, uptake, and resultant injury, dose exposure is difficult to predict (Talbot 1979; Grattan et al. 1981; McCune et al. 1977; EPA-600/3-76-078).

Plant species and crop varieties vary significantly in their tolerance to drift deposition and to soil salinity (Talbot 1979; Maas 1985). In general, salt uptake, plant injury, and reduction in crop yield have been shown to increase with increasing levels of airborne salt or deposition and with time of exposure (CONF-740302, 1975b; Mulchi and Armbruster 1981; Maas; Grattan et al.; EPA-600/3-76-078). Some plants, however, have shown a slight increase in vegetative productivity [e.g., tobacco at < 4 kg/ha (3.6 lb/acre) per week (Mulchi and Armbruster 1983) and cotton at 8 kg/ha (7 lb/acre per week) (Hoffman et al. 1987)]. Based on experimental exposures, a yield reduction of 10 percent has been estimated for deposition levels as low as 4.7 kg/ha (4.2 lb/acre) per week to corn, a species sensitive to foliar salt injury (Mulchi and Armbruster 1981). Relationships between experimental levels of salt deposition, foliar concentrations of sodium and chloride, and corn yield show that yield may be slightly reduced even at rates as low as 2 kg/ha (1.8 lb/acre) per week (Mulchi and Armbruster 1981). Also, bush beans can have reduced yield depending on the age of plants, with older plants being most sensitive (EPA-600/3-76-078). Deposition rates near nuclear-plant towers, according to available deposition data (Section 4.3.5.1.2), appear to be generally below the rates that would affect sensitive agricultural crops.

Talbot (1979) tabulated salt deposition amounts known to induce acute toxicity symptoms in vegetation (Table 4.2). Corn was the most sensitive crop, showing injury above 1.8 kg/ha (1.6 lb/acre) per week; the least sensitive was pinto beans, showing injury above 253 kg/ha (226 lb/acre) per week. Armbruster and Mulchi (1984) showed that foliar salt deposition of 3.2 to 8.8 kg/ha (2.9 to 7.9 lb/acre) per week increased foliar chloride content and damaged foliage of corn, with the higher deposition reducing the yield of grain by as much as 11 percent. They found similar results for soybeans, with bean yields

Table 4.2 Estimates of salt-drift deposition rates estimated to cause acute injury to vegetation

Species	Deposition above which injury is expected (kg/ha/week)
Crops and ornamental plants	
Zea mays (corn)	1.82
Glycine hispida var York (soybean)	7.28
Gossypium hirsutum (cotton)	8.0
Medicago sativa (alfalfa)	15.7
Forsythia intermedia var spectabilis (forsythia)	189.6
Phaseolus vulgaris var Pinto (pinto bean)	252.8
Albizzia julibrissin rosea (mimosa)	379.2
Koelreutaria paniculata (golden rain tree)	568.8
Native species	
Cornus florida (flowering dogwood)	1.2 (in Maryland) 47.4 (in New York)
Fraxinus americana (white ash)	1.3 (in Maryland) 18.9 (in New York)
Tsuga canadensis (Canadian hemlock)	9.4
Pinus strobus (white pine)	189.6
Quercus prinus (chestnut oak)	379.2
Robinia pseudoacacia (black locust)	379.2
Acer rubrum (red maple)	474.0
Hammamelis virginiana (witch hazel)	1042.8

Source: Adapted from Talbot 1979 and Hoffman et al. 1987.
Note: To convert kg/ha to lb/acre, multiply by 0.8924.

reduced by as much as 7 percent at the highest deposition rate.

W. C. Hoffman et al. (1987) experimentally exposed cotton and cantaloupe in the arid environment near Palo Verde to foliar salt deposition rates of 8 to 415 kg/ha (7 to 370 lb/acre) per year total salt and alfalfa to depositions up to 829 kg/ha (740 lb/acre) per year. They found foliar injury in alfalfa only at the highest deposition level but no injury to cantaloupe or cotton despite increases in foliar Na^+ and Cl^-. Yields of cantaloupe and alfalfa were not reduced, but 415 kg/ha (370 lb/acre) per year reduced cotton boll production and seed cotton yield by approximately 25 percent.

The burning quality of tobacco is known to be adversely affected by elevated Cl^-. Experiments have shown that burning quality, or length of time the leaf will burn, is impaired by increasing experimental doses of salt deposition (Mulchi and Armbruster 1983). A 17 percent reduction in burning quality was estimated for a Cl^- deposition of 5 kg/ha (4.5 lb/acre) per week, based on regression relationships of deposition, leaf chloride concentration, and leaf burn (Mulchi and Armbruster 1983).

Field studies of the effects of salt drift have been conducted at the Turkey Point plant and the coal-fired Chalk Point plant. Hindawi et al. (EPA-440/5-86-001) investigated field exposures of bean and corn plants to saltwater drift from a test cooling tower and power spray module at the Turkey Point plant. Salt concentrations in tissues of bean and corn plants increased with time during three weeks of exposure and decreased exponentially with distance from the salt drift source. Some injury to leaves was visible at the site of greatest exposure.

The coal-fired Chalk Point plant has a relatively high potential impact from natural-draft cooling towers because brackish water is used for cooling. Other than the Hope Creek plant, all nuclear plants with natural-draft towers use fresh water for cooling. Deposition rates at Chalk Point were measured at 12 monitoring sites at distances of from 1.6 km to 9.6 km (1 to 6 miles) from the towers during their initial 5 years of operation (Mulchi et al. 1982). No increased deposition resulting from cooling-tower operation was detected at these distances. Deposition rates at the sites ranged from about 0.5 to 1.2 kg/ha (0.4 to 1 lb/acre) per month for NaCl, which comprises most of the solids in the brackish cooling water. Monitoring sites, which were established to study effects on agricultural crops, were not located in areas closer to the towers because no active cropland was in these areas and because the plant, located on a peninsula on the Patuxent River, is bounded by water except to the north and north-northwest. Most drift probably deposits in the river.

A study of tobacco plants 3 years after Chalk Point cooling towers began operating failed to find any increase in leaf salt content that could be attributed to drift (Mulchi and Armbruster 1983). Chloride levels in tobacco and chloride and sodium levels in corn and soybeans at 1.6 km (1 mile), the closest distance crops were grown to the Chalk Point towers, were within the range of preoperational values and were no higher than levels found up to 9.6 km (6 miles) from the towers (Mulchi et al. 1982; Mulchi and Armbruster 1983).

4.3.4.1.3 Effects on Soils

Drift deposition also has the potential to damage vegetation by soil salinization. Soil salinization does not usually occur in areas where rainfall is sufficient to leach salts from the soil profile. In arid regions, however, such as at Palo Verde, cooling tower drift has the potential to increase soil salinity and thus affect native and agricultural plants (McBrayer and Oakes 1982). Salinity of irrigated soils in arid regions may also be increased by drift, even though such soils already have a high salinity resulting from salts in irrigation water and high evaporation rates. Responses of crop plants to soil salinity appear to be poorly correlated to their tolerance to foliar-applied salts (Grattan et al. 1981; Maas 1985).

In an experiment in a more humid environment, salts were applied to soils to simulate drift deposition from the Chalk Point coal-fired plant with brackish water cooling towers. One-time applications of 14–112 kg/ha (13–100 lb/acre) NaCl affected leaf Cl^- in corn and soybeans but resulted in no visible damage or reduction in yield (Armbruster and Mulchi 1984). These soil salt treatments also increased soil pH and extractable cations (Armbruster and Mulchi 1984), but leaching by winter precipitation returned soil to pretreatment status.

In humid environments, effects of drift deposition on soils appear transitory if they can be detected at all. Field measurements of the effects of the operating cooling towers at Chalk Point showed no changes in soil chemical elements at distances of 1.6 to 9.6 km (1 to 6 miles) (Mulchi et al. 1982). In a study of five saltwater cooling towers near Galveston Bay, Texas, salt deposition up to 746 kg/ha/year was found within 100 m (328 ft) of the towers, with levels decreasing to <52 kg/ha (46 lb/acre) per year at 434 m (1424 ft) (Wiedenfeld et al. 1978). Weekly deposition ranged from 4.27 kg/ha (3.81 lb/acre) per week to 58.8 kg/ha (52.5 lb/acre) per week. In the survey, salt content of the soil at 104 m (341 ft) from the towers returned to previous levels when towers were shut down during the winter.

4.3.4.2 Plant-Specific Operational Data

Annual reports of environmental monitoring for vegetation damage at nuclear plants were reviewed. Vegetation monitoring included detailed measurements of vegetation structure and composition on permanent plots, aerial infrared photography with subsequent field surveys for vegetation injury, or general surveillance. Vegetation damage ranging from foliar chlorosis to defoliation can be identified on false-color infrared aerial photographs (NUREG/CR-1231). Vegetation monitoring for drift effects has been conducted at 18 nuclear plants. Most of the nuclear plants are not located close to agricultural areas, but six of the plants monitored crops, pasture, orchards, or ornamental vegetation. None reported visible damage to ornamental vegetation or reduction in crop yield (Table 4.3).

A detailed study at Palo Verde in Arizona showed that, after 6 years of operation, no change in agricultural soils attributable to cooling tower emissions occurred. Although significant increases or decreases occurred in some soil parameters at some monitoring locations, these changes appear unrelated to cooling-tower operation and were believed to have been caused by irrigation management, cropping, and fertilizer application. At the conclusion of the 6-year study, no significant effects on

Table 4.3 Results of nuclear facility monitoring for cooling-tower drift effects on terrestrial vegetation

Plant	Vegetation effects	Type of monitoring
	Natural draft	
Arkansas	No visible damage; no foliar chemical changes after one year	Aerial photography; foliar chemistry; orchard, native trees
Beaver Valley	No visible damage	Aerial photography; soil pH and conductivity; native vegetation
Byron	No visible damage	Aerial photography; crops; woody, ornamental, and native vegetation
Callaway	No visible damage	Aerial photography; permanent vegetation plots; native trees
Davis-Besse	No visible damage	Aerial photography; soil chemistry; native vegetation
Hope Creek	No visible damage after one year; no foliar chemical changes after one year	Ground survey; foliar chemistry; soil chemistry; native vegetation
Three Mile Island	No visible damage	Visual inspection; crops and native vegetation
Trojan	No visible damage	Aerial photography; pasture, ornamental and native vegetation
	Mechanical draft	
Catawba	Possible ice damage to loblolly pine < 61 m (200 ft) from towers	Aerial photography; ground survey; native trees
Duane Arnold	No visible damage	Visual inspection; native vegetation
Edwin I. Hatch	No visible damage	Aerial photography; permanent vegetation plots; native vegetation

Table 4.3 (continued)

Plant	Vegetation effects	Type of monitoring
Joseph Farley	No visible damage	Aerial photography; native vegetation
Palisades	Severe ice damage < 61 m (200 ft) from towers; some icing beyond 250 m (820 ft); sulfate injury < 150 m (492 ft) from towers; change in vegetation caused by damage to trees	Aerial photography; permanent vegetation plots; native vegetation
Palo Verde	No visible damage; foliar salt concentrations increased on site	Aerial photography; foliar chemistry; soil chemistry; crops and native vegetation
Prairie Island	Frequent ice damage to oaks adjacent to towers; change in canopy structure caused by ice damage; reduced viability in acorns from oaks near towers	Aerial photography; ground survey; acorn viability survey; native vegetation
River Bend	No visible damage	Aerial photography; permanent vegetation plots; native vegetation
Fort Saint Vrain	No visible damage	Aerial photography; crops; native vegetation
Washington	No foliar chemical changes	Foliar chemistry; soil chemistry; native vegetation

crops or native vegetation had been noted, and the study was discontinued (Halliburton NUS 1992).

At the Palisades plant in Michigan, concern was expressed by owners of nearby fruit orchards about possible effects of elevated humidity on the incidence of disease, particularly apple scab, in their orchards. The concern was that increased humidity could result in the need for increased applications of disease-control sprayings and thus increase orchard operating costs. NRC staff recommended a survey program to assess impacts of cooling-tower moisture on yield, quality, and frequency of disease-control sprayings (NRC 1978). Weather conditions encouraging apple scab are temperatures of 17 to 24°C (63 to 75°F) and

>85 percent relative humidity for 9 h or more. A study was conducted to determine these weather conditions near Palisades cooling towers and in more distant areas (Ryznar et al. 1980). Long-term weather records from weather stations outside the influence of the Palisades cooling towers were analyzed. In addition, a network of meteorological stations was established in the vicinity of the Palisades plant. No increase in weather occurrences favoring apple scab was observed that could be related to Palisades operation.

4.3.4.3 Conclusion

Monitoring results from the sample of nuclear plants and from the coal-fired Chalk Point plant, in conjunction with the literature review and information provided by the natural resource agencies and agricultural agencies in all states with nuclear power plants, have revealed no instances where cooling tower operation has resulted in measurable productivity losses in agricultural crops or measurable damage to ornamental vegetation. Because ongoing operational conditions of cooling towers would remain unchanged, it is expected that there would continue to be no measurable impacts on crops or ornamental vegetation as a result of license renewal. The impact of cooling towers on agricultural crops and ornamental vegetation will therefore be of small significance. Because there is no measurable impact, there is no need to consider mitigation. Cumulative impacts on crops and ornamental vegetation are not a consideration because deposition from cooling tower drift is a localized phenomenon and because of the distance between nuclear power plant sites and other facilities that may have large cooling towers. This is a Category 1 issue.

4.3.5 Terrestrial Ecology

This section addresses the impact of cooling tower drift on natural plant communities (Section 4.3.5.1) and the impact of bird mortality resulting from collisions with natural-draft cooling towers (Section 4.3.5.2).

4.3.5.1 Effects of Cooling-Tower Drift

This section addresses the extent to which natural plant communities near nuclear plants are affected by exposure to salts, icing, or other effects (e.g., fogging and increased humidity) caused by operation of cooling towers. The approach to evaluating this issue is the same as that used for evaluating the impact on agricultural crops in Section 4.3.4.

4.3.5.1.1 Overview of Impacts

The potential impacts of cooling tower operation on native vegetation are similar to those for agricultural crops, including salt-induced leaf damage, growth and seed yield reduction, and ice-induced damage (see Section 4.3.4). In addition, native vegetation may suffer changes in community structure (Talbot 1979) in response to ice damage or differences in species tolerances to drift. Increased fogging and relative humidity near cooling towers have little potential to affect native vegetation, and no such impacts have been reported.

The following standard of significance is applied to the effects of cooling tower operation on natural plant communities. The impact is of small significance if no measurable degradation (not including short-term, minor, and localized impacts) of natural plant communities results from cooling tower operation.

Species vary in their sensitivity to soil salinity and foliar salt deposition, and their tolerances of drift deposition are not well known. Curtis et al. (PPSP) determined that experimental exposure to saline cooling-tower drift for one growing season resulted in foliar damage to vegetation when leaf Cl^- levels were between 3145 and 9000 µg/g dry weight. These investigators also found that several species of trees growing under field conditions were not always as sensitive to salt deposition as they were under greenhouse conditions. Actual sensitivities of native trees may therefore be less than those shown in Table 4.2. Age of leaves also affects sensitivity to deposition. McCune et al. 1977 found that the youngest leaves of deciduous woody species and the year-old needles of conifers were more susceptible than leaves of other ages. Seasonal deposition, therefore, has the potential to affect these species groups differently. The most sensitive native species, flowering dogwood, shows injury from deposition above 1.2 kg/ha (1.1 lb/acre) per week, and the least sensitive species, witch hazel, shows injury above 1042.8 kg/ha (930.6 lb/acre) per week (Talbot 1979). Deposition rates near nuclear plant cooling towers, according to available deposition data, appear to be generally below the rate that would adversely affect dogwood.

Talbot (1979) reviewed studies of vegetation damage at nine industrial cooling tower installations. Three of the six installations having mechanical draft towers (one saltwater and two freshwater) produced some damage to native vegetation within 215 m (705 ft). Natural draft towers at three sites had no reported visible effects on vegetation. Natural draft cooling towers using brackish water at the coal-fired Chalk Point plant resulted in elevated chloride concentrations in vegetation after 1 year of tower operation (PPSP-CPCTP-18), but symptoms of salt toxicity in native trees had not been observed after 2 years of operation (Lauver et al. 1978), after which monitoring was terminated because of the absence of significant effects (C. L. Mulchi, University of Maryland, personal communication with H. Quarles, ORNL, Oak Ridge, Tennessee, March 15, 1995).

Impacts on native vegetation as a result of soil salinization (Section 4.3.4) are not expected except possibly in arid environments. Although according to McBrayer and Oakes (1982), the predicted annual salt deposition of 25 to 50 kg/ha (22 to 51 lb/acre) near the Palo Verde cooling towers could increase soil salinity enough to alter distribution of certain species because natural soil salinity is already close to their salt tolerances, a monitoring study conducted over the first 6 years of cooling tower operation showed no significant effects on native vegetation or crops (Halliburton NUS 1992).

4.3.5.1.2 Plant-Specific Operational Data

Vegetation monitoring at nuclear plants is described in Section 4.3.4. Of the 18 plants reviewed, visible vegetation damage resulting from cooling tower operation was reported for only the Catawba, Palisades, and Prairie Island plants, all with mechanical-draft towers (Table 4.3). At these facilities, damage has been reported primarily within 150 m of the towers. Although no vegetation damage was reported at Palo Verde, increased foliar salt concentrations were found on-site (Halliburton NUS 1992).

At the Catawba Plant a few loblolly pine trees adjacent to the cooling towers were apparently damaged by ice. Damage to the trees consisted of some browning of needles on trees nearest the towers.

At Palisades, monitoring conducted in response to observed vegetation damage included chloride and sulfate deposition and visual observation of damage. Vegetation damage resulted primarily from sulfate and was more extensive than at any other nuclear facility because, at Palisades' unique location, the tops of the cooling towers are lower than the tops of forested dunes on the site. This unique position of the cooling towers contributes to interception of cooling tower emissions by dune vegetation. Vegetation injury ranged from visible signs to severe necrosis of leaves to near-total defoliation in areas with maximum impact. In 1975, severe icing from drift interception also caused extensive damage by breaking branches as well as trunks of trees (Rochow 1978). Approximately 8 ha (20 acres) was affected by sulfates and icing, including about 6 ha (15 acres) of forest. Sulfate damage resulted from addition of sulfuric acid to the cooling water. However, this practice was discontinued, thus significantly reducing the impacts; and the severe icing in 1975 may have resulted from unusual weather conditions combined with a possible cooling tower malfunction (Ryznar et al. 1980).

Vegetation damage was found to correlate with elevated rates of sulfate deposition from the Palisades towers (Rochow 1978); chloride deposition, however, was less than 1.0 g/m^2/month in areas of extensive vegetation damage and did not correlate with the damage. Sulfate deposition rates were 0.61 g/m^2/month between 700 and 1609 m (2296 and 5278 ft) and 9.0 g/m^2/month within 50 m (164 ft) of the tower. About 75 percent of the sulfate fell out within 145 m (129 ft) of the towers (Rochow 1978). Heaviest damage to vegetation was in areas receiving more than 5 g/m^2/month sulfate, but areas receiving 2 to 5 g/m^2/month also were heavily damaged. Areas receiving 1 to 2 g/m^2/month were damaged primarily in the upper portions of trees.

Monitoring at Prairie Island included aerial photography, ground surveys of vegetation, and acorn viability monitoring. Viability of acorns collected from red oak trees located near the mechanical-draft towers was low, although acorn production appeared normal. Icing from plume downwash, which occurred frequently, may have damaged developing embryos in the acorns, which take 2 years to develop (Richardson 1976; Richardson 1978). Ice also damaged some of the trees growing adjacent to the towers. Because the towers at Prairie Island have not been used for cooling during the winter since 1984, icing damage has been eliminated.

Monitoring at Palo Verde included drift deposition, soil chemistry, salt concentrations in vegetation, and aerial photography. Drift deposition up to 95.6 kg/ha (85.3 lb/acre) per year has occurred on the site within 1.6 km (1 mile) of the cooling towers. Amounts of approximately 25 to 50 kg/ha (22 to 45 lb/acre) per year were predicted to alter soil salinity enough to affect vegetation over the long term (McBrayer and Oakes 1982). Increases in soil sodium, potassium, or chloride content have been reported, but increases also occurred in some sites that were distant from the towers (Halliburton NUS 1992). Observed changes in soil chemistry at Palo Verde appeared to be unrelated to cooling tower operation, and no effects on vegetation were reported.

4.3.5.1.3 Conclusion

Monitoring results from the sample of nuclear plants and from the Chalk Point plant, in conjunction with the literature review and information provided by the natural resource agency and agricultural agencies in all states with nuclear power plants, have revealed no instances where cooling tower operation has resulted in measurable degradation of the health of natural plant communities. Observed vegetation damage caused by icing and cooling-tower drift at mechanical draft towers usually is minor and localized in small ares (e.g., Catawba and Prairie Island). Damage to native vegetation has not occurred at Chalk Point coal plant and the Hope Creek nuclear plant, which use brackish water for cooling and represent a comparatively high probability of impact from operation of natural draft towers. Therefore, damage at other nuclear plants with natural draft towers is unlikely. Damage from operation of mechanical-draft towers at Palisades was more extensive than for the other nuclear plants, but was limited to about 8 ha (20 acres) on the site. The damage resulted from Palisades unique location, the addition of sulfuric acid to cooling water, and possibly from a cooling tower malfunction combined with unusual weather conditions. The use of sulfuric acid was discontinued, significantly reducing the impact. Cooling tower drift in the arid environment at Palo Verde has not affected native species through soil salinization: no actual damage was reported over a 6 year study of cooling tower operation (Halliburton NUS 1992). The only potential mitigation measures would be to change to another cooling system or to modify the cooling towers to reduce the amount of drift. Because the impacts of cooling tower drift on native plants are expected to be of small significance at all plants and because the potential mitigation measures would be costly, no mitigation measures beyond those implemented during the current term license would be warranted. Cumulative impacts on natural plant communities are not a consideration because of the distance between nuclear power plant sites and other facilities that may have large cooling towers. This is a Category 1 issue.

4.3.5.2 Bird Collisions with Cooling Towers

This section addresses the significance of avian mortality resulting from collisions of birds with natural-draft cooling towers at nuclear plants. Natural-draft towers, which are tall structures, cause some mortality, whereas mechanical-draft towers cause negligible mortality and are not addressed here. This issue was evaluated by reviewing the general literature for avian collision mortality associated with all types of man-made objects, as well as the monitoring studies conducted at six nuclear plants. The literature review is presented in Section 4.5.6.2. The significance of the mortality caused by cooling towers is determined by examining the actual numbers and species of birds killed and comparing this mortality with the total avian mortality resulting from other man-made objects and with the abundance of bird populations near the towers.

4.3.5.2.1 Overview of Impacts

Throughout the United States, millions of birds are killed annually when they collide with man-made objects, including radio and TV towers, windows, vehicles, smoke stacks, cooling towers, and numerous other objects. An overview of collision mortality for all types of man-made objects is included in the discussion of transmission lines in Section 4.5.6.2.

Avian mortality due to man-made structures is of concern if the stability of the local population of any bird species is threatened or if the reduction in the numbers within any bird population significantly impairs its function within the local ecosystem. Avian mortality resulting from collisions of birds with cooling towers is considered to be of small significance if the losses do not threaten the stability of local populations of any species and if there is no noticeable impairment of its function within the local ecosystem.

4.3.5.2.2 Plant-Specific Analysis

Monitoring of bird collisions has been done at several nuclear plants with natural draft cooling towers, including the Susquehanna plant near Berwick on the Susquehanna River in eastern Pennsylvania, the Davis-Besse plant on the shore of Lake Erie in north central Ohio, the Beaver Valley plant on the Ohio River in extreme western Pennsylvania, the Trojan Plant on the Columbia River in extreme northwestern Oregon, the Three Mile Island plant near Harrisburg in southeastern Pennsylvania, and the Arkansas Nuclear One plant on Dardanelle Lake in northwestern Arkansas. The following information was obtained from nuclear plant annual monitoring reports and from a few other sources, as cited.

At the Susquehanna plant, surveys were conducted on weekdays during spring and fall migration from 1978 through 1986. This plant's natural draft towers are 165 m (540 ft) tall and illuminated at the top with 480-V aircraft warning strobe lights. About 1500 dead birds (total for all survey years) of 63 species were found that had apparently collided with the cooling towers. Others were probably lost in the tower basin water during plant operation. Most of the birds were passerines (songbirds). Fewer collisions seemed to occur during plant operation, when cooling tower plumes and noise may have frightened birds away from the towers. From 1984 through 1986, eight dead bats were also found, including little brown myotis, red bat, and big brown bat.

At Davis-Besse, extensive surveys for dead birds were conducted from fall 1972 to fall 1979. Early morning surveys at the 152-m (499-ft-) tall cooling tower were made almost daily from mid-April to mid-June and from the first of September to late October. After the tower began operating in the fall of 1976, some dead birds were lost through the water outlets of the tower basin. A total of 1554 dead birds were found, an average of 196 per year. The dead birds included 1222 at the cooling tower, 222 around Unit 1 structures, and 110 at the meteorological tower. Most were night-migrating passerines, particularly warblers, vireos, and kinglets. Waterfowl that were abundant in nearby marshes and ponds suffered little collision mortality. Most collision mortalities at the cooling tower occurred during years when the cooling tower was not well illuminated (1974 to spring 1978). After completion of Unit 1 structures and the installation of many safety lights around the buildings in the fall of 1978, collision mortality was significantly reduced (average of 236 per year from 1974 through 1977, 135 in 1978, and 51 in 1979). Diffusion of light from these safety lights may illuminate the cooling tower in such a way that birds can see and avoid it. Lights at nuclear plants may not confuse birds to the extent sometimes caused by lights on radio or TV towers (Section 4.5.6.2). Lights illuminating the Pilgrim Nuclear Station in Massachusetts apparently were not a problem to migrating birds, which were monitored by radar. The orientation, flight speed, and altitude of these birds appeared unaffected by the lights, although on one of nine nights, flight direction at the station was different from that in a control area and flight altitude was higher (Marsden et al. 1980).

At Beaver Valley, surveys were conducted in spring and fall from 1974 through 1978 at the natural draft tower. A total of 27 dead birds were found. At the Trojan Plant, surveys were conducted weekly in 1984 and 1988 at the 152-m 499-ft-) tall cooling tower, meteorological tower, switch yard, and generation building. No dead birds were found. At the 113-m (371-ft-) tall cooling towers at Three Mile Island, a total of 66 dead birds were found from 1973 through 1975 (Temme and Jackson 1979). No dead birds were found at Arkansas Nuclear One, where monitoring at the natural-draft tower was done twice weekly from October 15 through April 15 in 1978–79 and 1979–80.

4.3.5.2.3 Conclusion

Existing data on cooling-tower collision mortality suggest that cooling towers cause only a very small fraction of the total bird collision mortality (see Section 4.5.6.2 for a review of this mortality). The relatively few nuclear plants having natural-draft towers in the United States (approximately 32 units), combined with the relatively low bird mortality at individual natural draft towers, shows that (1) these nuclear plant towers are not greatly affecting bird populations (see Section 4.5.6.2.1) and (2) their contribution to the cumulative effects of bird collision mortalities is very small. Mechanical-draft cooling towers, which are not nearly as tall as natural-draft towers, and other facilities pose little risk to migrating birds.

Local bird populations are apparently not being significantly affected by collision with cooling towers. Waterfowl and other birds that are commonly present as permanent or summer residents around nuclear plants do not frequently collide with the towers. Instead, a very high percentage of the collision mortalities occur during the spring and fall bird migration periods and involve primarily birds migrating at night. Studies that have been conducted at six nuclear plants, in conjunction with literature reporting total collision mortality (Section 4.5.6.2), show that (1) avian mortality associated with cooling towers is a very small part of the total mortality and (2) local bird populations are not being significantly reduced. Data on collision mortality were found for only 6 of the 20 nuclear plants with natural-draft cooling towers. Collision mortality at one or more of these plants may be greater than at the plants where surveys were conducted.

Avian mortality resulting from collisions of birds with cooling towers involves sufficiently small numbers for any species that it is unlikely that the losses would threaten the stability of local populations or result in a noticeable impairment of the function of a species within local ecosystems. There is no reason to believe that the annual mortality rate resulting from collision of birds with any cooling tower would be different during the license renewal term. Thus, avian mortality resulting from collision with cooling towers is of small significance. A potential method of mitigating avian morality would be to illuminate natural draft cooling towers at night. Because it is unlikely that the numbers of birds killed from collision with cooling towers are large enough to affect local population stability or impair the function of a species within the local ecosystem, consideration of further mitigation is not necessary. Because any contributions of cooling tower collisions to overall bird mortality have already been expressed in species populations, it is not expected that there will be any incremental or cumulative impact on bird populations from cooling tower collision mortality due to relicensing of current nuclear plants. The cumulative effect of bird mortality is further considered with transmission lines in Section 4.5.6.2. Avian mortality resulting from collision with cooling towers is a Category 1 issue.

4.3.6 Human Health

Some microorganisms associated with cooling towers and thermal discharges can have deleterious impacts on human health. Their presence can be enhanced by thermal additions. These microorganisms include the enteric pathogens *Salmonella* sp. and *Shigella* sp. as well as *Pseudomonas aeruginosa* and the thermophilic fungi (Appendix D). Tests for these pathogens are well established, and factors germane to their presence in aquatic environs are known and in some cases controllable. Other aquatic microorganisms normally present in surface waters have only recently been recognized as pathogenic for humans. Among these are Legionnaires' disease bacteria (*Legionella* sp.) and free-living amoebae of the genera *Naegleria* and *Acanthamoeba*, the causative agents of various, although rare, human infections. Factors affecting the distribution of *Legionella* sp. and pathogenic free-living amoebae are not well understood. Simple, rapid tests for their detection and procedures for their control are not yet available. The impacts of nuclear plant cooling towers and thermal discharges are considered of small significance if they do not enhance the presence of microorganisms that are detrimental to water and public health.

Potential adverse health effects on workers due to enhancement of microorganisms are an issue for steam-electric plants that use cooling towers. Potential adverse health effects on the public from thermally enhanced microorganisms is an issue for the nuclear plants that use cooling ponds, lakes, or canals and that discharge to small rivers. These plants are all combined in the category of small river (average flow less than 2830 m^3/s (100,000 ft^3/s) in Tables 5.18 and 5.19. These issues were evaluated by reviewing what is known about the organisms that are potentially enhanced by operation of the steam-electric plants.

Because of the reported cases of fatal *Naegleria* infections associated with cooling towers, the distribution of these two pathogens in the power plant environs was studied in some detail (Tyndall et al. 1983; see also Appendix D). In response to these various studies (Appendix D), many electric utilities require respiratory protection for workers when cleaning cooling towers and condensers. However, no Occupational Safety and Health Administration (OSHA) or other legal standards for exposure to microorganisms exist at present. Also, for worker protection, one plant with high concentrations of *Naegleria fowleri* in the circulating water successfully controlled the pathogen through chlorination before its yearly downtime operation (Tyndall et al. 1983).

Changes in the microbial population and in the use of bodies of water may occur after the operating license is issued and the application for license renewal is filed. Ancillary factors may also change, including average temperature of water resulting from climatic conditions. Finally, the long-term presence of a power plant may change the natural dynamics of harmful microorganisms within a body of water by raising the level of *N. fowleri*, which are indigenous to the soils. Increased populations of *N. fowleri* may have significant adverse impacts. On entry into the nasal passage of a susceptible individual, *N. fowleri* will penetrate the nasal mucosa. The ensuing infection results in a rapidly fatal form of encephalitis. Fortunately, humans in general are resistant to infection with *N. fowleri*. Hallenbeck and Brenniman (1989) have estimated individual annual risks for primary amebic meningoencephalitis caused by the free living *N. fowleri* to swimmers in fresh water, to be approximately 4×10^{-6}. Heavily used lakes and other fresh bodies of water may merit special attention and possibly routine monitoring for *N. fowleri*.

Thermophilic organisms may or may not be influenced by the operation of nuclear power plants. The issue is largely unstudied. However, NRC recognizes a potential health problem stemming from heated effluents. Occupational health questions are currently resolved using proven industrial hygiene principles to minimize worker exposures to these organisms in mists of cooling towers. NRC anticipates that all plants will continue to employ proven industrial hygiene principles so that adverse occupational health effects associated with microorganisms will be of small significance at all sites, and no mitigation measures beyond those implemented during the current term license would be warranted. Aside from continued application of accepted industrial hygiene procedures, no additional mitigation measures are expected to be warranted as a result of license renewal. This is a Category 1 issue.

Public health questions require additional consideration for the 25 plants using cooling ponds, lakes, canals, or small rivers (all under the small river category in Tables 5.18 and 5.19) because the operation of these plants may significantly enhance the presence of thermophilic organisms. The data for these sites are not now at hand and it is impossible to predict the level of thermophilic organism enhancement at any given site with current knowledge. Thus the impacts are not known and are site-specific. Therefore, the magnitude of the potential public health impacts associated with thermal enhancement of *N. fowleri* cannot be determined generically. This is a Category 2 issue.

4.3.7 Noise Impacts

When noise levels are below the levels that result in hearing loss, impacts have been judged primarily in terms of adverse public reactions to the noise. Generally, power plant sites do not result in off-site levels more than 10 dB(A) above background. However, some sites have calculated impacts to critical receptors at this level and above. Noise level increases larger than 10 dB(a) would be expected to lead to interference with outdoor speech communication, particularly in rural areas or low-population areas where the day-night background noise level is in the range of 45–55 dB(A). Generally, surveys around major sources of noise such as large highways and airports have found that, when the day-night level increases beyond 60 to 65 dB(A) (FICN 1992), noise complaints increase significantly. Noise levels below 60 to 65 dB(A) are considered to be of small significance.

The principal sources of noise from plant operations are natural-draft and mechanical-draft cooling towers, transformers, and loudspeakers. Other occasional noise sources may include auxiliary equipment such as pumps to supply cooling water from a remote reservoir. Generally, these noise sources are not perceived by a large number of people off-site.

In most cases, the sources of noise are sufficiently distant from critical receptors outside the plant boundaries that the noise is attenuated to nearly ambient levels and is scarcely noticeable. However, during the original license application process, some of the sites identified critical receptors near plant boundaries that would experience noise levels greater than 10 dB above ambient. Those levels would increase the difficulty in outdoor speech communication. (The noise would require that people speak louder to communicate.) In no case is the off-site noise level from a plant sufficient to cause hearing loss.

Natural-draft and mechanical-draft cooling towers emit noise of a broadband nature, whereas transformers emit noise of a specific tonal nature at harmonics of the 60-Hz primary frequency. The frequencies with important intensities are 120, 240, 360, and 480 Hz. Loudspeakers emit noise at audible frequencies, generally below 5000 Hz. Because of the broadband character of the cooling towers, the noise associated with them is largely indistinguishable and less obtrusive than transformer noise or loudspeaker noise. Transformer noise is distinct because of its specific low frequencies. These low frequencies are not attenuated with distance and intervening materials as much as higher frequencies are; thus, low frequencies are more noticeable and obtrusive. However, at most sites employing cooling towers, transformer noise is masked by the broadband cooling tower noise. Loudspeakers would be a more intermittent source of noise.

Cooling tower and transformer noises do not change appreciably with time. No change in noise levels or their attendant impacts would be expected during the license renewal term.

License renewal does not add to the extent of noise impacts, either in frequency distribution or in intensity. No major changes in the noise profile of power plants is anticipated. The only possible source of added impacts would be the result of additional people who build homes near enough to the site that they are affected by noise. At the noise levels anticipated, no cumulative biological impacts are expected.

During the license renewal term, noise impacts will be the same as during the initial license term. These impacts were found to be generally not noticed by the public, thus noise impacts are of small significance. Consideration was given to mitigating these noise impacts. Because the principal sources of noise are cooling towers, transformers, and loudspeakers, these sources would be the focus of noise reduction efforts. Reduction in loudspeaker noise could be accomplished by restricting such use to emergencies only and using personal electronic pagers to contact personnel. Mitigation of the low-frequency noise from cooling towers or transformers is much more difficult and would require shielding by massive concrete structures or earthen berms.

Because these noise reduction methods would be costly and given that there have been few complaints and the noise impacts are so small, no additional mitigation measures are warranted for license renewal. This is a Category 1 issue.

4.4 COOLING PONDS

4.4.1 Introduction

Power plants that use cooling ponds compose a unique subset of closed-cycle systems in that they operate as once-through power plants [i.e., large condenser flow rates (Table 2.1)] that withdraw from and discharge to relatively small bodies of water created for the plant. Cooling ponds reduce the heat load to natural bodies of water from power plant operations without the construction and operational expenses of cooling towers. The natural body of water is not relied on for heat dissipation but is used as a source of makeup water to replace that lost to evaporation and as a receiving stream for discharges from the cooling pond.

4.4.1.1 Types of Cooling Ponds

The range of power plants that use cooling ponds or lakes represents a gradation from closed-cycle power plants sited on small cooling ponds to once-through power plants sited on large, multipurpose reservoirs. For the purpose of this section, a cooling pond will be defined as "a man-made impoundment that does not impede the flow of a navigable system and that is used primarily to remove waste heat from condenser water prior to recirculating the water back to the main condenser" (ORNL/NUREG/TM-226). Under this definition, nine nuclear power plants use cooling ponds: Braidwood, Clinton, Dresden, La Salle, H. B. Robinson, South Texas, Virgil C. Summer, Wolf Creek, and Turkey Point (actually an extensive system of canals for recirculating water). Effects of other power plants located on large, multipurpose reservoirs (e.g., Comanche Peak and William B. McGuire) are included in the analysis of once-through cooling systems in Section 4.2.

The surface areas of the cooling ponds associated with these nine plants range from 629 to 2924 ha (1573 to 7310 acres). Braidwood, Clinton, Dresden, La Salle, and South Texas all use large cooling ponds that rely on nearby rivers for makeup water. Both H. B. Robinson and Clinton recycle their heated effluent in cooling ponds that are impoundments of relatively small creeks. The Virgil C. Summer plant dissipates waste heat to Monticello Reservoir, which in turn receives makeup water from Parr Reservoir. Wolf Creek recycles its condenser cooling water through a cooling pond that receives its makeup water from nearby John Redmond Reservoir. Turkey Point recirculates condenser cooling water through a complex series of canals.

4.4.1.2 Cooling Pond Emissions and Effluents

Power plants sited on cooling ponds do not have unique effluents or emissions. The examples considered in this section represent open-cycle condenser cooling systems that use the man-made pond to recirculate cooling water. Discharges to natural waters are used primarily to control the buildup of dissolved solids, analogous to blowdown from cooling towers, and may or may not have elevated temperatures. The types of emissions and effluents are the same as those considered for once-through cooling systems in Section 4.2.

Also, intake and discharge effects are regulated in the same way as for once-through cooling systems [i.e., through NPDES permits and, if needed, CWA Section 316(a) and (b) determinations (see Section 4.2 for a discussion of these regulatory mechanisms)].

Accelerated evaporation of water from a cooling pond produced by thermal loading from the power plant increases the concentration of total dissolved solids (TDS). Concentrations of TDS in cooling reservoirs average about 1.8 times those in the makeup waters (ORNL/NUREG/TM-226). Contaminants may also accumulate in the pond water and sediments. Accumulation of such water quality constituents as metals (copper or zinc) and chlorinated organic compounds in water, sediments, and aquatic biota has been cited as a potential issue for power plants located on cooling ponds.

4.4.2 Surface Water Use and Quality

This section and Section 4.4.4 review the past and ongoing impacts on aquatic resources of operation of nuclear power plants with cooling ponds. Any ongoing impacts will probably continue into the license renewal term because the cooling system design and operation are not expected to change. Judgments about the significance of these issues during the license renewal term are based on published information, agency consultation, and information provided by the utilities (Appendix F) applicable to every nuclear power plant in the United States. The conclusions reached in these sections apply to all nuclear power plants with cooling ponds.

4.4.2.1 Water Use

Nine nuclear power plants use off-stream ponds or lakes as cooling devices. Although these off-stream bodies of water were specifically designed to serve as cooling systems for temperature reduction before discharge into a river or reservoir, some (e.g., La Salle County Nuclear Station) provide recreational fishing opportunities in addition to cooling. The water-use issue associated with operation of cooling ponds is the availability of adequate streamflows to provide makeup water, particularly during droughts or in the context of increasing in-stream and off-stream uses. Two nuclear power plants, the Braidwood Station and the Wolf Creek Generating Station, have already experienced water-use conflicts.

Braidwood, which withdraws makeup water for its cooling pond from the Kankakee River, will face future water availability conflicts as Joliet, Illinois, becomes a potential downstream water user. Potential use of water upstream for irrigation may also affect the Kankakee River flow and the availability of water for the Braidwood facility. In response to other water-use demands, Braidwood, La Salle County, Dresden, and other nuclear facilities using cooling ponds or lakes, particularly those on the same river system as other thermoelectric generating facilities, may have to reevaluate their overall water requirements and tolerances to drought conditions. For example, Braidwood was forced to cease withdrawal from the Kankakee River during much of July and August 1988 because the flow of the river was below the level at which makeup withdrawals were permitted [Commonwealth Edison Company response to NUMARC survey (NUMARC 1990); Gary Clark, telephone interview with V. R.

Tolbert, ORNL, Oak Ridge, Tennessee, July 5, 1990]. These plants could increase the sizes of their cooling ponds or adopt other measures to compensate for an inability to withdraw makeup water during low flows or because of competing water uses (Gary Clark, Illinois Division of Water Resources, personal communication to V. R. Tolbert, ORNL, Oak Ridge, Tennessee, July 5, 1990).

Probably the most important change in the consideration of water-use impacts since the initial licensing of most of the nuclear generating facilities has been the increased emphasis on in-stream flow for preservation of aquatic habitat, riparian (streamside) habitat, and associated biota. An example of potential water-use conflicts is associated with the withdrawal of makeup water by the Wolf Creek Generating Station in Kansas. Water for the Wolf Creek cooling lake is withdrawn from the Neosho River downstream of John Redmond Reservoir. Riffle (shallow water) areas of this river serve as habitat for a threatened fish species, the Neosho madtom. Makeup water withdrawals during severe drought conditions could affect the riffle habitat of this species (Harold Spiker, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, June 28, 1990).

Nuclear power plants that withdraw makeup water for cooling ponds from small bodies of water may need to curtail operations during drought periods or may experience future conflicts with other water users (including increasing emphasis on in-stream uses). This potential issue affects only a small number of existing plants, and mechanisms exist for resolving these conflicts (e.g., through derating the plant during temporary drought periods or, if longer-term solutions are required, by the periodic renewals of the plants' NPDES permits). Consultations with regulatory agencies indicate that water use conflicts are already a concern at two of the nine nuclear power plants with cooling ponds (Braidwood and Wolf Creek). Because water use conflicts may be of small or moderate significance during the license renewal period, this is a Category 2 issue for nuclear plants with cooling systems that utilize cooling ponds. The effects of consumptive water use on in-stream and riparian communities could also be of small or moderate significance, depending on the plant, and also are a Category 2 issue.

4.4.2.2 Water Quality

An issue associated with the operation of a cooling pond is potential alteration of the quality of both pond and natural receiving waters as a result of the addition and concentration of a variety of chemicals. As with all other types of condenser cooling systems, chemicals (e.g., chlorine) may be added to control biofouling and to inhibit scaling and corrosion in the condenser tubing. In addition, corrosion products are leached into the circulating water flow and may be concentrated in the recirculating system.

Discharges of heat and chemical contaminants are controlled by the NPDES permits that are issued and periodically renewed for each power plant (Section 4.2). Whereas the volume of water that is discharged to a natural body of water from a cooling pond may be comparable to that discharged as blowdown from a cooling tower, the concentration of dissolved solids is less. In ORNL/NUREG/TM-226, Parkhurst and McLain estimate that the average concentration of TDS is about 400 percent above ambient in the blowdown from cooling towers and about 180 percent above ambient in the discharge from cooling reservoirs. Greater quantities of biocides may also be needed for cooling towers than for cooling ponds because of the additional need to control biofouling on the cooling tower surfaces.

Larimore and McNurney (EPRI EA-1148) compared the water quality of a power plant cooling lake (Lake Sangchris in Illinois) with that of a nearby lake unaffected by power plant discharges. The most obvious differences resulted from the heat input and power-plant-induced circulation, which prevented seasonal thermal stratification in the cooling lake. With the exception of temperature, no water quality differences between the two lakes were attributed to power plant operations.

Becker et al. (EPRI EA-1054) examined available data from 14 cooling impoundments (all associated with fossil-fuel power plants) to identify water quality and ecological effects. These 14 cooling impoundments were selected from a population of 135 steam-electric power plant cooling ponds across the United States as those most likely to provide "worst-case" conditions for identifying impacts from power plant operation. Selection was based on load ratio, that is, impoundment surface area divided by rated plant generating capacity in megawatt (electrical). The authors assumed that cooling impoundments with low load ratios (relatively little dilution of power plant discharges) would be most likely to exhibit discharge-related water quality and ecosystem effects. Neither low DO concentration nor supersaturation of other dissolved gases was a problem, although oxygen deficits occurred in deeper waters of those cooling ponds that stratified. There was no indication that plant chlorination increased the chloride concentration of closed impoundments. Evaporation from a completely closed pond (no blowdown) resulted in gradual, long-term concentration of inorganic constituents, but levels did not exceed those commonly tolerated by aquatic life.

Potentially more important than the overall increase in TDS is the concentration of specific constituents—for example, heavy metals. The accumulation of heavy metals in cooling ponds via evaporation and bioconcentration has not been identified as a concern by the utilities or regulatory agencies, although specific studies appear to be uncommon. In a survey of 14 cooling impoundments, Becker et al. (EPRI EA-1054) found data on metals for only one. Trace metal concentrations were measured at North Lake, a cooling impoundment in Texas with one of the lowest load ratios in the study. North Lake is a completely enclosed system with essentially no drainage. As a result of high evaporative water losses, water levels cannot be maintained solely by precipitation, so makeup water must be pumped from the nearby Trinity River. In 15 years of operation, the cooling impoundment was refilled about 5.5 times, a situation that should lead to relatively high concentrations of water quality constituents. The North Lake data indicated that trace metals (copper, chromium, iron, lead, manganese, and zinc) were not accumulating in the impoundment, and the levels were too low to be toxic to the ecosystem (Sams 1976). On the other hand, a study of copper concentrations at eight nuclear power plants indicated that the highest chronically elevated concentrations in the discharge waters occurred at the H. B. Robinson Steam Electric Plant Unit 2, a plant with a cooling impoundment (ASTM STP 854). Examination of a variety of factors, including influent water quality and copper specification, led Harrison (ASTM STP 854) to conclude that elevated levels of copper in the H. B. Robinson plant effluent could be attributed to the low-pH water in the region, which caused relatively high leaching of copper from the condenser tubes. The naturally high corrosivity of the water appeared to be the cause of elevated copper concentrations at this plant. The copper-containing tubing was subsequently replaced because of high leakage, eliminating copper loading to the cooling pond [Carolina Power & Light Company response to NUMARC survey (NUMARC 1990)].

Although power plant chlorination may result in the presence of chlorinated organic compounds, the potential accumulation of these materials appears to have been studied rarely. Sams (1976) investigated the possible buildup of total chlorinated organic compounds in the closed cooling impoundment of a fossil-fueled power plant but detected no quantitative differences between the pond and its makeup water source.

The Illinois Department of Conservation has expressed concern about the adverse influence of discharges from the Dresden Nuclear Power Station cooling pond on the temperature and water quality of the Kankakee River (Mark Frech, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, July 2, 1990). EPA has also pointed out that Dresden may have difficulty meeting temperature limits in the future as water quality improves and standards become more stringent (Robert Springer, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, June 29, 1990). With this exception, the effect of operation on water quality is not a concern at the nine nuclear power plants that use cooling ponds as part of their condenser cooling systems. In all cases, the NPDES permits and 316(a) determinations that limit the discharge of heat and other pollutants are periodically reevaluated and renewed by the EPA or state water quality permitting agencies, allowing existing or future water quality issues to be resolved in a timely manner.

The impacts of condenser cooling system discharges on water quality of cooling ponds are considered to be of small significance if water quality criteria (e.g., as contained in NPDES permits) are not violated and if aquatic organisms in the vicinity of the plant are not bioaccumulating metals or other contaminants. Based on review of literature and operational monitoring reports, consultations with utilities and regulatory agencies, and comments on the draft GEIS, degradation of water quality in cooling ponds has not been a problem at most existing nuclear power plants. Mitigation was effective at the one plant that experienced elevated metal levels during the current license period. Effects are considered to be of small significance for all plants. Heat is rapidly dissipated in the vicinity of the power plant so that far-field, cumulative effects would not be expected. No evidence of existing, significant accumulation of contaminants in or near cooling ponds was found in the literature or provided by regulatory agencies. No change in operation of the cooling system is expected during the license renewal term, so no change in effects of discharges on water quality of cooling ponds is anticipated. Effects of discharges to cooling ponds could be reduced by operating additional water treatment systems, greater flushing of the cooling pond/reservoir, or by reducing the plant's generation rate. However, because the effects of discharges on water quality of cooling ponds are considered to be impacts of small significance and because these changes would be costly, the staff does not consider the implementation of these potential mitigation measures to be warranted. Effects of condenser cooling water discharges on water quality of cooling ponds are a Category 1 issue.

4.4.3 Aquatic Ecology

As noted in Section 4.4.2, the concentrations of TDS in cooling ponds averages less than three times that in the makeup water. Such concentrations of most water quality constituents are unlikely to affect aquatic biota. However, elevated levels of particular constituents may be of greater concern. For example, formerly elevated copper concentrations in the effluent from the H. B. Robinson plant (Section 4.4.2) were implicated in increased deformities and reduced reproductive capacity in the bluegill population residing in the cooling pond (NUREG/CR-2822; ASTM STP 854). Harrison and Lam (NUREG/CR-2822) concluded that these sublethal effects were the result of leaching of copper from the condenser tubes by the low-pH water in the pond. Although the highest concentrations of copper in fish tissue were found in bluegills collected in the discharge area, tissue concentrations were also elevated in the intake site compared with an upstream control site. Following replacement of the copper-alloy condenser tubing, fish populations recovered and skeletal deformities disappeared [Carolina Power & Light Company response to NUMARC survey (NUMARC 1990)].

In addition to potential effects from water quality degradation, aquatic biota of cooling ponds may be affected by impingement, entrainment, and thermal discharges. These effects are the same as those considered for once-through cooling systems (Section 4.2.2), except that they mainly influence aquatic communities that did not exist before creation of the cooling pond; natural communities are affected to a lesser extent by the relatively small withdrawals and discharges associated with makeup water and blowdown. In a review of impacts of cooling impoundments of fossil-fuel power plants, Becker et al. (EPRI EA-1054) detected no major detrimental impacts on fish populations from power plant operation. The qualitative effects observed included earlier seasonal spawning and faster growth rates, which the authors attributed to elevated water temperatures. Information was not adequate to determine quantitative power plant effects on fish populations in the 14 impoundments studied. Larimore and McNurney (EPRI EA-1148) compared fish populations of a cooling lake and a nearby noncooling lake. Largemouth bass in the cooling lake spawned earlier, grew faster, were more accessible to anglers in the winter, and had lower rates of parasitic infestation. Parkhurst and McLain (ORNL/NUREG/TM-226) reviewed effects of cooling reservoirs on fish populations. They concluded that (1) effects on game fish populations are generally insignificant or positive but rarely negative, (2) growth rates are generally similar to those of fish from other waters, (3) some species may spawn earlier in the heated environment, (4) many species are attracted to the heated areas during the winter and avoid those areas in the summer, and (5) the thermal tolerances of species inhabiting heated waters are often higher than those for the same species inhabiting ambient-temperature waters.

Consultations with regulatory agencies and nuclear utilities that operate cooling ponds have revealed some site-specific concerns. For example, the Virgil C. Summer Nuclear Station has experienced thermal-discharge-effect-related fish kills in recent summers in and around the heated water discharge bay (James A. Timmerman, Jr., letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, July 2, 1990). These fish kills were localized; they do not appear to have had any adverse effect on the cooling pond population. The utility is investigating the specific causes of the fish kills to implement corrective actions [South Carolina Electric & Gas Company response to NUMARC survey (NUMARC 1990)]. Concerns about biological effects of inadequate in-stream flows below the Wolf Creek Generating Station, particularly during drought years, have been raised (Harold L. Spiker, letter to G. F. Cada, ORNL, Oak Ridge, Tennessee, June 28, 1990). This water-use issue is discussed in Section 4.4.2.1.

The operating experience of nuclear power plants using cooling ponds indicates that impacts on aquatic resources appear to be a function of unique characteristics of the plant or the environment and not generally the result of the cooling system technology. Water-use conflicts (Braidwood, Wolf Creek) and hot weather fish kills (Virgil Summer) could occasionally develop at many fossil-fuel and nuclear power plants. Elevated concentrations of trace metals, which should be most apparent in recirculating cooling ponds, were a concern at only one plant. In this example, elevated copper concentrations in the effluent are believed to have resulted from the leaching of copper from condenser tubing by naturally acidic water; the extent to which buildup of copper in the pond by the recirculation of cooling water also contributed to the subsequent biological effects was not determined. Because effects on the bluegill population have been eliminated by the replacement of the condenser tubing with noncopper alloys, recirculation of residual copper in the cooling pond does not appear to be a problem.

Water quality and aquatic ecology issues for nuclear power plants that use cooling ponds, are summarized in Table 4.4. As noted for power plants with once-through cooling systems in Section 4.2.3.2, operational experience indicates that most early aquatic resource concerns have been found to be of small significance at all sites, and no mitigation measures beyond those implemented during the current term license would be warranted. For the reasons given in Section 4.2.2, these are Category 1 issues. However, entrainment and impingement of fish and thermal discharge effects are of sufficient concern on large cooling ponds that support valued aquatic resources that they continue to be examined in detail as part of CWA Section 316(a) and (b) demonstrations. Section 316(a) or (b) determinations are pending for two of the nine nuclear power plants with cooling ponds (Braidwood and Clinton). Further, changes in aquatic communities of either the cooling ponds or source bodies of water could warrant reexamination of entrainment, impingement, or heat shock effects at any of the plants before the time of license renewal. For some plants, the large volumes of water withdrawn, heated, and discharged back to the receiving water may cause adverse effects to fish populations during the license renewal term. Because impacts of fish entrainment and

Table 4.4 Significance of aquatic resources impacts for license renewal of existing nuclear power plants that use cooling ponds

Issue	Impact significance[a]
Water quality, hydrology, and use	
Water-use conflicts	2
Altered current patterns at intake and discharge structures	1
Altered salinity gradients	1
Temperature effects on sediment transport capacity	1
Altered thermal stratification of lakes	1
Scouring due to discharged cooling water	1
Eutrophication	1
Discharge of chlorine or other biocides	1
Discharge of metals in waste water	1
Discharge of sanitary wastes and minor chemical spills	1
Effects of consumptive water use and riparian communities	2
Aquatic ecology	
Impingement of fish	2
Entrainment of fish, early life stages	2
Entrainment of phytoplankton and zooplankton	1
Thermal discharge effects	2
Cold shock	1
Thermal plume barrier to migrating fish	1
Distribution of aquatic organisms	1
Premature emergence of aquatic insects	1
Stimulation of nuisance organisms (e.g., shipworms)	1
Losses from predation, parasitism, and disease among organisms exposed to sublethal stresses	1
Gas supersaturation (gas bubble disease)	1
Low dissolved oxygen in the discharge	1
Accumulation of contaminants in sediments or biota	1

[a] A 1 means that the impact is expected to be of small significance at all sites. A 2 means that the impact may be of moderate or large significance at some sites.

impingement and of thermal discharge effects could be small, moderate, or large, depending on the plant, these are Category 2 issues for nuclear plants that use cooling ponds.

4.4.4 Terrestrial Ecology

The issue evaluated in this section is the extent to which vegetation and wildlife are affected by increased fogging, humidity, and icing near cooling ponds and by water contaminants that may be present in the ponds. The primary impacts of cooling ponds on terrestrial ecological resources occurred when the ponds were constructed and filled, resulting in flooding and loss of terrestrial plant and animal communities. Potential impacts during plant operation include exposure of terrestrial habitats near the ponds to increased levels of humidity, icing, and fog. Also, waterfowl and other wildlife that use the ponds may be exposed to increased levels of dissolved solids and other contaminants released from the power plant. Fogging, humidity, icing, and the presence of dissolved solids and other contaminants that might be present in or at cooling ponds are of concern if they are present at levels that threaten the stability of local wildlife populations or vegetation communities in the vicinity of the cooling ponds. If there is no threat to the stability of local wildlife populations or vegetation communities, then any impact is considered of small significance.

These potential impacts apparently have not been a problem at any plant with cooling ponds. No significant damage to or loss of vegetation has been reported to result from increased humidity, fog, or icing. Without damage to vegetation, wildlife populations should not be affected. Water quality in the ponds is not being degraded to the extent that aquatic life is adversely affected (Sections 4.4.2 and 4.4.4). Therefore, wildlife using these ponds should not be significantly affected by changes in water quality or by loss of aquatic food or prey. Bioaccumulation of contaminants in the bodies of wildlife predators feeding on aquatic biota is not expected to be a problem because of the very low concentrations of contaminants. Because no threat to the stability of local wildlife populations or vegetation communities is found for any cooling pond, the impacts are found to be of small significance. Potential mitigation measures would include excluding wildlife (e.g., birds) from contaminated ponds, converting to a dry cooling system, or reducing plant output during fogging or icing conditions, the impacts are found to be so minor that consideration of additional mitigation measures is not warranted. These effects of cooling ponds are so minor and so localized that cumulative impacts are not a concern. This is a Category 1 issue.

4.5 TRANSMISSION LINES

Impacts of transmission lines result from their maintenance, electromagnetic fields, corona, and rights-of-way (ROW). Their impacts on air quality (Section 4.5.2), land use (Section 4.5.3), human health (Section 4.5.4), surface water quality and aquatic ecology (Section 4.5.5), terrestrial ecology (Section 4.5.6), floodplains and wetlands (Section 4.5.7), and historic and aesthetic resources (Section 4.5.8) are assessed in this section. As at the construction permit stage, the transmission corridor of concern is that which was constructed between the plant switchyard to its connection with the existing transmission system. No new transmission line construction is planned in existing or new corridors. The types of impacts of transmission lines during the license renewal period will be the same as those during the first 40 years of operation.

4.5.1 Introduction

Transmission lines use voltages of about 115 or 138 kV and higher. In contrast, local or area distribution lines use voltages below 115 or 138 kV. Only transmission lines are discussed in this document. Extra-high-voltage transmission lines operate at 345 to 800 kV, whereas ultra-high-voltage (UHV) lines operate at 1000 kV and above. Lines up to 765 kV, a voltage occurring primarily in the eastern United States, are in commercial operation, whereas UHV lines are still in the testing stage of development. The principal advantage of higher-voltage lines is that they can transmit proportionately more power than can lower-voltage lines.

Detailed descriptions of transmission lines and basic electrical concepts are provided by ORNL-6165, DOE/BP-945, and BNWL-1774. Typical transmission line structures, shown in Figure 4.1, range in height from about 20 to 52 m (65 to 170 ft) and provide average spans (the distance between structures) of about 106 to 350 m (350 to 1150 ft). The structures support a three-phase system of conductors and two ground wires above the conductors. The ground wires intercept lightning strikes to prevent the strikes from hitting the conductors and adversely affecting power system operation. The most common structure types are the H-frame and lattice; single-pole and guyed-Y types are less common. The H-frame is usually made of wood and is used for lower-voltage lines. The metal lattice structure is capable of bearing more weight than the H-frame, allowing greater span length, higher-voltage lines, and more circuits for a given width of ROW.

Transmission lines must be inspected periodically to detect any deterioration of or damage to line components. This inspection can be done from the ground but is often done from a helicopter. Maintenance or repairs of power lines may require that vehicles gain access to the lines.

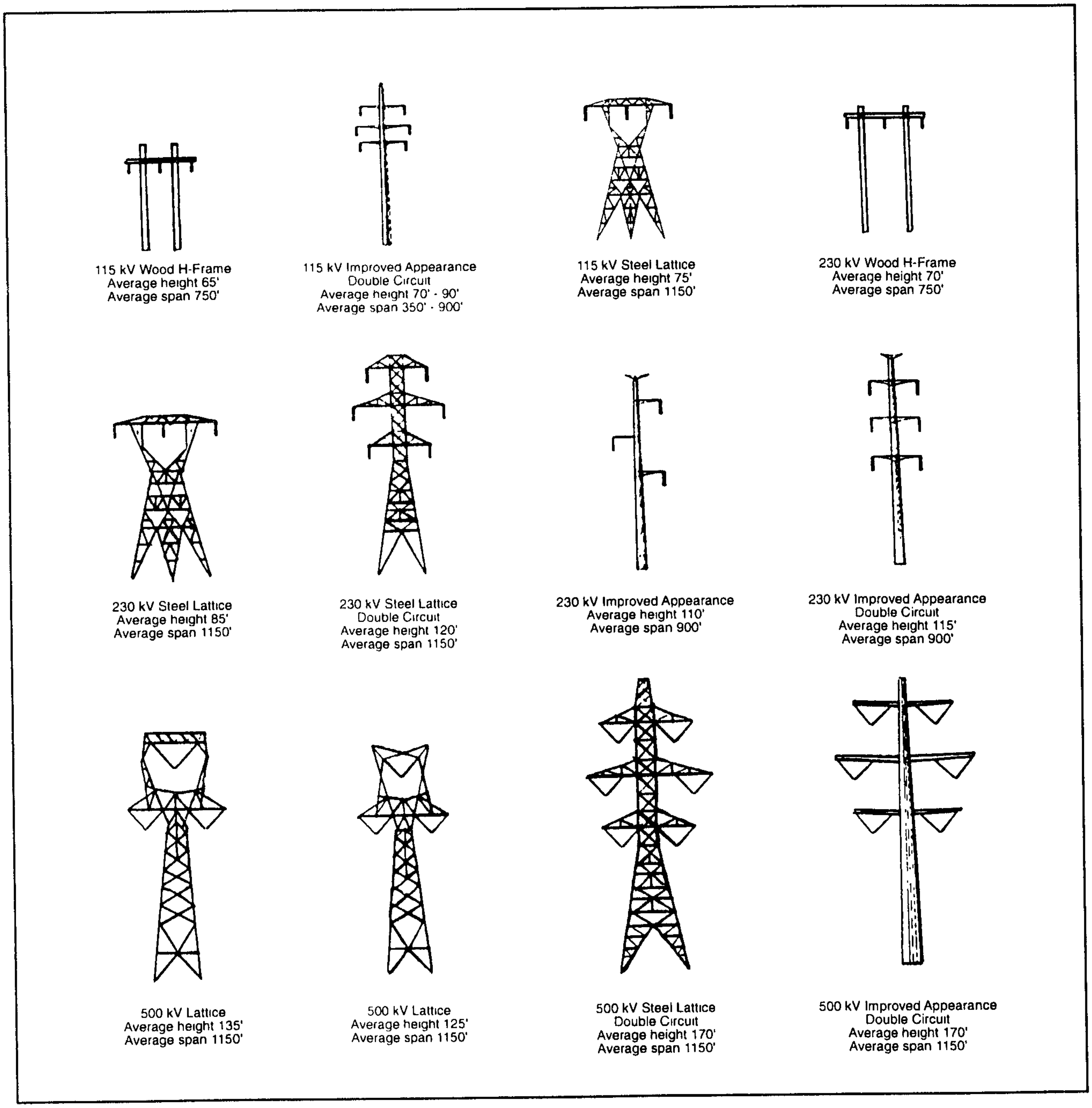
Electric and magnetic fields, collectively referred to as electromagnetic field or EMF, are produced by operating transmission lines. EMF strength at ground level varies greatly under these lines, generally being stronger for higher-voltage lines, a flat configuration of conductors (as opposed to, for example, the delta configuration), relatively flat terrain, terrain with no shielding obstructions (e.g., trees or shrubs), and a closer approach of the lines to the ground. At locations where field strength is maximum, measured values under 500-kV lines often average about 4 kV/m, but sometimes exceed 6 kV/m. Maximum electric field strengths at ground level are 9 kV/m for 500-kV lines and 12 kV/m for 765-kV lines (DOE/BP-945).

Measured magnetic field strengths at the location of maximum values beneath 500-kV lines often average about 70 mG (milligauss). During peak electricity use, when line current is high, the field strength may peak at 140 mG (about 1 percent or less of the time) (DOE/BP-945).

The term "corona" generally refers to the electrical discharges occurring in air subjected to the strong electric fields adjacent to phase conductors. Corona generally is not a problem at voltages below 345 kV. Corona results in audible noise, radio and TV interference, energy losses, and the production of ozone and oxides of nitrogen.

An ROW must be acquired by the utility to prevent certain land uses and vegetation growth from interfering with transmission line operation. To ensure power system reliability, the growth of tall vegetation under the lines must be prevented (by cutting or herbicides) to avoid physical interference with lines or the potential for

ORNL DWG95-7685



115 kV Wood H-Frame
Average height 65'
Average span 750'

115 kV Improved Appearance
Double Circuit
Average height 70' - 90'
Average span 350' - 900'

115 kV Steel Lattice
Average height 75'
Average span 1150'

230 kV Wood H-Frame
Average height 70'
Average span 750'

230 kV Steel Lattice
Average height 85'
Average span 1150'

230 kV Steel Lattice
Double Circuit
Average height 120'
Average span 1150'

230 kV Improved Appearance
Average height 110'
Average span 900'

230 kV Improved Appearance
Double Circuit
Average height 115'
Average span 900'

500 kV Lattice
Average height 135'
Average span 1150'

500 kV Lattice
Average height 125'
Average span 1150'

500 kV Steel Lattice
Double Circuit
Average height 170'
Average span 1150'

500 kV Improved Appearance
Double Circuit
Average height 170'
Average span 1150'

Figure 4.1 Examples of typical transmission line towers. *Source:* DOE/BP-945.

short-circuiting from the line to the vegetation. At the edge of ROW, trees that could topple onto the lines must be removed.

ROW maintenance is described in greater detail by FWS/OBS-79/22, ORNL-6165, BNWL-1774, and Byrnes and Holt (1987).

4.5.2 Air Quality

Small amounts of ozone and substantially smaller amounts of oxides of nitrogen are produced by transmission lines during corona, a phenomenon that occurs when air ionizes near isolated irregularities on the conductor surface such as abrasions, dust particles, raindrops, and insects. Several studies have quantified the amount of ozone generated and concluded that the amount produced by even the largest lines in operation (765 kV) is insignificant (SNYPSC 1978; Scott-Walton et al. 1979; Janes 1980; Varfalvy et al. 1985). Monitoring of ozone levels for 2 years near a Bonneville Power Administration 1200-kV prototype line revealed no increase in ambient ozone levels caused by the line (Bracken and Gabriel 1981; DOE/BP-945). Ozone concentrations generated by transmission lines are therefore too low to cause any significant effects. The minute amounts of oxides of nitrogen produced are similarly insignificant. A finding of small significance is supported by the evidence that production of ozone and oxides of nitrogen are insignificant and does not measurably contribute to ambient levels of those gases. Potential mitigation measures (e.g., burying transmission lines) would be very costly and would not be warranted. This is a Category 1 issue.

4.5.3 Land Use

4.5.3.1 Overview of Impacts

The concerns addressed by this section involve the extent to which license renewal and up to an additional 20 years of plant operation will preclude alternative uses of the transmission line corridor and the relative value that should be placed on such alternative uses. At the time of a license renewal application the transmission corridor and lines will have been in place for well over 20 years, having been initially constructed to furnish power to the site for construction of the plant. Even after cessation of plant operation the transmission line to the site would continue to be used to bring power in to the site during decommissioning. It is likely that a utility would locate new generating capacity on a site and utilize the existing transmission corridor. The site and transmission corridor are valuable assets for the utility. Therefore, the most likely scenario is that regardless of whether a license is renewed it should be anticipated that a transmission corridor will continue in use for the transmission of power indefinitely.

The issue addressed by this section is the extent to which existing transmission lines will, after relicensing, continue to preclude productive use of land or interfere with land uses (e.g., cultivation). Impacts are expected to be no different from those that have occurred during past power line operation. Impacts are described and assessed by reviewing the published literature reporting monitoring data on this topic. No monitoring data on land-use impacts were found that deal with transmission lines specifically associated with nuclear plants. However, because transmission lines associated with nuclear plants are no different from lines associated with other types of generating facilities, literature on any type of transmission line is applicable to the analysis in this section.

The impact of transmission lines on land use resulting from license renewal is considered of small significance if there is no increase in the amount of land committed to the corridor right-of-way and if there are no major changes in the use patterns of the corridor resulting from renewal of the operating license. Alterations in the corridor path could result in impacts of moderate to large significance. Relocating the transmission corridor could result in large land use impacts. There is no basis to believe that any alteration in a transmission corridor would be made in conjunction with license renewal.

The presence of a transmission line and its ROW precludes certain land uses on the ROW that could bring economic gain to the landowner and decreases the profits of forestry, agricultural, orchard, and vineyard operations. However, the landowner has been compensated to some extent for these economic losses by the initial purchase of the ROW easement or, in some cases, by purchase of the land itself.

The construction of buildings or any other permanent structures that could interfere with transmission line operation is usually prohibited on a power line ROW. In contrast, several land uses can occur on ROW without endangering line operation and are usually not restricted by the ROW easement, including hiking, hunting, off-road vehicle use, grazing, agricultural cultivation, irrigation, and roads. Power-line corridors on private property may sometimes increase the frequency of trespassing.

In rural areas, the primary impact on land use is continuing interference with agricultural cultivation, orchards, vineyards, spraying, and irrigation. Some mobile irrigation facilities are very long and may cover an entire field or a large part of the field in one operation (Varner and Patel 1984). The presence of a transmission line structure in such a field may require that the irrigation facility be segmented into two or more independent pieces. Such segmentation increases the labor requirements and the costs of the irrigation facility. Aerial spraying of an agricultural field is restricted by transmission lines; spraying costs may be increased, and the extra maneuvers that the aircraft pilot must make to avoid the lines may lessen the effectiveness of the pesticide coverage.

Impacts on crop production that may have been caused by transmission line interference with aerial spraying have been reported by one field study of cotton, rice, and soybean fields crossed by a 500-kV line in eastern Arkansas (Parsch and Norman 1986). This study hypothesized that crop yields could be reduced either by EMFs (see Section 4.5.6.3) or by inadequate aerial spraying directly under the power lines. Only cotton yields were found to be reduced: 15 percent less lint was produced under the lines than 150 ft from the lines. The resulting loss of income from cotton was estimated as $85.25 per year for an 1100-ft (335-m) span of the lines, based on a 15 percent yield reduction and an average lint yield of 480 lb/acre. The field sampling and statistical analyses were extensive; the observed yield reduction appeared to be real rather than a sampling error. However, the study could not determine whether the EMF or line interference with aerial spraying caused the yield reduction.

The presence of a transmission line structure in any agricultural field, irrigated or not, will continue to exclude land from production and increase the time and money required to perform weed control, cultivation, and harvesting. The major (e.g., 70–90 percent) economic cost results from the exclusion of otherwise productive land from cultivation. The amount of land area affected depends on the structure type and size, the type of crop, and the agricultural practices involved (Grumstrup et al. 1982; EPRI WS-78-141). For lattice-type structures 8 to 9.8 m^2 (26 to 32 ft^2) at the base, the exclusion of productive land varies from about 488 to 976 m^2 (1600 to 3200 ft^2) for each structure. Operations for cultivating some types of crops can be conducted beneath structure bases if the structure is large enough, thus minimizing losses. The presence of guy wires significantly increases the area of land excluded from production, while non-guyed single-pole and H-frame structures have about half as much impact as lattice structures (Grumstrup et al. 1982). Minor additional costs result from the maneuvering necessary for farm machinery to avoid tower legs. Lattice structures and guyed structures interfere more with farming practices than do pole-type structures.

Costs also depend on the relative locations of transmission line structures within fields (Table 4.5). A study of corn, soybean, wheat, oats, buckwheat, and hay fields in Ontario found that the amount of land excluded from production increased in the following order of structure locations: (1) straddling a fence row (minimal impact); (2) adjacent to a fence row; (3) adjoining the headland (the end of the field where the tractor turns) but in the main part of the field; (4) midfield; and (5) within the headland, near, but not adjacent to, a fence row (maximum impact) (EPRI WS-78-141). In tobacco fields, equipment operations differed from those in grain fields, and structures in midfield obstructed cultivation on about twice as much land area as did structures in the headland (Scott 1982). For a variety of grain crops, the economic losses caused by power lines were accounted for by the following factors: time lost—about 30 percent of the costs; land excluded from production—about 60 percent; damaged crop costs—about 2 percent; and material loss—about 8 percent (EPRI WS-78-141). In vineyards, orchards, and tobacco fields, about 75 to 95 percent of the total costs resulted from the continuing exclusion of land from production (EPRI WS-78-141; Scott 1982). In general, the economic losses associated with transmission line structures are closely related to the value of the affected crop, and the percentage of total economic loss resulting from land lost to cultivation is proportionately higher for higher value crops (Scott 1982). Tobacco, orchard, and vineyard crops have relatively high value per acre; grain crops have lower value.

Utilities sometimes locate transmission lines in agricultural areas rather than wooded areas to minimize maintenance costs. Although utilities pay a higher price for ROW on agricultural land, overall costs are minimized by avoiding the higher long-term costs of ROW vegetation maintenance that would be necessary in wooded areas (EPRI WS-78-141).

The potential impact of transmission lines on land use differs among nuclear plants in different geographic regions because land

Table 4.5 Estimated losses in crop profits caused by a lattice structure[a]

Crop	Structure location	
	Midfield	Headland
Tobacco	$356	$132
Peach orchard[b]	95	84
Vineyard[b]	117	53
Wheat	15	—
Soybeans	18	—
Grain corn	25	—
Silage corn	30	—

[a] The currency is the Canadian dollar 1977–1980. The structure is 8.5 × 8.5 m (28 by 28 ft) at the base and its orientation is square to the crop rows as opposed to diagonal to crop rows.

[b] The midfield value is based on not being able to drive equipment under structures and is an average of several midfield variations of structure positioning.

Sources: EPRI WS-78-141; Scott.

uses (e.g., different types of agricultural crops) are different in different regions. The type and extent of the impacts of power lines on land use are relatively well known, and no monitoring of land-use impacts has been done for any specific nuclear plant.

4.5.3.2 Conclusion

There is no basis to believe that the renewal of any operating license will change existing land use in the transmission line corridor either in terms of the amount of land committed or activities taking place within or adjacent to the corridor. For this reason, the staff finds that the impacts of transmission lines on land use attributable to license renewal is of small significance. Ongoing land use impacts would be expected to continue, e.g., constraints on agricultural activity. Although transmission line towers prevent some land from being cultivated or grazed, the amount of land area involved represents only a very small fraction of existing cropland and pasture in the vicinity of transmission lines. Therefore, the reduction in total harvest or livestock production typically has no significant impact on individual farm production or on overall production in larger regions such as townships or counties. The interference with aerial spraying caused by transmission lines can affect an area that is larger than that of the tower site, but the yield in this larger area would not be expected to be reduced by more than a small fraction (e.g., a 15 percent yield reduction in cotton).

The presence of transmission lines does not cause additional permanent loss of farmland (in the sense that farmland is lost, for example, to parking lots and buildings during urban development). Any restrictions on land use within the corridor right-of-way would have been imposed and compensated for as necessary years earlier.

Additional mitigation might require removal of wires, towers, and tower bases so that the entire area previously occupied by towers could be used for farming. Because such mitigation would be costly and would provide little environmental benefit, further consideration of mitigation is not warranted. The significance of any impacts is so minor and localized that cumulative impacts are not an issue. This is a Category 1 issue.

4.5.4 Human Health

The two human health issues related to transmission lines are the acute effect, shock hazard, and the potential for chronic effects from exposure to electric and magnetic fields. As stated previously, the transmission line of concern is that between the plant switchyard and the intertie to the transmission system. Transmission lines are necessary to transfer energy from all types of electrical generating facilities to consumers. Therefore, these issues are generic to the 118 nuclear power plants. Issues are evaluated by referral to the National Electric Safety Code [NESC (1981)] for the shock hazard issue and a review of relevant literature for the issue of potential chronic effects from exposure to the electric and magnetic fields surrounding transmission lines.

EMFs resulting from 60-Hz power transmission lines fall under the category of nonionizing radiation. An example of ionizing radiation is the X-ray. Much of the general population has been exposed to power line fields since near the turn of the century. However, except for the concern about electrical shock from insulated conductors such as fences, there was little concern about health effects from such exposures until the 1960s. A series of events during the 1960s and 1970s heightened public interest in the possibility of non–shock-related health effects from nonionizing radiation exposures and resulted in increased scientific investigation in this area (Wilson et al. 1990). Then, in 1979, results of an epidemiological study suggested a correlation between proximity to high-current wiring configurations and incidence of childhood leukemia (Wertheimer and Leeper 1979). This report resulted in additional interest and scientific research; however, no consistent evidence linking harmful effects with 60-Hz exposures has been presented.

4.5.4.1 Acute Effects (Shock Hazard)

Primary shock currents are produced mainly through direct contact with conductors and have effects ranging from a mild tingling sensation to death by electrocution. Tower designs preclude direct public access to the conductors. Secondary shock currents are produced when humans make contact with (1) capacitively charged bodies such as a vehicle parked near a transmission line or (2) magnetically linked metallic structures such as fences near transmission lines. A person who contacts such an object could receive a shock and experience a painful sensation at the point of contact. The intensity of the shock depends on the EMF strength, the size of the object, and how well the object and the person are insulated from ground.

Design criteria that limit hazards from steady state currents are based on the NESC (1981), adherence to which requires that utility companies design transmission lines so that the short-circuit current to ground, produced from the largest anticipated vehicle or object, is limited to less than 5 mA. In practice, this limits the electric field near roadways to about 7–8 kV/m. No similar code exists for the limitation of the magnetic fields of transmission lines; however, because of concerns about the safety of magnetic fields, several states have created their own regulations. See Nair et al. (1989) for a review of these regulations.)

With respect to shock safety issues and license renewal, three points must be made. First, in the licensing process for the earlier licensed nuclear plants, the issue of electrical shock safety was not addressed. Second, some plants that received operating licenses with a stated transmission line voltage may have chosen to upgrade the line voltage for reasons of efficiency, possibly without reanalysis of induction effects. Third, since the initial NEPA review for those utilities that evaluated potential shock situations under the provision of the NESC, land use may have changed, resulting in the need for a reevaluation of this issue.

The electrical shock issue, which is generic to all types of electrical generating stations, including nuclear plants, is of small significance for transmission lines that are operated in adherence with the NESC. Without review of each nuclear plant transmission line conformance with NESC criteria, it is not possible to determine the significance of the electrical shock potential. This is a Category 2 issue.

4.5.4.2 Chronic Effects

4.5.4.2.1 Results of Ongoing Research

Substantial scientific evidence from laboratory studies funded primarily by DOE and EPRI indicates that extremely low-frequency (ELF) electric and magnetic fields can, under certain conditions, cause biological effects (Wilson et al. 1990; Polk and Postow 1986; Adey and Lawrence 1984; Chiabrera et al. 1985; EPA/600/6-90/005A; Carpenter and Ayraptyan 1994). The importance of these effects for humans who are exposed to transmission line fields is not clear. Perhaps the greatest deficiency in understanding at this time is the lack of a mechanistic theory capable of predicting biological effects from low-level EMF exposures (EPA/600/6-90/005A). Without an understanding of how these EMF fields are interacting with biological functions, the knowledge gained from scientific studies is of limited value both in evaluating the importance of the study results and in devising rational protection strategies for the public and for utility workers.

At exposure levels capable of producing relatively high current densities (10 to 100 mA/m^2), a substantial body of evidence has been accumulated indicating that EMF fields may influence biological function (IRPA/INIRC 1990). Such exposures have been suggested to induce chromosome aberrations, alter the distribution in molecular weights during protein synthesis, inhibit production of melatonin, alter calcium binding in brain tissue, influence RNA transcription, and produce a variety of other effects (OTA-BPA-53 1989). Questions concerning the potential carcinogenic effects of EMF field exposure have been raised as a result of suggestive epidemiological findings and some laboratory experiments. Two currently accepted models of cancer are the initiation-promotion paradigm (Easterly 1981; Stevens et al. 1990). Currently, most investigators conclude that EMF fields are not likely to act as initiators because they have not been shown to cause genetic damage (Aldrich and Easterly 1987). EMF effects on RNA transcription, however, could imply increased reduction of oncogene products, and some investigators consider such data to be indicative of genetic effects (Goodman et al. 1983; Goodman et al. 1987; Goodman and Henderson 1986, 1988). Work is in progress on an attempt to replicate the studies suggesting modification of transcription by EMF. However, attempts thus far have been unsuccessful. Moreover, it has not been shown that EMF fields are cancer promoters, but the presence of some reported EMF bioeffects reveals the need for further study of this issue (Byus et al. 1987; Cain et al. 1986).

The EMF epidemiologic literature has been reviewed extensively (Aldrich and Easterly 1987; Ahlbom; Coleman and Beral 1988; EPA/600/6-90/005A; NRPB 1992). The strongest evidence of an association between certain forms of cancer and exposure to magnetic fields comes from the studies of childhood cancers, namely leukemia, cancer of the central nervous system (CNS), and lymphoma.[1] Several studies have found somewhat elevated, statistically significant risks and elevated nonsignificant risks for these three site-specific cancers in children for whom magnetic fields either have been estimated by the types of wires near their homes or have been measured at 2 mG (0.2 μT) or more. However, there are contradictory results within these same studies, and dose-response relationships could not be substantiated, except in Savitz et al. (1988), based upon limited information on wiring codes. [Savitz and Kaune (1993) have offered an improved analysis of this work.] Furthermore, little information exists on personal exposure and length of residency in the EMFs. Additional but weaker evidence of an association between leukemia, cancer of the CNS, and perhaps cancer of other sites comes from the occupational studies of EMF exposure.

The studies of residential adult exposures to EMFs also provide mixed evidence of a risk of leukemia, mainly because of lack of power or low exposure to levels of EMFs that are hypothesized as being associated with cancer. For the same reasons, these studies cannot be used as support for denying that such an association exists. However, the case control study of cancer in Colorado residents (Wertheimer and Leeper 1982) does support an association with CNS cancer and lymphoma if proximity to high-current electrical wiring configurations is assumed to be an adequate surrogate for exposure.

A careful review of the epidemiological studies involving leukemia, lymphoma, and cancer of the CNS shows a pattern of response that suggests, but does not prove the possibility of, a causal link. Evidence from a large number of biological test systems shows that these fields induce some biological responses in laboratory settings. However, the explanation of which biological processes are involved and the way in which these processes could causally relate to each other and to the induction of malignant tumors is not understood.

4.5.4.2.2 Transmission Line Exposures Relative to Domestic Exposures

An important question regarding regulations is whether transmission line exposures contribute significantly to total EMF field exposures. In most cases, fields produced inside the home by appliances and electrical wiring exceed contributions from transmission line fields. Exceptions to this rule are individuals living adjacent to high-voltage transmission line ROW. Also relevant is the fact that exposures to transmission line fields are considered more continuous than those to appliance fields because transmission line fields permeate large areas (e.g., an entire home). Fields generated by appliances are generally more localized, resulting in intermittent exposures as individuals move around and as the appliances are turned on and off.

Some comparisons (of induced currents) among transmission line exposures, domestic exposures, and exposures used in bioeffects experiments can be made using induced current density as an exposure metric. According to data provided in OTA-BPA-53, field strengths on the ROW of a 500-kV line induce body currents that are higher than those induced by domestic exposures produced by typical electrical appliances. Comparison with bioeffects experiments (OTA-BPA-53) shows that while current densities in many bioeffects experiments are higher than those typically induced by household exposures, some are significantly less. These comparisons are based, however, on average current densities predicted in humans, because EMF dosimetry has not advanced to the point of determining specific current densities in various tissues and organs. Nor has mechanistic understanding identified what field characteristics are important biologically.

4.5.4.2.3 Conclusion

Potential chronic effects are unquantified at this time. Subsequent to the 1992 National Energy Policy Act, a sequence of events relative to ELF research took place. The National Institute of Environmental Health Sciences (NIEHS) was made responsible for directing the EMF biological research funded through the Department of Energy. To oversee policy and general direction of this research, a National EMF Advisory Committee was assembled. Both the EPA and the National Institute for Occupational Safety and Health now maintain EMF hotlines, yet NIEHS has taken the position that the NIEHS has the sole responsibility for declaring whether a hazard exists and the magnitude of that hazard. Federal regulations are not anticipated in the near future, but some states have developed and other states are in the process of developing pertinent ambient field levels at ROW boundaries.

A careful review of the biological and physical studies of 60-Hz EMFs has failed at this time to uncover consistent evidence linking harmful effects with field exposures. EMF fields are unlike other agents that have a toxic effect (e.g., toxic chemicals and ionizing radiation) in that dramatic acute effects cannot be forced and longer-term effects, if real, are subtle. Nonetheless, a wide range of biological responses have been reported to be affected by EMF fields.

Even if clear adverse effects were apparent in the epidemiology literature or with some biological assay, considerable additional work would be required to determine how and what to mitigate, because evidence suggests that some EMF bioeffects do not follow the typical "more intensity is worse" relationship. Furthermore, there may be a subtle relationship between the intensity of the local geomagnetic field and the appearance of effects for some intensities of 60-Hz fields. This complicating evidence points to the fact that, while much experimental and epidemiological evidence has been accrued, the pieces still do not fit together very well.

Because of inconclusive scientific evidence, the chronic effects of EMF could not be categorized as either a Category 1 or 2 issue. NRC will continue to monitor the research initiatives, those within the national EMF program and others internationally, to evaluate the potential carcinogenicity of EMF fields as well as other progress in the EMF study disciplines. If NRC finds that a consensus has been reached by appropriate federal health agencies that there are adverse health effects, all license renewal applicants will have to address the health effects in the license renewal process.

4.5.5 Surface Water Quality and Aquatic Ecology

A basic concern with right-of-way and service road maintenance is the effect that such maintenance activities may have on the health of nearby aquatic ecosystems. The effects are considered of small significance if there is no measurable change in species diversity, abundance or health within the aquatic ecosystem. An effect of moderate significance is defined as one resulting in reduced abundance or health of one or several species that may eventually lead to the demise of the species. An effect of large significance is defined as one resulting in the loss of any species on which a high recreational or commercial value is placed or the collapse of the existing ecosystem.

Potential effects of transmission lines on aquatic resources would arise mainly from water quality impacts associated with maintaining power line ROW and service roads. Where roads cross or border on surface waters, soil erosion could cause elevated turbidity and sedimentation. Appropriate control techniques (e.g., grassed or wooded buffer strips between the road and the body of water) will minimize impacts. Because ROW are normally maintained by mowing or selective application of herbicides (Section 4.5.1.4), soil erosion from power line corridors should not normally be a problem. Potential toxic effects of herbicides that are applied to power line ROW and subsequently transported to surface waters should be considered in the maintenance program. By using herbicides approved for ROW use in accordance with FIFRA, significant adverse effects of herbicides are avoided. Mowing and other activities needed to maintain transmission line corridors are readily controllable to minimize impacts to aquatic resources. These activities are not expected to change during the license renewal term.

Changes in any affected aquatic ecosystem due to construction and maintenance practices will have taken place long before consideration of license renewal. Ongoing management practices with respect to controlling soil erosion and the proper application of herbicides will continue over the term of a renewed license. The aquatic ecosystem is expected to be unaffected by license renewal with no measurable change in species diversity, abundance or health. The effect of transmission lines on surface water quality and aquatic ecology is then of small significance. The continued use of proper management practices with respect to soil erosion and application of herbicides is expected. Impacts of any transmission lines on aquatic ecosystems over a larger geographic area or over time will be stable and not cumulative. The effect of transmission line right-of-way maintenance on surface water quality and aquatic ecology is a Category 1 issue.

4.5.6 Terrestrial Ecology

This section evaluates the impacts of ROW management on wildlife (Section 4.5.6.1); the impacts of bird collisions with transmission lines (Section 4.5.6.2); and the impacts of EMFs on plants, wildlife, and livestock (Section 4.5.6.3).

4.5.6.1 Impacts of ROW Management on Wildlife

The extent to which wildlife populations are affected by vegetation control on transmission line ROW is the issue evaluated by this section. The effects of ROW management in the transmission corridor during the license renewal term are considered of small significance if habitat diversity remains the same as that of the surrounding area, or is increased, while species population declines (if any) in the surrounding habitat are small. The significance of the impact is evaluated by a review of the voluminous published literature on this topic. Numerous scientific papers published mainly during the late 1970s and the 1980s were reviewed for this analysis. Data are not available for lines associated specifically with nuclear plants, but the literature applies to such lines because the same methods for ROW management are used for transmission lines associated with any type of generating facility. This issue was addressed by NRC environmental impact statements for the construction permit stage and the operating license stage.

Most data on the impacts of power line corridors on wildlife are for relatively moist areas of the United States where vegetation growth is rapid and vegetation must be controlled to prevent its interference with the transmission lines. In arid regions, little or no vegetation control is required, and the potential effects on wildlife are small. Potential effects are also small where lines cross croplands, because no vegetation management is required. The following discussion is therefore applicable primarily to forested regions where the utility must conduct vegetation control on transmission line ROW.

Broadcast spraying of herbicides and mowing of the entire corridor have greater periodic impacts on wildlife than do selective cutting or selective application of herbicides. Mowing reduces the vegetation on the ROW to a low stubble, and the remaining vegetation or the regrowth the first year after cutting provides little food or cover for wildlife. As a result of the reduced vegetation, populations of the primary species of birds that nest on a transmission line ROW have been shown to be reduced. Mammal populations may also be reduced, although few data have been collected to show such an impact. Resprouting and regrowth of vegetation on the ROW is usually rapid after cutting. If the vegetation is cut only once every 4 years rather than annually, it usually develops into a dense mixed growth of shrubs, shrub patches, saplings, forbs, and grasses. Bird populations increase along with the vegetation until the next mowing, when the cycle begins again (de Waal Malefyt 1984; Everett et al. 1981; Kroodsma 1982).

Broadcast spraying of herbicides is also done on a periodic basis and causes a cyclic effect on wildlife. However, spraying often kills entire plants, and resprouting is less common. Therefore, after a number of spraying cycles, some plant species are greatly reduced in abundance on the ROW. The resulting plant community consists of herbicide-resistant species and is often not very diverse. Grasses, ferns, and relatively few species of shrubs are usually the dominant vegetation. Correspondingly, the wildlife community has relatively few species and low population densities, and bird-nesting success in grass and forb areas on ROW has been observed to be low. Therefore, from the wildlife perspective, broadcast spraying is usually considered the least desirable vegetation maintenance technique. Annual mowing could have an effect similar to broadcast spraying but is seldom if ever used as a routine management technique for transmission line ROW (Cavanagh et al. 1976; Chasko and Gates 1981, 1982; de Waal Malefyt 1984; Hartley et al. 1984). Broadcast spraying of herbicides on some ROW that currently is mowed may become necessary if woody vegetation becomes too dense, as in ROW through mesophytic forests where forest regeneration is rapid (Luken et al. 1991).

Selective cutting or spraying of vegetation has less impact on wildlife because low-growing shrubs and other vegetation are left undisturbed and provide good wildlife habitat. Selective techniques are labor-intensive and thus may be more expensive than broadcast spraying or mowing. A primary goal of these selective techniques is to eliminate undesirable plant species from the ROW while keeping those that provide good wildlife habitat and that will not interfere with the power lines. Cutting and spraying are often combined because cut stems must often be sprayed to prevent resprouting and thus eliminate the plant. As the desirable plant species begin to dominate the ROW, they gain a competitive advantage and help to prevent the reestablishment of undesirable plants; thus, the long-term vegetation maintenance costs may be reduced (FWS/OBS-79/22, Luken et al. 1994).

Herbicides are generally not highly toxic to wildlife when they are properly applied for ROW management. Therefore, toxic effects of herbicides on wildlife are generally of little concern to wildlife biologists or wildlife managers. Of the many papers reviewed for this analysis, none expressed serious concern for toxic effects.[2] Rather, herbicide effects on wildlife have been shown to result from the vegetation changes that occurred as a result of herbicide application.[3] Changes in vegetation on an ROW or in any other habitat always cause changes in the wildlife community, whether the vegetation is cut or modified by herbicides. As in the case of cutting, herbicide effects on vegetation are usually beneficial to some wildlife species and detrimental to others. The literature referenced above shows that, as long as a diverse plant community remains on herbicide-treated ROW, a diverse wildlife community will also be present.

The maintenance of ROW vegetation as a low-growing plant community results in an ROW wildlife community that is characteristic of such vegetation. This wildlife community has some species of small mammals and birds that are not present in the natural plant communities bounding the ROW. Therefore, the presence of the ROW vegetation adds to the number of wildlife species found in the area. In addition, the ROW provides food and cover for many species of animals that were already present before line construction.[4] Forest edge along the ROW as well as along other open areas may provide some benefit to wildlife, but benefits of such an edge appear to have been overrated (Chasko and Gates 1982; Kroodsma 1984a, 1984b, 1987; Reese and Ratti 1988; Small and Hunter 1989).

The presence of the transmission line and its cleared corridor is apparently not a great disturbance to any wildlife species. Based on all of the literature reviewed, no wildlife species is known to have disappeared from habitats adjoining the corridors after line construction. Some species, however, are less abundant in the forest near the corridor than in the deeper forest, indicating avoidance of the transmission lines and/or the corridor (Kroodsma 1984b, 1984c). Because these species also appear to avoid other types of clearings (e.g., croplands or pasture), the openness of the corridor appears to be the feature being avoided, not the line itself. Predation on eggs and nestlings of forest birds has been observed to be greater near the forest/corridor edge than in the deeper forest and may be one factor responsible for some species appearing to avoid or to be less dense near the corridor (Chasko and Gates 1981, 1982).

The overall effect on wildlife of a transmission line corridor located within a forest appears to be an increase in the number of species present in the total corridor and forest area, while some populations of forest species are slightly lower as a result of the corresponding decrease in amount of forest habitat. Some bird and mammal species that inhabit grassy or brushy habitats are added to the area and are responsible for the increase in the number of species. At the same time, all other forest species remain in the area, and some find improved cover or food resources in the ROW. Population declines in forest species are usually small because the ROW is narrow and occupies only a small fraction of a forested area.

A current concern among ornithologists is the high degree to which forested habitats are being fragmented into smaller and smaller areas as a result of clearing for agriculture and urbanization. This fragmentation appears to be at least partly responsible for significant declines in the populations of many migrant bird species (Small and Hunter 1988; Yahner and Scott 1988). Transmission line corridors, probably because of their narrowness, have not been noted as a significant factor in forest fragmentation impacts on birds.

Where corridors cross particularly important wildlife habitats, impacts may be of greater concern. Impacts on winter habitats of certain big game animals were a particular concern. However, impact studies done for deer wintering yards in the northeastern United States and southeastern Canada (Jackson 1980; Willey and Marion 1980; Doucet et al., 1983, 1987), deer in winter habitats in the Northwest (Loft and Menke 1984), and elk winter habitats in the West (Nelson 1986) showed no significant impact.

Although animal population density is cyclic in response to vegetation changes in ROW, over the long term (i.e., over many cycles) the populations appear relatively stable, with no species being significantly affected. The overall impact of transmission line corridors, based on an extensive literature, appears to be neither significantly adverse nor significantly beneficial. The consensus among wildlife biologists appears to be that cleared transmission line corridors and their maintenance do not have significant adverse impacts and that corridors provide valuable wildlife habitats if properly managed. Of the papers reviewed for this GEIS, none was found that identified any impact of transmission line corridors on wildlife that was of great concern to the authors. The evidence supports a conclusion that continued ROW management during the license renewal term will not lower habitat diversity or cause significant changes in species populations in the surrounding habitat. Thus the impacts are of small significance. The only potential mitigation measure would be relocation of the transmission lines to less sensitive areas, but this would not be warranted due to the small benefit and high capital cost of such actions. No mitigation measures beyond those implemented during the current term license would be warranted and little potential for cumulative impacts is indicated. This is a Category 1 issue.

4.5.6.2 Avian Mortality Resulting from Collisions With Transmission Lines

Numerous studies have been published of avian mortality resulting from collisions with transmission lines and other man-made objects. The issue is whether collision mortality is large enough to cause long-term reductions in bird populations. The analysis of this issue is based on published literature addressing bird collisions with all types of man-made objects and applies to all transmission lines regardless of the type of generating facility. Monitoring data collected at one nuclear plant, Prairie Island, are also summarized.

Avian mortality resulting from collisions with transmission lines is of concern if stability of local populations of any bird species is threatened or if the reduction in the numbers within any bird population significantly impairs its function within the ecosystem. Avian mortality resulting from collisions of birds with transmission lines is considered to be of small significance if there is no threat to the stability of local populations of any species and if there is no noticeable impairment of its functioning within the local ecosystem.

Many millions of birds die each year from natural causes, and millions are killed each year in the United States as a result of colliding with windows of houses and other buildings, radio and TV towers, vehicles, transmission and distribution lines, telephone lines, cooling towers, smokestacks, and many other man-made objects. Numerous papers have reported the more noticeable, sometimes spectacular, kills that have occurred at radio and TV towers and at transmission lines located near lakes or wetlands where birds are concentrated.[5] Large bird kills at radio and TV towers occur at night during spring and fall bird migration and involve primarily passerine birds (songbirds) that appear to be confused by tower lights (Crawford 1981; Larkin 1988; Maehr et al. 1983; Taylor and Kershner 1986). These lights, during conditions of low clouds or fog, create a surrounding area of diffuse light that flying birds are reluctant to leave, with the result that the birds fly in circles around the towers. Thus, these birds run a high risk of colliding with the towers' guy wires. In contrast, kills along transmission lines involve a greater fraction of heavier, less agile birds such as waterfowl and cranes. Inclement weather is often a contributing factor in transmission line kills; lights are not a contributing factor, because they generally are not used to mark transmission lines.

It is unknown to what extent avian populations decline as a result of collision mortality of all types or mortality associated specifically with transmission lines. Several authors have concluded that the mortality caused by transmission lines in their studies did not cause a significant reduction in the bird populations located in their study areas. However, some of these authors expressed concern for cumulative impacts (Beaulaurier et al. 1984; Faanes

1987; Meyer and Lee 1981). Cumulative impacts would accrue as migratory birds such as waterfowl migrate to different areas and are exposed to additional lines, whereupon more collisions occur and total mortality continues to increase.

A few authors have also pointed out that bird mortality along the many thousands of miles of transmission and communication lines in the United States is probably of greater significance than the more noticeable kills in certain transmission line locations where birds are concentrated (Avery 1981; Willard and Willard 1978). The amount of bird mortality in nonwetland areas or in areas of average bird numbers has received little study because the individual bird kills are spread out over long distances and are hard to find. Therefore, accurate estimates of the total bird mortality caused by transmission lines do not exist, and the significance of transmission line collision mortality with regard to long-term population effects cannot be accurately assessed.

Overall, relatively little concern about bird collision mortality has been expressed in the literature. Generally, collision mortality has appeared to be only a small fraction of total mortality and therefore has not been considered to have significant population impacts. Banks (1979) estimated that human activity and bird collisions with man-made structures resulted in the deaths of about 196 million birds per year or 1.9 percent of the total bird mortality (about 10 billion per year) in the continental United States. About 63 million of the estimated 10 billion annual bird deaths (i.e., 0.63 percent) resulted from collision with all types of man-made structures. The transmission line impact would be a fraction of this estimate. Stout and Cornwell (1976) reported on waterfowl mortality. They estimated that about 0.07 percent of the nonhunting waterfowl mortality resulted from collisions with lines, including transmission, distribution, and telephone lines. These estimates, which are essentially all that is available in the literature, suggest that transmission lines do not pose a serious threat to avian populations. Banks (1979) states that most of the human-related mortality is accounted for by relatively few species and that these species maintain large, harvestable populations. This, as Banks pointed out, suggests that human activities do not significantly affect most bird species. Banks concluded that "activities of man that do not necessarily result in the death of birds but rather reduce reproductive potential, such as habitat alteration and environmental contamination, are much more likely to have long-term effects on avian populations."

More recent literature on bird collision mortality has not raised strong concerns that the Banks (1979) and Stout and Cornwell (1976) estimates are too low. However, Avery (1981) pointed out that collision mortality may be significantly higher than Banks' estimate of 63 million. He states that the primary source of collision mortality appears to involve the millions of miles of transmission and communication lines and the billions of glass windows throughout the country. He cites collision mortality estimates higher than Banks' estimates (e.g., 80 million bird deaths annually from collision with windows), but a lack of information prevented him from estimating mortality resulting from collisions with transmission lines. No study reviewed for this GEIS has suggested that collision mortality is a significant factor in reducing the populations of common bird species.

Several reports have suggested that rare species sometimes could be significantly affected by transmission and communication lines, particularly if the lines passed through an area where such species were concentrated (Faanes 1987; ORAU-142, 1978c; Meyer and Lee 1981; Willard and Willard 1978). For example, A. J. Crivelli et al. (1988) surveyed Dalmatian pelican mortality resulting from collision with a line through a pelican wintering area. They concluded that this mortality would result in a 1.3 to 3.5 percent reduction in the number of pelican breeding pairs in Greece and Bulgaria. Whooping cranes, an endangered species in the United States, have collided with power lines on at least 10 occasions according to Faanes (1987). The principal known cause of death for wild fledged whooping cranes is collision with power lines (Morkill and Anderson 1991). Several papers reviewed by Kroodsma (ORAU-142, 1978b) reported that 10 percent of the known mortality of bald eagles from 1960 to 1972 apparently resulted from collisions with some object, frequently a transmission line. Willard and Willard (1978) reported that 4 out of 200 nesting female white pelicans in a small Oregon population died from collisions with transmission lines and considered this mortality to be a significant impact on a small, threatened population.

Several studies have reported on relatively large collision kills where transmission lines crossed wetland areas being used by large concentrations of birds (Anderson 1978; Beaulaurier et al. 1984; Faanes 1987; ORAU-142, 1978c; Malcolm 1982; Meyer and Lee 1981; Rusz et al. 1986). Although the authors were concerned about the mortality, most of them reported that the data indicated the mortality was a small fraction of the number of birds present and that the local bird population was not significantly affected. The case reported by Malcolm (1982) appears to involve the greatest collision mortality.

Two additional studies reported collision-caused deaths of sandhill and whooping cranes, two species that appear particularly susceptible to collision with transmission lines. In the San Luis Valley, Colorado, 78 sandhill cranes and 3 whooping cranes collided with lines during the fall and spring in 1983 and 1984, as reported by W. M. Brown et al. (1985). Whooping cranes were the most frequent casualty in proportion to their abundance (13 to 29 birds observed at various times). These authors also reported that at least eight other whooping cranes in the Rocky Mountain population struck transmission lines from 1977 to 1985. In Idaho, in an area where nine pairs of sandhill cranes were observed nesting, three sandhill cranes and one whooping crane collided with lines during the first year after line construction (Howard et al. 1985).

Sandhill crane mortality in general from 1978 through 1985 was reviewed by Windingstad (1988). Known mortality was as follows: toxins (e.g., from moldy corn and waste peanuts)— approximately 5550 cranes; hail storm (1 occurrence)—600; avian botulism—150; avian cholera— 125; lightning (1 occurrence)—90; collision with transmission lines—5 occurrences reported, the worst resulting in 51 carcasses at a line crossing the Platte River near a crane roost site (numbers in the other four occurrences were not reported); unknown cause—8; lead poisoning—4, avian tuberculosis—1; and predators—1. Despite this extensive mortality in sandhill cranes, their midcontinent population has increased dramatically during the past few decades.

Modification of existing transmission lines has been investigated to reduce collision mortality in localities where relatively large kills occur. The most promising modifications include removal of the ground wires in the most critical locations or placing markers on the ground wires to make them more visible to birds. Such markers include black-and-white ribbons, orange aviation marker balls, plastic spirals, and spiral vibration dampers (Alonso et al. 1994; Brown et al. 1985; Faanes 1987; Morkill and Anderson 1991; ORAU-142, 1978d). For example, Alonso et al. found that colored PVC spirals installed on groundwires reduced bird collisions by 60 percent, and Morkill and Anderson found that yellow aviation balls installed on groundwires reduced sandhill crane collisions by 56 percent.

No relatively high collision mortality is known to occur along transmission lines associated with nuclear power plants in the United States other than the Prairie Island plant in Minnesota. This plant is located on the Mississippi River southeast of Minneapolis and may be the only nuclear plant where surveys were done to find birds that collided with off-site lines. The plant's 1978 annual report presented a 5-year study of bird collisions with transmission lines near the river. Counts were conducted by walking several transects, usually on a weekly basis from April 22 through May 27 from 1974 through 1978. A total of 453 birds were found over the entire 5-year period of observation, primarily passerines (songbirds), mourning doves, ring-necked pheasants, and American coots. Waterbirds included 11 sora rails, 8 wood ducks, 3 mallards, 2 black ducks, 1 great blue heron, 1 ruddy duck, and 1 hooded merganser. No raptors were found. Most collisions apparently occurred during inclement weather. Scavengers probably removed many bird carcasses before they could be found.

Available literature on transmission line collision mortality is insufficient to determine conclusively whether bird populations are being significantly affected. Rather, existing data suggest that transmission lines associated with nuclear plants are probably responsible for only a small fraction of total collision mortality for transmission and distribution lines in general. Also, existing literature suggests that total collision mortality (cumulative impacts) associated with all types of man-made objects is not reducing bird populations significantly.

Based on (1) the fact that existing literature does not show significant impacts of collision mortality on overall species populations and (2) the lack of known instances where nuclear-plant lines are affecting large numbers of individuals in local areas, the staff concludes that the mortality resulting from bird collisions with transmission lines associated with license renewal and an additional 20 years of operation will not cause long-term reduction in bird populations and thus will be of small significance. Further, little potential for significance due to cumulative impacts is indicated. Finally, the modification of transmission lines would not be warranted because the impact is so small and such mitigation measures would be costly. This is a Category 1 issue.

4.5.6.3 Impacts of Electromagnetic Fields on Flora and Fauna

The effects of electromagnetic fields on terrestrial biota are considered to be of small significance if the overall health, productivity and reproduction of individual species appears unaffected.

The EMFs produced by operating transmission lines up to 1100 kV have not been reported to have any biologically or economically significant impact on plants, wildlife, agricultural crops, or livestock (DOE/BP-945; Miller 1983). Areas under and in the vicinity of the lines have been studied numerous times. Vegetation, foliar damage due to EMF-induced corona at leaf margins, agricultural crop production, wildlife population abundance, livestock production, and potential livestock avoidance of the lines have been investigated. Also, many laboratory experiments with plants and laboratory animals have been conducted, often using electric fields much stronger than those occurring under transmission lines.

4.5.6.3.1 Plants

Studies have shown that minor damage to plant foliage and buds can occur in the vicinity of strong electric fields. For example, tree foliage and buds that are close to transmission lines can be damaged and upward or outward growth of branches can be reduced. Damage typically occurs only to the tips and margins of leaves in the uppermost plant parts that are the closest to the lines. The damage in the form of a leaf burn is most prevalent on small pointed leaves and is similar to leaf damage that might occur as a result of drought or other environmental stresses. The damage generally does not interfere with overall plant growth (Miller 1983).

The damage is thought to result from heating caused by induced corona at the leaf tips and margins. The electric field is greatly focused by leaf points or marginal teeth, thus increasing its strength to the point that corona (Section 4.5.1.3) occurs. Night-vision instruments have shown this corona as a glow of light concentrated at leaf tips and margins. The damage apparently does not extend to lower levels of the plant because the electric field weakens with distance from the lines and because the upper plant parts shield the lower parts from the electric field.

In one experiment under an 1100-kV prototype line, the upward growth of alder and Douglas fir trees was reduced by this damage, with the result that the crowns of the trees became somewhat flattened on top and the overall crown developed a broader appearance than usual (Rogers et al. 1984). The growth of the lower parts of the trees and of lower-growing plants such as pasture grass, barley, and peas appeared unaffected (Rogers and Hinds 1983). In another experiment, 50-kV/m fields had no apparent effect on corn germination or the growth of corn seedlings; and the growth of corn, bluegrass, and alfalfa apparently was not affected by fields of 25–50 kV even though minor damage occurred to the outer fringes of the uppermost leaves (Bankoske et al. 1976). Germination of sunflower seeds in a 5-kV/m electric field was reduced by about 5 percent in some cases [4 out of 11 replicates (Marino et al. 1983)]. An experiment with several species of agricultural plants found that a maximum of about 1 percent of the total plant tissue was damaged by exposing the plants to 50-kV/m fields (Poznaniak and Reed 1978).

Lee (DOE/BP-945) reviewed several papers reporting studies in Indiana, Tennessee, and Arkansas. The productivity of corn and other crop plants was not affected by electric fields of 12 to 16 kV/m under a 765-kV line and a UHV test line in Indiana, although plants under the larger line suffered some leaf tip damage from induced corona. Corn production in Tennessee may have been reduced by electric fields up to 8.5 kV/m, but the authors indicated the results were inconclusive. An Arkansas study found normal yields of rice and soybeans but a 15 percent reduced yield of cotton beneath a 500-kV line (see Section 4.5.3). The researchers could not determine whether the reduced cotton yield resulted from electric field or ineffective aerial application of agricultural chemicals beneath the line.

4.5.6.3.2 Honeybees

Several studies have shown that honeybees in hives under transmission lines are affected by EMF (EA-4218; Rogers and Hinds 1983; Warren et al. 1981). Adverse effects include increased propolis (a reddish resinous cement) production, reduced growth, greater irritability, and increased mortality. These effects can be greatly reduced by shielding the hives with a grounded metal screen or by moving the hives away from the lines (Rogers and Hinds 1983; Lee 1980). V. P. Bindokas et al. (1988) showed that these impacts were not caused by direct effects of the electric fields on the bees but by voltage buildup and electric currents within the hives and the resultant shocks to bees. Bees kept in moisture-free nonconductive conditions were not adversely affected, even in electric fields as strong as 100 kV/m.

4.5.6.3.3 Wildlife and Livestock

Chronic exposure to EMF is experienced by small birds and mammals that primarily inhabit ROW corridors and by birds (primarily raptors) that nest in transmission line towers. EMF exposures to larger animals and livestock are usually relatively brief because these animals inhabit relatively large areas instead of small areas beneath the lines. Exposures occur as these larger animals pass beneath the lines or as birds fly by the lines.

The voluminous literature on population studies of small bird and mammal species in transmission line corridors (Section 4.5.6.1) has expressed virtually no concern for possible impacts of EMF. These species apparently thrive underneath the lines, where their abundance appears to depend on habitat quality rather than on the strength of the electric fields to which they are exposed or the size of the line. For example, the density of breeding birds under 500-kV lines in eastern Tennessee is greater than that in adjacent forests (Kroodsma 1984c, 1987) and appears to be greater than bird density in most grassland habitats or agricultural fields. Also, the density of small mammal populations near these lines appears to depend on habitat type rather than on the presence of the lines (Schreiber et al. 1976). A Minnesota study of a 500-kV line found little evidence of either a positive or negative effect of the power line on bird populations (Niemi and Hanowski 1984). Bird and small mammal populations under an 1100-kV line in Oregon were also apparently unaffected by line operations (Rogers and Hinds 1983). Habitat use by elk in western Montana was apparently unaffected by operation of a 500-kV line, as the elk used habitats along the power line in proportion to their availability (DOE/BP-1136).

Raptors, ravens, and some water bird species frequently nest and perch on transmission line towers, particularly in grassland areas where other suitable nest sites are lacking.[6] Thus, the birds are able to use habitats without suitable nest sites—habitats that they otherwise would not have used (Gilmer and Stewart 1983; Williams and Colson 1989). On high-voltage lines supported by metal lattice towers, the birds usually nest on the top (bridge) of the tower where the strength of the electric field is minimal (e.g., 5 kV/m or less) (Lee 1980). Lee found 80 percent of 110 nests on towers to be located on the tower bridge and cited previous studies that showed similar results.

The success of these tower nests in producing young appears to be no different from nests located in areas not exposed to EMF. In central North Dakota, 113 ferruginous hawk nests in high-voltage transmission line towers (18 percent of a total of 628 nests found) had a higher success rate (87 percent) than nests in other locations (however, a hail storm that missed the lines reduced the success of some other nests). The number of fledglings per occupied nest was 2.8 for ground nests (which were larger than tower or tree nests), 2.6 for tower nests, 2.3 for haystack nests, and 2.0 for tree nests (Gilmer and Stewart 1983). In Idaho, Steenhof et al. (1993) studied nesting success of ravens and raptors on a 576-km (370-mile) segment of 500-kV transmission line constructed in 1981. From 1981 through 1989 (the last year reported by Steenhof et al.), the numbers of these species nesting on transmission towers increased to 133 pairs, including roughly 64 percent common ravens, 21 percent red-tailed hawks, 9 percent ferruginous hawks, 6 percent golden eagles, and 0.3 percent great horned owls. Nesting success of these birds averaged 65 percent to 86 percent and was similar to or better than that of the same species nesting on other substrates. Lee (1980) reported finding 110 hawk and raven nests on 260 miles of 230-kV and 500-kV lines of the Bonneville Power Administration. Although the success of these nests was not monitored, the author reported that, based on a literature review, it was unlikely that nesting would be adversely affected by EMF found in most locations in transmission line towers.

Livestock in both field and laboratory studies have shown no significant impacts when exposed to EMF. In DOE/BP-945, J. M. Lee reviewed about 10 reports on effects of transmission lines on livestock in the United States and Sweden. These studies found no evidence that the growth, production, or behavior of beef and dairy cattle, sheep, hogs, or horses were affected by EMF. The studies involved 11 farms along a 765-kV line in Indiana, 55 dairy farms near 765-kV lines in Ohio, 36 herds of cattle near 400-kV lines in Sweden, a mail survey of 106 farms in Sweden, a study of fertility of 58 cows under a 400-kV line in Sweden compared with 58 in a control area, 30 swine raised beneath a 345-kV line in Iowa compared with 30 raised in a control area, and cattle behavior under an 1100-kV prototype line in Oregon. Cattle under the 1100-kV test line in Oregon were startled by the first occurrence of corona noise when the line was reenergized after a shutdown period (Rogers and Hinds 1983). From 1977 through 1981, grazing of cattle in pasture under the line appeared to be unaffected by line operation. In 1980–81, the cattle spent more time near the line during periods when it was deenergized than when it was operating, but spent an increasing amount of time under the line when it was operating as the growing season progressed (Rogers and Hind 1983).

In the Indiana study (Amstutz and Miller 1980), performance of livestock frequently under a 765-kV line on 11 farms was studied during a 2-year period (1977–1979; 9 farms participated for the full 2 years). Animals included 10 horses, 55 sheep, 149 beef cattle, 337 hogs, and 429 dairy cattle. Maximum field voltage levels recorded near ground level were about 9.1 kV/m. General health, behavior, and performance of the animals were not affected by the transmission line EMF.

In the Swedish study of cow fertility, 58 heifers were exposed to a 400-kV, 50-Hz transmission line from June to mid-October 1985 (Algers and Hultgren 1987). The length of exposure was 15 to 20 times longer than the average exposure per year for Swedish dairy herds exposed to 400-kV lines. No effects were observed on the frequency of malformations, the length or variation of the estrous cycle, the midcycle plasma progesterone level, the intensity of estrus, the number of inseminations per pregnancy, the overall conception rate, or the fetal viability. Previous studies of cattle showed no significant effects of EMF on reproduction.

4.5.6.3.4 Conclusion

No significant impacts of EMF on terrestrial biota have been identified. Although foliage very close to lines can be damaged, the overall productivity and reproduction of native and agricultural plants appear unaffected. Also, no evidence suggests significant impacts on individual animals or wildlife populations that are chronically exposed to EMF under transmission lines or in the towers. Livestock behavior and production also appear unaffected by line operation. Therefore, the potential impact of EMF on terrestrial biota is expected to be of small significance for all plants. The only potential mitigation would be to exclude plants and animals from the right of way, a measure with very severe impacts of its own. However, because the impact is of small significance and because mitigation measures could create additional environmental impacts and would be costly, no mitigation measures beyond those implemented during the current term license would be warranted. This is a Category 1 issue.

4.5.7 Floodplains and Wetlands

Transmission lines pass through floodplains and wetlands in many areas. This section evaluates the impacts on floodplains and wetlands that may result from periodic cutting or herbicide treatment of woody vegetation and the occasional use of heavy equipment for line repair. The analysis in this section is based on a literature review and applies to all power lines regardless of the type of generating facility.

Vegetation control is normally required only in forested areas where trees could grow tall enough to interfere with line operation. Marshes, ponds, or other types of wetlands lacking trees generally should not be subjected to vegetation control and thus should not be affected. In forested wetlands, most of which are on floodplains, vegetation may be cut by hand or with a tractor with a rotary blade or may be controlled by herbicides (Section 4.5.1.4). Impacts are generally restricted to the ROW and should have no significant impact on the functions and values that have been identified for floodplains, including storage and slow release of floodwaters, water quality maintenance, groundwater recharge, and support of wildlife populations (Greeson et al. 1979). Herbicides that are often used in prairie wetlands to improve habitat for waterfowl do not appear to have toxic effects on aquatic biota (Solberg and Higgins 1993).

Repair of transmission lines may require access by heavy equipment to tower sites in floodplains or wetlands. This access would damage vegetation and disturb wildlife, having the same types of impacts that occurred during construction of the line. Overall impacts are expected to be relatively minor because (1) line repairs at any one location are rarely required, (2) impacts would be temporary and restricted to relatively small areas, and (3) tower sites often avoid wetlands. Repairs made during winter would generally have less impact than repairs in summer, but often there may be no choice of season because of the necessity for immediate repair.

Studies in Massachusetts indicate that transmission lines and their ROW can be constructed and maintained through wetlands without significant impact (Nickerson and Dobberteen 1987; Thibodeau and Nickerson 1986). The studies were conducted in several areas where 345-kV lines were constructed through cattail marsh, wooded swamp, and shrub swamp/bog. Preconstruction studies were done in 1975 and 1976, and postconstruction studies were done from 1977 to 1982 and again in 1987. The cattail marsh was affected by the placement of heavy oak mats that were required so that heavy construction equipment could enter the marsh. This was done during the winter when the marsh was frozen and aerial parts of plants were dead. The marsh recovered to its original condition in 1 year. Line maintenance or repair using heavy equipment, if required, could be conducted during winter with no greater harm to a marsh.

In a bog, although vegetation was damaged by placement of oak mats and had not fully recovered after 10 years, the number of plant species in affected areas did not differ significantly from that in control areas. The authors recommended that line construction avoid bogs because of their extremely slow recovery.

Wooded swamp dominated by red maple showed significant change in vegetation structure because trees had to be removed from the ROW. After construction, the number of species and individuals returned to normal after 1 year, and a shrub layer became the dominant vegetation. After 10 years, the number of plant species in the ROW was greater than that in undisturbed swamp, even though the ROW vegetation had been mowed once (at a level of 3 ft) 6 years after construction. Because of the rapidity of swamp recovery after construction and the stability of the maintained ROW vegetation, the authors concluded that there was no substantial negative impact on wetland functioning. On swamp ROW cleared for lines from 1936 through 1939, selective cutting and herbicide treatment of cut stumps had been conducted. The numbers of species and individuals were similar to those in adjacent forest, and the ROW showed little evidence of disturbance except where trees had recently been cut (Nickerson and Dobberteen 1987; Thibodeau and Nickerson 1986).

No transmission line associated with a nuclear plant has been identified as being a significant impact on the functions and values of a wetland or floodplain. Only minor impacts of small significance are expected from ROW maintenance or line repair. Because the impact is of small significance and mitigation measures would be costly to implement, none of the mitigation measures identified above (i.e., placement of oak mats in affected areas and avoidance of maintenance during the growing season) would be warranted. This is a Category 1 issue.

4.5.8 Aesthetic Resources

This section evaluates the issue of transmission-line-induced impacts of continued operation of nuclear power plants on historic and aesthetic resources. Transmission lines are probably the most frequently seen equipment associated with power plants, particularly plants such as D. C. Cook or Diablo Canyon that are well hidden from public view. Transmission lines are the least novel in appearance when compared with highly visible nuclear power plant components such as cooling towers and containment vessels. Therefore, they are perceived with less bias than other components of the nuclear power plant complex. People may not even realize that some transmission lines are associated with a particular power plant, especially a nuclear plant.

The definitions of insignificant, noticeable, and significant levels of impact are the same as those described in Section 3.7.8.

The evaluation of past and projected future impacts of transmission lines on aesthetic resources involved staff examination of the experience at the seven selected case study sites, a brief survey of the projected and realized aesthetic impacts at the other operating nuclear power plants, a survey of the professional literature, and a search of recent newspaper and magazine accounts related to these issues.

Nuclear power plants are frequently sited near bodies of water for access to cooling water; their associated transmission lines often intrude into recreation, historic, or scenic areas. Most of the adverse impacts to date from transmission lines center on such incompatibility. Notable examples include Brunswick, Diablo Canyon, Millstone, Nine Mile Point, St. Lucie, and Vogtle. Crossings of major rivers, wetlands, wildlife areas, roads, lakes, cemeteries, and battlefields are the source of the disputes that have arisen. Various design, engineering, siting, construction, and metallic surface treatments have been made available to mitigate these conflicts.

In general, during the license renewal term, continued use of transmission lines and ROW is projected to cause little or no additional impacts beyond those that have already occurred. Some habituation to lines is likely to occur or continue. The problem of erosion of access roads under transmission lines at Diablo Canyon represents a type of impact that could worsen over time if mitigation is not effectively implemented. Proper maintenance of the t ransmission line corridor will help prevent aesthetic degradation. Additional mitigation measures such as replacement of towers or burying the transmission line would be excessively costly and would have additional environmental impacts.

The aesthetic impacts associated with continued operation of transmission lines are of small significance for all plants, and no mitigation measures beyond those implemented during the current term license would be warranted. This is a Category 1 issue.

4.6 RADIOLOGICAL IMPACTS OF NORMAL OPERATION

This section provides an evaluation of the radiological impacts on occupational personnel and members of the public during normal operation following license renewal. This evaluation extends to all 118 nuclear power reactors. Radiation exposures occurring after license renewal are projected based on present levels of exposures. Estimates of additional maintenance, testing, and inspections as a result of a variety of age-related changes in operational procedures were made based on the anticipated changes to current operation and are detailed in Section 2.6 and Appendix B. Added maintenance, testing, and inspection will be accompanied by increased exposure time to members of the work force but are not expected to significantly influence dose to members of the public. Regulatory requirements under which nuclear reactors presently operate are discussed in Section 3.8.1.1.

A detailed discussion is provided in Chapter 6 of the radiological impacts of low-level waste, mixed waste, and spent fuel generated by power reactors during the renewal period; the impacts attributable to the uranium fuel cycle; and the impacts of the transportation of fuel and waste.

In response to comments on the draft GEIS and the proposed rule, the standard defining a small radiological impact has changed from a comparison with background radiation to sustained compliance with the dose and release limits applicable to the activities being reviewed. This change is appropriate and strengthens the criterion used to define a small environmental impact for the reasons that follow. The Atomic Energy Act requires NRC to promulgate, inspect, and enforce standards that provide an adequate level of protection of the public health and safety and the environment. These responsibilities, singly and in the aggregate, provide a margin of safety. The definitions of the significance level of an environmental impact (small, moderate, or large) applied to most other issues addressed in this GEIS are based on an ecological model that is concerned with species preservation, ecological health, and the condition of the attributes of a resource valued by society. Generally, these definitions place little or no weight on the life or health of individual members of a population or an ecosystem. However, health impacts on individual humans are the focus of NRC regulations limiting radiological doses. A review of the regulatory requirements and the performance of facilities provides the bases to project continuation of performance within regulatory standards. For the purposes of assessing radiological impacts, the Commission has concluded that impacts are of small significance if doses and releases do not exceed permissible levels in the Commission's regulations. This definition of "small" applies to occupational doses as well as to doses to individual members of the public. Accidental releases or noncompliance with the standards could conceivably result in releases that would cause moderate or large radiological impacts. Such conditions are beyond the scope of regulations controlling normal operations and providing an adequate level of protection. Given current regulatory activities and past regulatory experience, the Commission has no reason to expect that such noncompliance will occur at a significant frequency. To the contrary, the Commission expects that future radiological impacts from the fuel cycle will represent releases and impacts within applicable regulatory limits.

4.6.1 Public Exposure

During normal operations after license renewal, small quantities of radioactivity (fission, corrosion, and activation products) will continue to be released to the environment in a manner similar to present operation. Analyses of historic effluent data presented in Appendix E have pointed to a systematic reduction in effluents (primarily airborne). While there is no empirical evidence of a leveling off, there will be a practical lower limit of effluent release.

Radioactive-waste management systems are incorporated into each plant and are designed to remove most of the fission-product radioactivity that leaks from the fuel, as well as most of the activation- and corrosion-product radioactivity produced by neutrons in the vicinity of the reactor core (Section 2.2). Improved fuel integrity in the 1980s was an important factor in reducing effluents. In addition, the effectiveness of the gaseous and liquid treatment equipment has increased significantly over the past two decades, as is evidenced by the continuously decreasing levels of effluents (NUREG/CR-2907). The amounts of radioactivity released through vents and discharge points to areas outside the plant boundaries are recorded and published semiannually in the radioactive effluent release reports for each facility. A discussion of the environmental pathways for radioactive effluent releases to the air and water was presented in Section 3.8.1.2. This section will focus on issues more unique to license renewal.

4.6.1.1 Radionuclide Deposition

The concentration of radioactive materials in soils and sediments builds up to an equilibrium value that depends on the rate of deposition and the rate of removal. Removal can take place through radioactive decay or through chemical, biological, or physical processes. For a given rate of release, the concentrations of longer-lived radionuclides and consequently the dose rates attributable to them would continue to increase if license renewal were granted.

In Regulatory Guide 1.109, explicit guidance is provided for calculation of dose for nearly all conceivable pathways. To account for the buildup of radioactive materials, buildup factors of the form $(1 - e^{-\lambda t})$ in the calculations are included, where λ is the radionuclide decay constant, and t is the midpoint of a facility's operational life. Hence, only radioactive decay is used in the removal term. Initially, most of the calculations for construction and operating stage permits used 15 years as the approximate midpoint of facility operating life. This value is now more often taken to be 20 years. The potential license renewal term is an additional 20 years; thus, the effective midlife is 30 years.

At present, most of the radiation dose commitments to the population resulting from atmospheric emissions are from the noble gases (NUREG/CR-2850 1993). The noble gases do not build up in the environment. Iodine-131, of interest because it has the ability to concentrate in the thyroid, achieves equilibrium within weeks. Tritium, cobalt, and cesium normally account for the greatest proportion of the dose from liquid effluents. Tritium is not known to concentrate in sediments or solids and hence does not build up. To determine whether the added period of operation following license renewal would, by virtue of buildup, result in significant (double) added dose, the ratios of buildup factors for midlives of 30 to midlives of 20 years were evaluated. These ratios amount to a 35 percent increase for ^{137}Cs and a 6 percent increase for ^{60}Co. This added increase due to buildup will not significantly change the total dose to members of the public.

One remaining topic about buildup in the environment warrants discussion. Buildup is not explicitly accounted for in the aquatic food pathway (i.e., fish, shellfish, etc.) This pathway relies on the use of bioconcentration factors. A bioconcentration factor for a nuclide is the ratio of the concentration in biota to the radionuclide concentration in water. In certain cases, the bioaccumulation factors may require reexamination. These principally involve fish (in the human food chain) that are bottom feeders. Bottom feeders may ingest worms and other biota that may remobilize radioactive materials accumulated in the sediments.

Accumulation of radioactive materials in the environment is of concern not only to license renewal, but also to operation under present licenses. NRC reporting rules require that pathways that may arise as a result of unique conditions at a specific site considered in licensees' evaluations of radiation exposures. If an exposure pathway is likely to contribute significantly to total dose (10 percent or more to the total dose from all pathways), it must be routinely monitored and evaluated. Environmental monitoring programs are in place at all sites to provide a backup to the calculated doses based on effluent release measurements. Since these programs are ongoing for the duration of the license, locations where unique situations give rise to significant pathways not detailed in NRC Regulatory Guide 1.109 will be identified if and when they become significant. If such pathways result in doses at a plant exceeding the design objectives of Appendix I to 10 CFR Part 50, action will be required.

4.6.1.2 Direct Radiation

Radiation fields are produced around nuclear plants as a result of radioactivity within the reactor and its associated components, low-level storage containers, and components such as steam generators that have been removed from the reactor (as described in Section 3.8). Direct radiation from sources within a light water reactor plant is due primarily to ^{16}N, a radionuclide produced in the reactor core by neutron activation of ^{16}O from the water. Because the primary coolant of an LWR is contained in a heavily shielded area, dose rates in the vicinity of light water reactors are generally undetectable and are less than 1 mrem/year at the site boundary. Some plants [mostly boiling water reactors (BWRs)] do not have completely shielded secondary systems and may contribute some measurable off-site dose. These sources of direct radiation will be unaffected by license renewal.

Original impact statements were reviewed for estimates of off-site dose from radioactive storage containers at both boiling-water reactors and pressurized-water reactors. These estimates suggested small dose contributions at site boundaries (Section 3.8.1.6). Nothing is anticipated to occur during license renewal to significantly change this estimate.

4.6.1.3 Transportation-Related Radiation Doses

The transportation of "cold" (unirradiated) nuclear fuel to the reactor, of spent irradiated fuel from the reactor, and of solid radioactive wastes from the reactor to a waste burial ground represents a source of exposure considered in 10 CFR Part 51.52. The contribution of the environmental effects of such transportation to the environmental costs of license renewal of the nuclear power reactor is set forth in Summary Table S-4 from 10 CFR 51.52. This issue is discussed in Section 6.4.

4.6.1.4 Radiological Monitoring

Background measurements at all sites were obtained during the preoperational phase of the monitoring program. Thus, each facility has characterized the background levels of radioactivity and radiation and their variations among the anticipated important pathways in the areas surrounding the facilities. The operational, off-site radiological monitoring program is conducted to provide data on measurable levels of radiation and radioactive materials in the site environs in accordance with 10 CFR Parts 20 and 50. The program assists and provides backup support to the effluent-monitoring program recommended in NRC Regulatory Guide 1.21, *Measuring, Evaluating, and Reporting Radioactivity in Solid Wastes and Releases of Radioactive Materials in Liquid and Gaseous Effluents from Light-Water-Cooled Nuclear Power Plants*. Such environmental monitoring programs are conducted to augment dose calculations and to ensure that unanticipated buildups of radioactivity will not occur in the environment. The environmental monitoring programs also identify the existence of effluents from unmonitored release points. An annual survey (land census) identifies changes in the use of unrestricted areas to provide a basis for modifying the monitoring programs.

4.6.2 Public Radiation Doses

Doses to the public during the license renewal term were estimated using current (baseline) levels and trends. For the period after license renewal, two measures of impact are appropriate. They are the dose to the maximally exposed individuals and the population dose. The latter is the average individual dose as a function of distance and sector location multiplied by the population in that sector at that distance.

4.6.2.1 Maximally Exposed Individual

Table 4.6 presents the dose to the maximally exposed individual resulting from airborne effluents as tabulated by NUMARC (1989) for the years 1985 to 1987. Under most circumstances, the dose calculations, made by the reporting utilities, result in an overestimate of dose because of conservative assumptions. The table shows that the greatest dose value for the maximally exposed individual from atmospheric releases (between 1985 and 1987) is 4.3 mrem.[7] On the average, about 5 percent of the sites report an annual dose of 1 mrem or greater to the maximally exposed individual. NRC has recently begun to estimate individual doses for comparison with 10 CFR Part 50, Appendix I objectives (NUREG/CR-2850 1994). Combining air and liquid pathways for calendar year 1990, operation at about 5 percent of the sites resulted in annual

Table 4.6 Calculated total body dose to the maximally exposed individual from routine airborne effluents (mrem)

Plant	1985	1986	1987
Arkansas, Unit 1	—	0.0017	0.0023
Arkansas, Unit 2		0.006	0.0044
Beaver Valley	—	0.023	0.0014
Brunswick	—	—	0.028
Catawba	0.88	2.2	0.89
D. C. Cook	0.057	0.02	0.024
Cooper	0.57	0.4	0.018
Crystal River	0.022	0.21	0.2
Davis-Besse	0.0081	0.00064	0.12
J. M. Farley	0.13	0.12	0.081
Grand Gulf	0.09	0.068	0.34
Haddam Neck	1.0	0.39	0.66
Oconee	0.15	0.087	—
Oyster Creek	1.4	4.3	0.17
Peach Bottom	0.041	0.12	0.015
Pilgrim	0.49	0.027	—
Quad-Cities, Unit 1	0.002	—	0.0025
Quad-Cities, Unit 2	0.002	—	0.0021
Rancho Seco	0.17	—	—
H. B. Robinson	—	0.016	0.068
Shearon Harris	—	—	0.022
E. I. Hatch	0.093	0.004	0.13
Indian Point	0.00078	0.00049	—
Kewaunee	—	0.12	0.00001
Limerick	—	0.00079	0.00022
McGuire, Unit 1	—	0.15	0.081
McGuire, Unit 2	1.8	—	0.0036

Table 4.6 (continued)

Plant	1985	1986	1987
Salem	0.016	0.028	0.047
Sequoyah	0.19	0.002	—
St. Lucie, Unit 1	0.013	0.011	0.0023
St. Lucie, Unit 2	0.0062	0.0021	0.0028
V. C. Summer	—	0.00051	0.000001
Susquehanna	0.1	0.0069	0.011
Three Mile Island	—	0.019	0.0028
Trojan	0.069	—	—
Turkey Point, Unit 1	—	0.0038	0.0087
Turkey Point, Unit 2	—	0.0042	0.0088
Waterford	—	—	0.66
Washington	—	0.013	0.024
Zion	0.044	0.092	0.00047

Source: NUMARC 1989.
Note: To convert millirem to millisievert, multiply by 0.01.

doses of 1–3 mrem to the total body; 32 percent of the sites, 0.1–1.0 mrem; and 63 percent of the sites, less than 0.1 mrem. A comparison of the data from Table 4.6 and from NUREG/CR-2850 (1994) with the design objective doses of Appendix I to 10 CFR Part 50 and the EPA dose limits (Section 3.8.1) shows that existing plants are operating far below allowable limits with respect to effluent control.

Given the conservative nature of the calculations leading to the doses of Table 4.6, the impact on maximally exposed persons around nuclear generating facilities is clearly very small.

4.6.2.2 Average Individual Dose and Population Dose Commitment

4.6.2.2.1 Recent Data

Trends for average individual doses for persons living around nuclear power plants reflect the small radiation dose levels seen in the maximally exposed individuals. Each year, NRC issues a report entitled *Population Dose Commitments Due to Radioactive Releases from Nuclear Power Plant Sites*. The latest publication is for the calendar year 1989 (NUREG/CR-2850, Vol. 11). Methods used in this series are described in Section 3.8.1. The prescribed calculational methods include several basic assumptions to ensure that the results are conservative. Table 4.7 (adapted from

Table 4.7 Summary of population and occupational doses (person-rem) for all operating nuclear power plants combined

Year	Population			Occupational
	Liquid	Air	Total	
1975	76	1,300	1,300	20,879
1976	82	390	470	26,107
1977	160	540	700	32,508
1978	110	530	640	31,801
1979	220	1,600	1,800	39,982
1980	120	57	180	53,795
1981	87	63	150	54,144
1982	50	87	140	52,190
1983	95	76	170	56,472
1984	160	120	280	55,235
1985	91	110	200	43,042
1986	71	44	110	42,381
1987	56	22	78	40,401
1988	65	9.6	75	40,769
1989	68	16	84	35,980
1990	—[a]	—	—	35,592
1991	—	—	—	28,515
1992	—	—	—	29,309

[a] Data not available.

Source: NUREG/CR-2850; NUREG-0713

Note: To convert person-rem to person-sievert, multiply by 0.01.

NUREG/CR-2850 and NUREG-0713) presents results obtained for a 15-year period ending in 1989. The numerical entries are person-rem received by those who live within a 50-mile radius of a site; data for individual sites also appear in these reports. The person-rem number is obtained by adding together the individual doses received by this population. For 1988, the cumulative person-rem varied from a low of 0.0015 at Grand Gulf to a high of 16 at McGuire. Seventy-five percent of the total came from 9 of the 67 sites, as shown in Table 4.8. (Information presented in Tables 4.8 and 4.9 was derived from NUREG/CR-2850, Vol. 10,

Table 4.8 Highest public dose data from nuclear power plant effluents, 1988

Plant	Population dose (person-rem)	Population within 50 miles (persons)	Average individual dose (mrem)
McGuire	16	1,800,000	0.0091
Summer	13	900,000	0.014
Zion	7.2	7,300,000	0.001
E. I. Hatch	6.4	350,000	0.018
Clinton	4	2,700	0.0015
Oconee	3.8	9,900	0.0039
Oyster Creek	2.2	3,600,000	0.0006
Harris	1.8	1,400,000	0.0013
Calvert Cliffs	1.7	2,800	0.00061
All sites	75	150,000,000[a]	0.0005

[a] This figure is inflated because not all sites are 100 miles apart, and some persons within each 50-mile radius were counted more than once.

Source: Adapted from NUREG/CR-2850, Vol. 10.

Note: To convert rem to sievert, or mrem to millisievert, multiply by 0.01.

Table 4.9 Individual public dose data from power plant effluents, 1988

Individual dose range (mrem)	Percentage of total	Cumulative percentage
0 to 0.000001	6 percent	6 percent
0.000001 to 0.00001	4 percent	10 percent
0.00001 to 0.00003	18 percent	28 percent
0.00003 to 0.0001	30 percent	58 percent
0.0001 to 0.0003	21 percent	79 percent
0.0003 to 0.001	13 percent	92 percent
0.001 to 0.003	5 percent	97 percent
0.003 to 0.01	< 2 percent	99 percent
0.01 to 0.03	< 1 percent	100 percent

Source: NUREG/CR-2850, Vol. 10.

Note: To convert mrem to millisievert, multiply by 0.01.

the most recent volume which presents data summaries with average individual doses.) The arithmetic mean annual radiation dose to people who lived in the vicinity of a U.S. nuclear power plant in 1988 was about 0.0005 mrem. The overall median for 1988 was less than 0.0003 mrem. A histogram shown in Figure 4.1 of NUREG/CR-2850 provided the information shown in Table 4.9.

Note that 97 percent of the individuals received 0.003 mrem or less during 1988. The most recent NCRPM report on this subject gives 300 mrem/year as the U.S. average dose from natural background radiation (NCRPM 1987). The addition of 0.018 mrem at the Hatch site as a result of plant operation is well within and indistinguishable from variations in natural background radiation (see Dudney et al. 1990).

According to the National Council on Radiation Protection and Measurements report, if a person moves from the coast to the Rocky Mountains, the natural annual doses can be increased by as much as 70 mrem. This 70-mrem addition to natural background which occurred because of a personal relocation is 7690 times greater than the average dose from operation of the McGuire nuclear facility during 1988.

4.6.2.2.2 Analysis of Current Trends

Projections into the future can be made on the basis of current trends. On that basis, average individual dose commitments were analyzed. The first objective of the analysis was to determine to what extent known information about all sites could be used to predict what the dose commitment values for each site were for the years 1979–1987. The second objective, if current dose commitments could be predicted adequately, was to use the models to predict future dose commitments for U.S. sites by extrapolating the characteristics used in the model and the population projections for the sites into future years (see Section E.3.2 for more details of this analysis).

A linear model was fitted to the dose data using combinations of independent variables. The independent variables that proved to be most predictive of the log (dose) values included calendar year, year of startup, size in megawatts, vendor (or manufacturer), and status (up or down). The linear model for estimation of air doses resulted in the following conclusions. The manufacturer with the highest air doses is Babcock-Wilcox (B-W) (but highly variable); the next highest is GE; and the lowest is Combustion Engineering (C-E). Air doses are decreasing with calendar year (for 1979 to 87) for all reactor types. The rate of decrease is fastest for GE reactors. The rate of decrease is much smaller for C-E reactors than for others, partly because these are lower to begin with. With the exception of C-E, all types have higher air doses from older reactors. For C-E, newer reactors have higher doses. Larger reactors had higher air doses. This relationship was strong and was a major contributor to the prediction of dose for each reactor site; it held true for all manufacturers but was much less evident in B-W reactors. The increase in air dose with size was largest for GE and for Westinghouse reactors. The overall model accounts for approximately 42 percent of the variation in the air dose values. For all reactor types (manufacturers), air doses decrease significantly when the reactor is operating below 25 percent capacity. This is not necessarily true for doses from liquid sources.

The linear model for estimating liquid dose resulted in the following conclusions: B-W reactors have significantly higher liquid doses than do reactors of other manufacturers, and GE reactors are next highest. Mixed sites (those with multiple reactors and different vendors) have the lowest liquid doses. GE and mixed sites have higher doses from liquid sources when they are operating below 25 percent of theoretical maximum output. Many mixed sites are partly GE reactors. All other manufacturers, all of which are pressurized-water reactors, have lower doses when they are operating below 25 percent capacity. Liquid doses are higher in older reactors only for GE reactors. For others, there is not a significant trend with reactor age. For GE reactors and for Westinghouse reactors, the larger reactors had higher liquid doses. The increase in liquid dose with megawatt capacity was much higher for GE reactors than for the other types. Liquid doses are overall much less predictable than air doses, and the resulting model fit for the liquid doses reflects this unpredictability. For liquid doses, the best-fitting model accounted for only about 20 percent of the overall variability in the model.

Liquid effluents are not decreasing significantly with time for any of the five types, although the coefficients are negative except for the mixed sites. Thus, the general trend with time is for air doses to decrease and for doses from liquid sources to decrease less rapidly. The decreasing trend in total dose commitment results mostly from the lower air dose estimates.

On the basis of the coefficients estimated with this analysis, it is apparent that the dose commitments are being systematically lowered. Results of the analysis were used to plot historical data against predicted doses (see sample figures in Section E.3). These figures portray how each sample reactor has performed with respect to other reactors in its class (i.e., age, size, vendor). Again, the dominant theme is the decline in dose commitment, which is almost universally observed. Even if there were a sudden cessation of the decline in dose to the public, levels are sufficiently low to represent an insignificant impact to humans.

4.6.2.3 Projected Doses for License Renewal

On the basis of information presented in the preceding section, radiation doses to members of the public can be projected into the license renewal period. The three factors upon which judgments can be made are the maximally exposed individual, the average exposed individual, and the cumulative exposure of a population. At present, each of these measures meets the design objectives and regulations. No aspect of future operation was identified that would substantially alter this situation. Rather, evidence presented above suggests that radioactive effluents and hence doses to the public are decreasing.

Maximum individual doses are reported in semiannual effluent release reports, and when these doses exceed Appendix I design objectives, the staff pursues remedial action. Thus these issues are handled on a case-by-case basis. A review of the atmospheric release data sources suggests that, in any given year, up to 5 percent of the power plants produce radiation doses of approximately 20 percent of the Appendix I design objectives (NUMARC 1989). No aging phenomenon has been identified which is expected to increase public radiation doses. Since the design objective provides a point of reference for visibility to the NRC staff, normally operating reactors are not expected to reach regulatory dose limits more often in the period after license renewal than they do at present. For these reasons, impacts to maximally exposed individuals in the public during future operation under license renewal are judged to be radiologically unchanged from present operations.

Similarly, radiation exposure to the average individual and collective dose to the population around a nuclear power plant are not anticipated to increase from present levels in the period after license renewal. Analysis of all available pertinent information suggests that, if anything, radiation doses to the public are decreasing.

Ninety-nine percent of the population within 50 miles of any plant received a dose of 0.003 mrem or less from nuclear power plant effluents in 1988 (Table 4.9). In 1990, the average dose to persons living within an 80-km (50-mile) distance from nuclear power plants was less than 0.001 mrem (NUREG/CR-2850 v. 12). If all 150 million people living within 80 km (50 miles) of nuclear plants receive 0.001 mrem/year for 70 years, the collective dose will be 10,500 person-rem. Using a risk coefficient of 5×10^{-4} cancer fatalities per person-rem, approximately 5 fatalities can be hypothesized. Among the 150 million people, about 30 million will die of spontaneous cancer. Hence, the added risk of cancer fatality is less than 1 in 6 million national cancer fatalities.

From a different perspective, the population of 150 million people would accumulate 45,000,000 person-rem/year from natural background radiation. The annual collective dose from operation of all 118 nuclear power plants, assuming an annual average individual dose as high as 0.002 mrem per person, is 300 person-rem. This is 150,000 times less than the collective dose from naturally occurring radiation. From this perspective, the contribution of nuclear power plants to the radiation dose to members of the public is not significant. Future increases in populations will result in proportional increases in population doses; that is, a doubling of the population around the 118 plants would result in a 600 person-rem annual collective dose. However, the population increase would not change the fact that the collective dose from plant operation is still 150,000 times less than that from naturally occurring radiation.

Cumulative impacts to average individual members of the public can be viewed from the same perspective presented in Section 3.8.1.7. During operation under license renewal, the average annual dose to the public from nuclear power plant operations will remain very small, less than 0.001 mrem/year. Cumulative radiation doses to members of the public will remain about 360 mrem/year and nuclear power plant operation will remain a very small part (less than 0.0003 percent) of the ionizing radiation dose to an average member of the U.S. population.

4.6.2.4 Mitigation

In addition to the regulations within 10 CFR Part 20.1101 (see Section 3.8.1.8) which speak directly to required operation under ALARA principles, 10 CFR Part 50.36a imposes conditions on licensees in the form of technical specifications on effluents from nuclear power reactors. These specifications are intended to keep releases of radioactive materials to unrestricted areas during operations to ALARA levels. Appendix I to 10 CFR Part 50 provides numerical guidance on dose-design objectives and limiting conditions for operation of LWRs to meet the ALARA requirements. These regulations will remain in effect during the period of license renewal.

Evidence presented in Section 3.6, Appendix E, and this section demonstrates that the ALARA process has been effective at controlling and reducing radiation doses to the public. Radiation doses to the public are declining both for average and total doses (Table 4.7) and for individual doses (Tables 4.10 and 4.11). No changes in the operation of power plants under license renewal are expected to increase radiation doses to the public compared with current operation. Because effective mitigation procedures are already in place, there is no need to consider additional mitigation during the period of license renewal.

4.6.2.5 Conclusion

Radiation doses to members of the public from current operation of nuclear power plants have been examined from a variety of perspectives and the impacts were found to be well within design objectives and regulations in each instance. No effect of aging that would significantly affect the radioactive effluents has been identified. Both maximum individual and average doses are expected to remain well within design objectives and regulations. In about 5 percent of the plants, maximum individual doses are approximately 20 percent of the Appendix I design objective. All other plants are operating far below this level.

Because no reason was identified to expect effluents to increase in the period after license renewal, continued operation well within regulatory limits is anticipated. The staff concludes that the significance of radiation exposures to the public attributable to operation after license renewal will be small at all sites. It should also be noted that the estimated cancer risk to the average individual due to plant operations is much less than 1×10^{-6}. No mitigation measures beyond those implemented during the current term license would be warranted because current mitigation practices have resulted in declining public radiation doses and are expected to continue to do so. This is a Category 1 issue.

4.6.3 Occupational Radiation Dose

To determine the significance of the estimated occupational dose during the license renewal term, the staff has examined the baseline trends in cumulative annual occupational dose at pressurized-water reactors and boiling-water reactors and the projected increments to occupational dose due to extended plant operation. These projections were compared with the occupational dose limit requirements of 10 CFR Part 20 and with dose levels now being experienced and were also used as the basis for estimates of cancer risk, which were compared with the spontaneous cancer rate.

4.6.3.1 Baseline Occupational Dose

Occupational radiation protection programs in place at nuclear power plants have maintained an annual average individual dose of only 0.28 rem during 1992 (Table 4.10), compared with an exposure limit of 5 rem. Furthermore, the distribution of individual dose (Table 4.11) indicates that only 3 people received doses at the highest reported level of between 4 and 5 rem and less than 0.5 percent of the workers received doses in excess of 2 rem. (Other supportive historical data can be found in Appendix E.)

Table 4.10 Light-water reactor (LWR) occupational whole-body dose data for boiling-water reactors (BWRs) and pressurized-water reactors (PWRs)

Year	Annual average whole-body dose (rem)		
	All LWRs	All BWRs	All PWRs
1973	0.94	0.85	1.00
1974	0.74	0.81	0.68
1975	0.82	0.86	0.76
1976	0.75	0.71	0.79
1977	0.84	0.89	0.65
1978	0.74	0.74	0.65
1979	0.66	0.73	0.56
1980	0.72	0.87	0.52
1981	0.71	0.73	0.61
1982	0.66	0.76	0.53
1983	0.70	0.82	0.56
1984	0.59	0.66	0.49
1985	0.46	0.54	0.41
1986	0.42	0.51	0.37
1987	0.39	0.40	0.38
1988	0.40	0.45	0.36
1989	0.34	0.36	0.33
1990	0.34	0.38	0.31
1991	0.29	0.31	0.27
1992	0.28	0.32	0.26

Source: NUREG-0713.

Note: To convert millirem to millisievert, multiply by 0.01.

Table 4.11 Number of workers at boiling-water reactor (BWRs), pressurized-water reactor (PWRs), and light-water reactor (LWRs) installations who received whole-body doses within specified ranges during 1992

Dose range (rem)	BWRs	PWRs	LWRs
<0.1 (measurable)	17,740	28,220	45,960
0.1–0.25	8,094	12,503	20,597
0.25–0.5	6,883	10,259	17,142
0.5–0.75	3,995	4,926	8,881
0.75–1.00	2,339	2,287	4,626
1.00–2.00	2,366	2,602	5,468
2.00–3.00	204	245	449
3.00–4.00	11	6	17
4.00–5.00	3	0	3
5.00–6.00	0	0	0
6.00–7.00	0	0	0
7.00–12.00	0	0	0
>12.00	0	0	0
Totals	42,095	61,048	103,143

Source: NUREG-0713, 1993.
Note: To convert millirem to millisievert, multiply by 0.01.

As plants age, there will be slight increases in radioactive inventories, resulting in slight increases in occupational radiation doses.

4.6.3.2 Projected Doses for License Renewal

During the license renewal term, the greatest increment to occupational dose over present doses would occur during a 10-year in-service inspection refueling (Table 2.8). The average dose increment related to the 10-year in-service inspection refueling would raise boiling-water reactor averages from a present 360 person-rem (Table 3.12) by 91 person-rem (10-year in-service inspection refueling, Table 2.8) to 451 person-rem and raise pressurized-water reactors from 219 person-rem by 51 person-rem to 270 person-rem. Under the conservative scenario (Table 2.11) these dose increments would add 108 person-rem to BWRs and 66 person-rem to PWRs. These increased levels for a single year are similar to the levels experienced at some plants during the past 2 two reporting years (Table 3.13). After the period of refurbishment, routine operating conditions are expected to cause, industry wide, approximately 32,000 person-rem/year exposure to plant personnel [i.e., 5 percent increase over the currently experienced 30,000 person-mrem/year (Appendix B)]. With the conservative scenario, there is about an 8 percent increase in radiation dose over current operating experience (Tables 2.8 and 2.11).

Within the radiation bioeffects community, one school of thought holds that any radiation exposure is accompanied by a risk of cancer. The other perspective is that below a certain dose and dose rate, no cancer risk is involved. The lowest statistically significant dose associated with excess cancer fatalities among the atomic bomb survivors is considered by ICRP 60 (1991) to be 20 rad. The collective dose to the U.S. population from natural background radiation is approximately 75 million person-rem/year; while not declaring itself on one side or the other on the risk issue, the 1990 BEIR-V report states that there may be no risk from this natural background radiation. If there is no risk from natural background radiation, the annual 32,000 person-rem dose may be of little concern. At the other extreme, if it is assumed that individual doses of less than 20 rem may be included in the collective dose without causing an exaggerated result, the full 32,000 person-rem dose to all workers at nuclear power plants for the typical case may be multiplied by the best estimate risk coefficient for workers (4×10^{-4}); this risk coefficient leads to an annual total of 13 deaths. Of these, 12 would be expected because of normal present-day operation and 1 would be expected to result from aging- and refurbishment-related changes in operation.

This analysis of typically expected conditions provides a range of 0 to 13 deaths induced per year as a result of license renewal, with one of these fatalities resulting from added dose due to aging; very little difference is estimated under the conservative scenario. Thus, radiation doses attributable to plant aging accumulated during the license renewal term might result in a 5 percent increase in the calculated cancer incidence to plant workers, but there may be no increase. The significance of the possible increase depends altogether on the degree of credibility assigned to the risk coefficient derived at high dose and dose rate and applied for low dose and dose rate. In any case, the risk associated with occupational radiation exposures after license renewal is not expected to be significantly different from that during the initial license term.

Currently, occupational radiation doses are on the order of 0.4 rem/year in addition to the 0.36 rem/year received by the typical U.S. resident. If occupational exposure increases by 8 percent as estimated for the conservative scenario, cumulative occupational radiation doses will increase from about 0.76 rem/year to 0.79 rem/year for those working at nuclear plants that operate after the initial license term. Under the typical scenario, occupational doses would increase approximately 5 percent over the currently experienced levels increasing average exposures to 0.78 rem/year.

4.6.3.3 Conclusion

Occupational doses attributable to normal operation during the license renewal term have been examined from several different perspectives. First, projected occupational doses during the period of maximum added dose, the 10-year in-service inspection refueling, are within the range of doses experienced during the past 2 reporting years. Second, the average dose increase of 5 to 8 percent to the typical plant worker would still maintain doses well below regulatory limits. Therefore, occupational radiation exposure during the term of the renewed license meets the standard of small significance. No mitigation measures beyond those implemented during the current term license would be warranted because the ALARA process continues to be effective in reducing radiation doses. This is a Category 1 issue.

4.7 SOCIOECONOMIC IMPACTS

This section reports on the socioeconomic impacts associated with nuclear power plant operations during the license renewal term. The staff reviewed the following socioeconomic issues: (1) changes to local housing caused by plant-induced population growth; (2) the magnitude of all nuclear plant tax payments in relation to total revenues in host communities; (3) disruptions to local public services (i.e., education, transportation, public safety, social services, public utilities, and tourism/recreation); (4) changes to local land use and development patterns resulting from plant-induced population growth and all tax payments; (5) the effects of plant operations on local employment and income levels; (6) plant-related disturbances to historic resources at and around the plant site; and (7) plant-related disturbances to aesthetic resources. Of these socioeconomic impacts only those directly affecting the natural and built environment are carried forward to the decision whether to renew an operating license. The regional economic impact including income, employment, and taxes are not considered in the license renewal decision. As in Chapter 3, plant-induced population growth was studied as a potential influence on a number of the impacts listed above.

The methodological techniques used to evaluate impacts are described briefly in Section 3.7.1 and are detailed in Section C.1; a brief summary of these methods is provided here. For this chapter, past impacts related to plant operations were studied so that the impacts of future operations could be predicted. The impacts projected for the case study sites represent the range of potential impacts at existing nuclear plants because the sample plants were selected to represent the range of nuclear plant sites nationwide. A detailed discussion of site-specific findings is presented in Sections C.4.1 through C.4.7 of Appendix C.

The size of the work force required during the license renewal term is an important determinant of population growth. The permanent license renewal term work force is expected to include those personnel who were on-site during the initial license term, up to 60 additional permanent operations workers per unit, and temporary refueling and maintenance workers during periodic plant outages. Estimates in Chapter 2 and Appendix B of additional work force required during license-renewal-term operations indicate that only one additional worker will be required on a continuous basis for maintenance and inspection activities. The more conservative figure (60 persons per unit) is used in the analysis to account for workers (contractors or rotating utility employees) who are not associated with refueling but may be on-site intermittently. The 60 persons per unit analysis represents an upper bound of the possible socioeconomic impacts.

In addition to those workers previously required during operations-period outages, another 30 workers will be needed for periodic outages during the license renewal term. Potential impacts associated with the presence of periodic outage workers were not systematically evaluated because the duration of these outages will be short (typically 3–4 months). However, evidence about past effects resulting from the temporary influx of refueling/maintenance workers was collected and used in the analysis to predict the impacts of refueling/maintenance during the license renewal term.

The site-specific projections presented here are based on the assumption that no other major construction projects will occur at the same time as refueling and maintenance activities. The potential cumulative population-related impacts during license-renewal-term refueling and maintenance activities would result from the combined populations associated with refueling/maintenance and other concurrent construction activities (not necessarily related to the power plant). Analyses of various refurbishment scenarios (see Appendix C and Chapter 3) suggest the potential magnitude of cumulative impacts resulting from different work force sizes. For example, about 800 refueling/maintenance workers (i.e., about the mean number of workers involved in regularly scheduled outages) combined with another construction work force of about 200, for a total of 1000 workers, would have only small adverse impacts at all but the most remote and sparsely populated sites (e.g., Wolf Creek). Combined work forces of 2,300 could induce large impacts to housing, education, and transportation at some sites. A sensitivity analysis indicates that impact magnitudes would not be increased by a work force as large as 3,400.

The population growth that has resulted from operations at the case study plants has been small, ranging from less than 0.1 percent to 13 percent of a local area's total population (see Table 4.12 and Appendix C). As discussed in Section 3.7.1, the staff believes that Indian Point and Wolf Creek serve as the lower and upper bounds, respectively, of operations-related growth as a percentage of a study area's total population. Thus, population growth that has resulted from worker in-migration is estimated to range at all plants from less than 0.1 percent to 13 percent.

Certain characteristics of the license renewal term work force (e.g., percentage residing in the study area, percentage moving into the study area, percentage of in-migrants accompanied by families) were assumed to be similar to those of the current plant staff and were used to make projections concerning population growth. Information about the impacts that have resulted from population growth during a plant's operation was used to estimate the population-driven impacts that would occur during the plant's license renewal term.

Based on predictions for the case studies, new plant-related population growth resulting from the license renewal term at any nuclear plant would be much smaller than the growth that has resulted from operations thus far. Growth related to increased employment during the license renewal term is expected to represent between less than 0.1 percent and 0.8 percent of the local area's total population for all plants. Because the number of additional permanent workers required at any plant would be relatively small (up to 60 per unit) and because the communities around the plants have already accommodated the existing work force during operations, it is likely that license renewal terms would result in only minimal long-term plant-related population increases for most plants. Therefore, new (incremental) population-driven impacts generally would be minimal, and impacts

Table 4.12 Impact area population growth associated with current and additional permanent plant staff at seven plants in the case study[a]

Plant	Current number of permanent plant staff	Population increase from current staff	Population growth from current staff as a percentage of study area's total population	Projected population increase from additional permanent staff	Population growth from additional staff as a percentage of study area's total population
Arkansas Nuclear One	2205	3418	7.4%	189	0.3%
D. C. Cook					
Bridgman/Lake Township	1252	141	3.0%	15	0.3%
Berrien County		1109	0.7%	104	< 0.1%
Diablo Canyon	1300	2149	1.0%	199	< 0.1%
Indian Point					
Dutchess County	1335	415	0.2%	39	< 0.1%
Westchester County		316	< 0.1%	32	< 0.1%
Oconee	2300	504	0.9%	41	< 0.1%
Three Mile Island	1086	246	1.7%	13	< 0.1%
Wolf Creek	1044	1137	13.3%	68	0.8%

[a] Includes both direct and indirect workers and their families.
Source: Staff computations.

already occurring during current operations would continue with only slight increases during the license renewal term.

4.7.1 Housing

Two types of housing impacts related to workers' demand for housing may occur during license renewal term operations: (1) new housing impacts resulting from the in-migration of additional plant operations workers and (2) the continuing impacts arising from the housing demands of workers involved in periodic plant outages for refueling and maintenance. A third type of impact, unrelated to workers' demands, is the continuing impact of the plant on housing value and marketability.

4.7.1.1 Definition of Significance Levels

Detailed definitions of significance levels of impacts that result from increased housing demand are provided in Section 3.7.2. In summary, small impacts result when no discernible change in housing availability occurs, changes in rental rates and housing values are similar to those occurring statewide, and no housing construction or conversion occurs. Moderate impacts result when there is a discernable reduction in housing availability, rental rates and housing values exceed the inflation rate elsewhere in the state, and minor housing conversions or temporary additions occur. Large impacts occur when project-related demand results in very limited housing availability, considerable increases in rental rates and housing values, and substantial conversion of housing units.

Definitions of the significance of the plant's impacts on the desirability of housing located close to the plant follow. A small impact on housing desirability results when very few or no instances of outmigration occur because of the operation of the nuclear power plant. Also, very few cases of prospective home buyers refusing a home because of its proximity to the plant would occur. Under normal plant operations, housing values should remain within the range of regional fair market prices. Moderate impacts on housing desirability include occasional difficulty in finding a buyer for a house because of its proximity to a nuclear plant. Impacts are also moderate if the proximity of the nuclear plant is cited as a reason for discounting the sale price of the housing units. Impacts on housing desirability are considered large if substantial migration from houses in the vicinity of the plant occurs or if realtors find it difficult or impossible to sell homes in the area. A large impact may also result if a sustained and substantial drop in housing value occurs because of the house's proximity to the plant. Such impacts may be evidenced by a gradual increase in housing value with increasing distance from the plant.

4.7.1.2 Analysis

Housing Demand

The in-migration of plant personnel associated with current operations at each of the seven case study sites has had small impacts on housing. The number of operations workers required at the plants is small relative to original construction work force size, and the operations workers have been introduced gradually to the site so that housing demand has also increased gradually. The demand for housing by refueling workers was found to have a large impact at only one site (Wolf Creek). In that case, approximately 640 additional workers were on-site during the plant outage.

Based on impacts associated with current term operations, population-driven housing impacts resulting from additional permanent workers in the license renewal term would be small at all case study sites. The housing demand resulting from an additional 60 workers per unit would not be large enough to strain the housing markets of communities in which the plants are located and would result in a small impact even in areas where little growth in housing is expected.

Impacts related to the demand for housing resulting from the in-migration of refueling workers are projected to continue to be the same as those currently being experienced—with slight exacerbation due to the additional 30 temporary refueling workers (Section 4.7.1). Thus large impacts may continue at one case study site, Wolf Creek. At other case study plants, these continuing housing impacts associated with in-migrating refueling workers would remain small to moderate.

Housing Marketability

The prevailing belief of realtors and planners in communities surrounding the case study plants is that the plants have had little if any effect on the marketability or value of homes in the vicinity. Housing choices of local residents are rarely affected by the presence of the plant. However, buyers from outside the community are occasionally averse to purchasing properties close to a nuclear power plant. Housing markets have not been affected by this situation because of its infrequency. The value of housing units in close proximity to the plants has experienced only small impacts. A slight negative impact did result because of the accident at Three Mile Island Unit 2; the price of houses in two small subdivisions close to the plant dropped slightly below fair market value after the accident and stayed that way for a brief period following it. At some sites, housing values have increased slightly because of amenities such as sewer systems and improved school systems that were made possible because of tax payments by the nuclear plant.

The license renewal term of the plants will be very much like the original operations period but will include additional safety and maintenance activities. Thus, impacts on housing marketability and values that have occurred during operations will continue during the license renewal term. At all case study sites, only small impacts on housing value and marketability are projected to continue.

4.7.1.3 Conclusion

No demand-related impacts are expected during regular operations, and only small impacts to housing value and marketability are projected. During continuing periodic refueling/maintenance outages, housing demand impacts during refueling/maintenance may range from small to large at various sites. The observed relationship between demographic characteristics and projected housing impacts at the case study sites suggests that large impacts are possible when a work force exceeding 600 persons is required at a site located in a low-population area or in an area that has or recently has had growth control measures that limit housing development. This is a Category 2 issue.

4.7.2 Taxes

This section describes the importance of nuclear plant tax payments as a source of local government revenue. These payments may be made directly to local government jurisdictions or indirectly to local government jurisdictions through state tax and revenue-sharing programs. The tax impacts of operations during the license renewal term were projected based on the current magnitude of tax payments by nuclear plants in relation to total revenues in their local areas (Section C.4.1.3).

4.7.2.1 Definition of Significance Levels

Significance levels during license term renewal operations are considered small if new tax payments are < 10 percent of the taxing jurisdiction's revenue, moderate if payments are 10 to 20 percent, and large if payments represent > 20 percent of revenue. A detailed description of these significance categories is in Section 3.7.3.1. However, the tax payments used to calculate impacts during the license renewal term are all property taxes paid by the nuclear plant, not just the increment due to refurbishment-related improvements.

4.7.2.2 Analysis

The primary taxing authorities for most of the case study plants are the county and city in which the plant is sited and the local school district. The tax-related impacts experienced by those jurisdictions vary widely, depending on the relative size of the taxing jurisdictions and the taxing structure of the state in which the case study is located. The magnitude of current nuclear plant tax payments relative to total local revenues and the associated impact levels is shown in Table 4.13.

The primary tax-related impact expected to occur during the license renewal term at the seven case study plants would be the continuation of tax revenues paid by utilities to local taxing authorities. An additional new tax impact would result from the increase in each plant's assessed value because of refurbishment-based improvements and the associated increase in tax payments. The magnitude of this increase is unknown and may depend on the state's (or other assessing authority's) method of assessment and previous agreements or laws that limit increases in assessed valuation. Generally, the relative importance of tax payments to local jurisdictions during the license renewal term would be similar to that of payments during the current term, although the size of the payments is projected to increase somewhat (see Table 4.13).

4.7.2.3 Conclusion

Tax-related impacts from the continued operation of nuclear plants would range from small to large, as at the case study sites. Tax impacts would consist of the continued effect of direct and indirect tax payments to local jurisdictions, which began before license renewal, in combination with the increase in payments because of refurbishment-related improvements. Impacts of this kind are judged to be beneficial.

4.7.3 Public Services

The approach used to determine past impacts of plant operations and project future public service impacts during the license renewal term is discussed in the introduction to Section 3.7 (also see Section C.4.1.3). For most public services, future impacts were determined based on the projected number of in-migrating workers. To project impacts to local educational systems, however, the number of workers accompanied by their families and the associated family size were also important.

The levels of significance for impacts to public services are the same as those discussed under refurbishment: (1) education, Section 3.7.4.1; (2) transportation, Section 3.7.4.2; (3) public safety, Section 3.7.4.3; (4) social services, Section 3.7.4.4; (5) public utilities, Section 3.7.4.5; and (6) tourism and recreation, Section 3.7.4.6. In general, impacts are small if the existing infrastructure (facilities, programs, and staff) could accommodate any plant-related demand without a noticeable effect on the level of service. Moderate impacts arise when the demand for service or use of the infrastructure is sizeable and would noticeably decrease the level of service or require additional resources to maintain the level of service. Large impacts would result when new programs, upgraded or new facilities, or substantial additional staff are required because of plant-related demand (see Section 3.7.4).

Table 4.13 Current property taxes as percent of total revenues for taxing jurisdiction at seven nuclear power plants in the case study

Plant	Local taxing jurisdiction	Percentage of revenue	Magnitude of beneficial effect
Arkansas Nuclear One	Pope County (study area)	26	Large
	Russellville School District	42	Large
D. C. Cook	Berrien County (study area)	14	Moderate
	Lake Township (study area)	88	Large
	Bridgman School District	81	Large
Diablo Canyon	San Luis Obispo Co. (study area)	11	Moderate
	San Luis Coastal Unified School District	39	Large
Indian Point	Westchester County (study area)	0	Small
	Town of Cortlandt	33	Large
	Hudson School District	37	Large
	Village of Buchannan	49	Large
Oconee	Oconee County (study area)	14	Moderate
	Oconee School District	14	Moderate
Three Mile Island	Londonderry Township (study area)	< 1	Small
	Middletown Borough (study area)	< 1	Small
	Royalton Borough (study area)		
	Lower Dauphin School District	< 1	Small
		< 1	Small
Wolf Creek	Coffey County (study area)	45	Large
	Burlington School District	63	Large

Source: Staff computations.

4.7.3.1 Education

Few if any operations-related impacts on education were found at the case study sites. Communities had no substantial problems assimilating the children of the plant staff into local school systems. Educational impacts during the license renewal term would be small at all case-study sites, as has been the case during past operations. The number of new students would be low relative to the size of current school systems. This small impact could be mitigated by hiring additional staff members for the schools, building new educational facilities, or adding modular classrooms to existing facilities. However, because the impact is so small and implementation of these measures would be costly, such measures would not be warranted.

Based on the case-study analysis, educational impacts are projected to be of small significance at all plants. Because no additional teaching staff or classroom space would be needed, no mitigation measures beyond those implemented during the current term license would be warranted. This is a Category 1 issue.

4.7.3.2 Transportation

Transportation impacts related to current operations have been small at most sites but small to moderate at Three Mile Island and Wolf Creek during refueling and maintenance outages. Impacts to transportation during the license renewal term would be similar to those experienced during current operations and would be driven mainly by the workers involved in current plant operations. The 60 additional permanent workers expected during the license renewal term would represent only a small incremental addition to the continuing impacts from past normal operations, while the 30 incremental workers required during periodic refueling/maintenance outages would represent only a small increase in the number of workers typically involved in periodic outages under the original term of the license.

Based on past and projected impacts at the case study sites, transportation impacts would continue to be of small significance at all sites during operations and would be of small or moderate significance during scheduled refueling and maintenance outages. Because impacts are determined primarily by road conditions existing at the time of the project and cannot be easily forecast, a site specific review will be necessary to determine whether impacts are likely to be small or moderate and whether mitigation measures may be warranted.This is a Category 2 issue.

4.7.3.3 Public Safety

Overall, no serious disruptions of services occurred at the case study sites during the operations period. Existing services were adequate to handle the influx of plant staff. Impacts during license renewal would be largely the same as those that occurred during past operations. There would be little or no need for additional police or fire personnel. For this reason impacts would be of small significance at all sites. This small impact could be mitigated by hiring additional police or fire personnel, purchasing additional fire or police vehicles, building police or fire stations, or making improvements and additions to existing facilities. However, because existing services are projected to be adequate to handle plant-related demands and because mitigative measures would be costly, no mitigation measures beyond those implemented during the current term license would be warranted. This is a Category 1 issue.

4.7.3.4 Social Services

Information from case study sites and the literature support a determination of only small impacts on local social services associated with past operations. Impacts to social services during license renewal would be essentially the same as those that have occurred during past operations and would be of small significance at all sites. These impacts could be mitigated by hiring additional staff to administer existing social service programs or establishing new social service programs. However, because no change in the level of services is anticipated and because mitigative measures would be costly, no mitigation measures beyond those implemented during the current term license would be warranted. This is a Category 1 issue.

4.7.3.5 Public Utilities

Overall, there have been minimal impacts to public utilities as a result of plant operations. The existing capacity of public utilities was sufficient to accommodate the small influx of plant staff, and some locales experienced a noticeable decrease in the level of demand for services with the completion of original plant construction. Although impacts to public utilities during license renewal would be very similar to those that occurred during past operations, an increased problem with water availability may occur in conjunction with plant demand and plant-related population growth as a result of current water shortages in some areas. These shortages may result in moderate impacts to public water supplies at sites with limited water availability. This is a Category 2 issue.

4.7.3.6 Tourism and Recreation

Impacts to recreation and tourism during the license renewal term would be largely the same as those that have occurred during operations in the current term. Few or no adverse effects have occurred during current operations at the case-study sites, and some positive effects have resulted because taxes paid by the plants have allowed some municipalities to improve their recreational facilities and programs. Some plants have also increased local tourism. Based on the case study analysis, it is projected that any adverse impacts would be small at all plants and would primarily be the continuation of impacts of past operations. Some positive impact to tourism and recreation also may continue. These impacts could be mitigated by improving existing recreation facilities or adding recreation areas to meet the expanded demand. Because current facilities would be adequate to accommodate local demand and adding new facilities would be costly, no mitigation measures beyond those implemented during the current term license would be warranted. This is a Category 1 issue.

4.7.4 Off-Site Land Use

This section evaluates the impact of plant-induced changes on local land-use and development patterns produced by plant operation during the license renewal term. Detailed definitions of the three magnitudes of land-use change are provided in Section 3.7.5.1. The magnitude of change to off-site land use is considered small if very little new development and minimal changes to an area's land-use pattern result. Moderate change results if considerable new development and some changes to the land-use pattern occur. The magnitude of change is large if large-scale new development and major changes in the land use pattern occur. During the renewal term, new land-use impacts could result from plant-related population growth or from the use by local governments of the plants' tax payments to provide public services that encourage development. This analysis examines the land-use changes associated with past operations to project the potential new impacts of operations during the license renewal term. Conflicts between off-site land use and nuclear plant operations are not expected because federal regulations (10 CFR Part 54) require each licensee to ensure that its nuclear plant remains appropriately protected from any site-related hazards (e.g., airplanes, toxic gases), new or existing at the time the plant was licensed.

4.7.4.1 Analysis

In most cases, the land-use changes that have resulted from operations at the case study plants have been moderate (see Table 4.14 and Appendix C). However, local property tax payments that the utility makes on its nuclear plants have stimulated large indirect land-use changes in one study area because the local jurisdictions has been able to provide the public services (e.g., sewer and water lines, roads) necessary to support substantial industrial development.

For population-driven land-use impacts, the impact predictors are the same as those discussed for refurbishment (Section 3.7.5). The assessment of new tax-driven land-use impacts considered (1) the size of the plant's tax payments relative to the community's total revenues, (2) the nature of the community's existing land-use pattern, and (3) the extent to which the community already has public services in place to support and guide development. In general, if the plant's tax payments are projected to be small relative to the community's total revenue, new tax-driven land-use changes during the plant's license renewal term would be small, especially where the community has preestablished patterns of development and has provided adequate public services to support and guide development. If the plant's tax payments are projected to be medium to large relative to the community's total revenue, new tax-driven land-use changes would be moderate. This is most likely to be true where the community has no preestablished patterns of development (i.e., land use plans or controls) or has not provided adequate public services to support and guide development in the past, especially infrastructure that would allow industrial development. If the plant's tax payments are projected to be a dominant source of the community's total revenue, new tax-driven land-use changes would be large. This would be especially true where the community has no preestablished pattern of development or has not provided adequate public services to support and guide development in the past.

It is projected that population growth related to worker in-migration in the license renewal term would result in small land-use impacts for all of the socioeconomic case study areas (see Appendix C). In contrast, it is projected that new tax-driven land-use impacts would be large at one case study site and moderate at the others during the license renewal term.

4.7.4.2 Conclusion

Based on predictions for the case study plants, it is projected that all new population-driven land-use changes during the license renewal term at all nuclear plants will be small because population growth caused by license renewal will represent a much smaller percentage of the

Table 4.14 Levels of operations-related land-use change at seven case study sites

Plant	Magnitude
Arkansas Nuclear One	Moderate
D. C. Cook	Moderate
Diablo Canyon	Small
Indian Point	Moderate
Oconee	Moderate
Three Mile Island	Small
Wolf Creek	Large[a]

[a] Change due to tax-related impacts.
Source: The staff.

local area's total population than has operations-related growth. Also, any conflicts between offsite land use and nuclear plant operations are expected to be small. In contrast, it is projected that new *tax-driven* land-use changes may be moderate at a number of sites and large at some others. Because land use changes may be perceived by some community members as adverse and by others as beneficial, the staff is unable to assess generically the potential significance of site-specific off-site land use impacts. This is a Category 2 issue.

4.7.5 Economic Structure

The effects of plant operations during the license renewal term on local employment are predicted by comparing the projected number of direct and indirect jobs created during the license renewal term at a plant with projected total employment for the appropriate study area. Relatively few *new* plant-related jobs would be created during the license renewal term. Nearly all plant-related employment (and associated impacts) expected during that time period would represent a continuation of employment (and impacts) from past operations.

4.7.5.1 Definition of Significance Levels

A detailed explanation of levels of impact significance is in Section 3.7.6.1. Economic effects are small if plant-related employment accounts for <5 percent of total study area employment, moderate if it accounts for 5 to 10 percent, and large if it accounts for more than 10 percent of total study area employment. In summary, the relevant workers are those involved in plant operation, including both new and existing workers. Also, if the magnitude of plant-related employment relative to total study area employment is close to the upper bound for a particular significance level, the impact should be placed in the next higher significance category if the site is remotely located and has a low population density. A site is considered remote if, within a distance of 80 km (50 miles), there is no city with more than 100,000 persons. Low population density is less than 50 persons per 2.6 km^2 (1 square mile). This adjustment factor is necessary to determine the importance of plant employment to the local area in light of its proximity to other areas with competing employment opportunities.

4.7.5.2 Analysis

The economic impacts that have resulted from operating the case study plants range from small to large (see Table 4.15 and Appendix C). Plant-related employment ranges from less than 1 percent to 18 percent of total employment in the communities near the case study plants.

The economic impacts projected to occur during the license renewal term would be primarily a continuation of impacts that already have occurred. At most case study sites, the share of total local employment represented by plant-related employment will be the same as or slightly less than that during current operations (Table 4.15).

4.7.5.3 Conclusion

Based on the findings for the case study sites, economic impacts would be beneficial at all nuclear plant sites. These beneficial impacts would range from small to large.

Table 4.15 Current and projected employment effects of plant operation for the sites in the case study[a]

	Current operations		License renewal term operations	
Plant	Percentage of study area employment[b]	Magnitude of impact	Percentage of study employment[b]	Magnitude of impact
Arkansas Nuclear One	12	Large	8.9	Large
D. C. Cook				
Bridgman/Lake Township	8	Moderate	8.1	Moderate
Berrien Co.	2	Small	1.8	Small
Diablo Canyon	2	Small	1.2	Small
Indian Point	< 1	Small	< 1.0	Small
Oconee	7	Moderate	3.6	Small
Three Mile Island	13	Large	9.8	Large
Wolf Creek	18	Large	7.1	Moderate

[a] Includes the effect of direct *and* indirect jobs and income created by plant operations.
[b] By place of residence.
Source: Appendix C.

4.7.6 Aesthetic Resources

This section evaluates the impacts on aesthetic resources from continued operation during an extended license renewal period. Significance levels of impacts are the same as those described in Section 3.7.8. The analysis of aesthetic impacts focuses on the visibility and perception of the plants' buildings, particularly containment structures and cooling towers and their associated water vapor plumes. These site features are often visible from neighborhoods, roads, and recreation-based water bodies over a wide area. However, no new visual changes are expected during the renewal term, and impacts primarily would be those that currently exist and would change only as the public's perceptions changed or as new information about affected resources arose.

The evaluation of impacts of past power plant operations and projected future impacts on aesthetic resources involved the following: (1) staff examination of local perceptions at the seven case study sites, as reported by key informants; (2) a brief survey of the original and eventually realized aesthetic impacts at other operating nuclear power plants; (3) a survey of relevant academic literature; and (4) a review of recent newspaper and magazine articles related to these issues. In addition, the staff reviewed several final environmental impact statements prepared by NRC for plants located in areas where aesthetic impacts were perceived to be an important issue: the Indian Point Nuclear Power Plant, located in the lower Hudson River Valley in New York (NUREG-0042, NUREG-0574, Jones and Jones 1975); the Greene County Nuclear Plant in the mid-Hudson River Valley (NUREG-0512); the Montague Nuclear Plant, in north Central Massachusetts (NUREG-0084); and Floating Nuclear Plant, an offshore location (NUREG-0394). Finally, the staff reviewed research sponsored by NRC that developed an econometric model for explaining and predicting visual aesthetic impacts.

4.7.6.1 Analysis

Nuclear power plants—particularly those with natural draft cooling towers—stand out starkly from their backgrounds both physically and symbolically. Their containment buildings and, when present, their hyperbolic cooling towers mark these industrial facilities as decidedly different, although their novelty typically appears to wear off for people who view them repeatedly.

Nuclear plants are usually situated in open areas near bodies of water, rendering cooling towers even more visible. Although they are visible from as far away as 10 miles, the structures are typically partially obscured by trees, buildings, or even slight changes in topography. There are few environments where such structures are perceived as well integrated with surrounding landscapes. Additionally, the visible vapor plumes associated with cooling towers can rise more than 5000 ft above the towers and extend as far as 9 miles downwind. Such a presence, although visible only part of the time under certain meteorological and seasonal conditions, extends the plant-related viewshed considerably beyond that of a tower alone.

At Indian Point, opposition to the plant is difficult to separate from opposition to its effect on aesthetic values, which, according to critics, have been diminished by the plant (K. Kennedy; D. Samson; N. Castro; D. Clyde; L. Gobrecht; K. Sauer telephone interviews with James Saulsbury, June 22, 1990). However, based on a viewshed analysis by landscape architects, the plant is either not visible from or is only insignificantly visible from historical sites in the area (Jones and Jones 1975). The plant is visible from the Peekskill Waterfront, from the Stoney Point Marina, from several established areas in Buchanan and Peekskill, and from approaches on the Hudson River (NUREG-0574). Although opposition to a nuclear facility and aesthetic concerns may both be issues in Westchester County, New York, it appears to be far from the situation in South Carolina (Oconee) and Kansas (Wolf Creek). Structures of the D. C. Cook plant (Michigan) and the Diablo Canyon plant (California) are sufficiently hidden or integrated into the existing landscapes that it is difficult to generalize about the public's attitude toward effects on aesthetic resources. The surrounding community seems generally well accustomed to the Arkansas Nuclear One plant in rural Arkansas and has some reservations only about the cooling tower and plume. The 1979 accident at the Three Mile Island plant (Pennsylvania) illustrates how attitudes seem to have directly affected aesthetic preferences (see Appendix C).

From the analysis of the case study plants (summarized in Table 4.16), perceptions of adverse impacts on aesthetic resources from the continued operation of nuclear power plants are probable in limited circumstances. Such circumstances would include areas that have concentrated aesthetic resources within a plant's viewshed or areas where past associations with a plant could diminish one's enjoyment of the physical environment. But even in these circumstances, the staff has not found clear and widespread evidence of adverse consequences to community institutions and functions that would justify characterizing a site as having a large impact.

Among the case study sites, Wolf Creek, Three Mile Island, Oconee, and Diablo Canyon all have had some impacts on prehistoric sites. At Wolf Creek, the presence of the nuclear power plant was credited as a positive force in local preservation efforts because (1) it brought new people into the area, who in turn influenced local citizens regarding the value and benefits that support of historic preservation could bring to a community, and (2) the increased incomes and expanded work force resulted in some neglected structures becoming occupied and repaired (M. Sirico; M. Reams telephone interviews with James Saulsbury, June 22, 1990).

Historic and archaeological resources can vary widely from site to site. Furthermore, they may have been identified only recently (e.g., an archaeological site) or their historic significance only recently established (e.g., a historic building). For these and other reasons, the National Historic Preservation Act of 1966 requires that the agency undertaking a major action consult with the State Historic Preservation Office to determine whether historic resources exist on or near the site and whether they will be affected by the proposed action.

4.7.6.2 Conclusion

The staff believes that the case studies and the other sources of information consulted have bounded the impacts of continued operation of nuclear power plants on aesthetic resources. Under the proposed provisions of license renewal, no applicant is expected to alter the existing visual intrusiveness of any plant. Certainly, the staff expects that some individuals at nuclear plant sites would perceive the plant structures and vapor plumes negatively. These perceptions will be based on purely

Table 4.16 Summary of past and projected impacts on aesthetic resources from operation of seven nuclear power plants in the case study

Impact predictors	Arkansas Nuclear One	D. C. Cook	Diablo Canyon	Indian Point	Oconee	Three Mile Island	Wolf Creek
Plant located near physical or environmental contexts memorialized in popular or professional media	No	No	No	Yes	No	No	No
Plant viewed as decidedly obtrusive into existing landscape	Somewhat	No	No	Yes	No	Yes	No
Active, widely shared, organized opposition to plant's operation because of plant's decided obtrusiveness	None	None	None	None	None	None	None
Measurable socioeconomic impact resulting from decreased aesthetic enjoyment of environment	No	No	No	Limited	No	Limited	No
Significance of past and projected impacts[a]	Insignificant	Insignificant	Insignificant	Moderate	Insignificant	Moderate	Insignificant

[a] Impacts during the license renewal term are expected to be the same as those experienced during past operations unless new information arises or there is a change in the context in which the plant operates.

Source: Appendix C.

aesthetic considerations (for instance, that the plant is out of character or scale with the community), on environmental and safety concerns, or on an anti-nuclear orientation. Whatever the consideration, the staff believes that these individuals' enjoyment of the environment will be depreciated. However, because license renewal will not alter the visual intrusiveness of any plant, the number of individuals having negative perceptions would probably remain constant. The number of such individuals has not been sufficient to measurably impact community institutions and functions in the past, so the staff believes that the impacts on aesthetic resources would be small in the future. For these individuals, mitigation through the use of nonreflective surfaces and tree plantings would be impractical from both efficiency and cost-benefit perspectives; therefore, no mitigation measures beyond those implemented during the current term license would be warranted. The impact on aesthetic resources is a Category 1 issue.

4.7.7 Historic and Archaeological Resources

This section evaluates potential impacts of license renewal term operations to historic and archaeological resources.

4.7.7.1 Definition of Significance Levels

Sites are considered to have small impacts of historic and archaeological resources (1) if the State Historic Preservation Office (SHPO) identifies no significant resources on or near the site, or (2) if the SHPO identifies (or has previously identified) significant historic resources but determines they will not be affected by plant refurbishment, transmission lines, and license-renewal-term operations and there are no complaints from the affected public about altered historic character, and (3) if the conditions associated with moderate impacts do not occur. Moderate impacts may result if historic resources, determined by the SHPO not to be eligible for the National Register, nonetheless are thought by the SHPO or local historians to have local historic value and to contribute substantially to an area's sense of historic character. Sites are considered to have large impacts to historic resources if resources determined by the SHPO to have significant historic or archaeological value would be disturbed or otherwise have their historic character altered through refurbishment activity, installation of new transmission lines, or any other construction (e.g., for waste storage facility). Determinations of significance of impacts are made through consultation with the state historic preservation officer.

4.7.7.2 Analysis

Impacts to historic and archaeological resources during the license-renewal term would be largely the same as those occurring during the current operations period. At the case-study sites, only small impacts are known to occur. However, any construction activity during the license renewal term, such as building a new waste storage facility or a new access road to a transmission corridor, could induce new impacts. Also, it is possible that previously unknown historic and archaeological resources will be identified or their historic significance will be established in the future. As discussed at length in Section 3.7.7, a determination of impact to historic and archaeological resources must be made through consultation with the SHPO as mandated by the National Historic Preservation Act.

4.7.7.3 Conclusions

Although it is unlikely that historic or archaeological impacts of moderate or large significance would occur during the license-renewal term, determinations of impacts to historic and archaeological resources are site-specific in nature and must be made through consultation with the SHPO. Any mitigation measures must likewise be determined on a case-by-case basis. Because site-specific and activity-specific information is needed to assess the significance of impacts to historic and archaeological resources, this is a Category 2 issue.

4.8 GROUNDWATER USE AND QUALITY

4.8.1 Groundwater Use

Those nuclear plants that use groundwater may affect the utility of groundwater to neighbors. This impact could occur as a direct effect of pumping groundwater, thereby either lowering the water table and reducing the availability or inducing infiltration of water of lesser quality into the ground. Neighboring groundwater users could also be affected indirectly if construction or operation of the power plant were to disrupt the normal recharge of the groundwater aquifer. The impact to neighboring groundwater users is likely to be most significant at a site where water resources are limited. Groundwater usage impact may be important at those sites where a power plant's usage rate exceeds 0.0063 m^3/s (100 gpm). Lower usage rates are not expected to impact sole source or other aquifers significantly.

Groundwater is not used at all nuclear power plants, and where it is used, the rate of usage varies greatly among users. Only Grand Gulf uses groundwater as a source of makeup to the condenser cooling system. This largest user employs a Ranney well collection system to draw groundwater from the Mississippi River alluvial aquifer. Other plants use lesser amounts of groundwater for service water systems or for potable water. Some licensed plants intentionally lower the groundwater table, either by pumping or by a system of drains, in the vicinity of building foundations.

The groundwater-use issue was evaluated by examining the groundwater requirements of appropriate subsets of nuclear power plants. Four subsets were established to encompass the entire scope of groundwater-use issues as described above. One subset consists of sites in regions where the water table or artesian water levels historically have been falling for a number of years (Atlantic and Gulf coastal plains, upper Midwest, Arizona, and California). A second subset consists of sites on both high ground and low-lying areas adjacent to the Great Lakes, the Atlantic and Gulf coasts, and the lower Mississippi River where extensive operational dewatering systems may have been installed. A third subset consists of plants with cooling towers adjacent to small rivers. The fourth subset consists of the only plant using groundwater for cooling tower makeup water.

Data were taken from appropriate final safety analysis reports (FSARs) and final environmental statements (FESs) pertaining to operation of nuclear power plants, and sites having potential groundwater-use conflicts were identified. Appropriate state water-use permitting agency representatives and U.S. Geological Survey (USGS) personnel were interviewed by telephone for additional information. Evaluations and conclusions for each of these groundwater-use scenarios are presented separately in the following discussion.

4.8.1.1 Potable and Service Water

Only one of the upper Midwest sites examined withdraws more than 0.0063 m^3/s (100 gal/min) of groundwater for potable and service water systems [Duane Arnold is permitted to withdraw 0.19 m^3/s (3000 gal/min) by the Water Supply Section, Environmental Protection Division, Iowa Department of Natural Resources]. Other plants (Braidwood, Cook, Dresden, Kewaunee, La Salle, Point Beach, and Zion) in the upper Midwest withdraw small amounts 19×10^{-5} to 536×10^{-5} m^3s (3 to 85 gal/min) of groundwater for potable water systems, or none at all. Except for Duane Arnold, all service water systems are supplied by alternative resources (municipal water systems, lakes, or rivers).

Several Atlantic and Gulf coastal plain sites that are not near municipal water suppliers withdraw larger amounts of groundwater than the upper Midwest sites for potable and service water systems. Withdrawals for these sites (Calvert Cliffs, Crystal River, Hope Creek, Salem, and River Bend) range from 0.025 to 0.050 m^3/s (400 to 800 gal/min). Other coastal sites (Turkey Point, St. Lucie, and Waterford) obtain potable and service water from municipal suppliers.

Only one of the two western sites withdraws groundwater for potable and service water systems. The Palo Verde site in Arizona withdraws 0.063 m^3/s (1000 gal/min) from a confined aquifer.

Many plants use groundwater only for potable water systems and require less than 0.0063 m^3/s (100 gal/min). The cones of depression around such wells generally remain within the plant boundary (typically the case for upper Midwest sites). Where the cone of depression does not extend beyond the site boundary, the plant groundwater use is not expected to contribute to cumulative impacts on groundwater supply. For sites having plant wells that produce more than 0.0063 m^3/s (100 gal/min) (sites that draw both service and potable water from wells), cones of depression may extend beyond the plant boundary. For these sites, a reasonable likelihood exists that off-site private wells will be impacted. The staff considers plant contributions to groundwater use to be of small significance where the plant groundwater consumption is less than 0.0063 m^3/s (100 gal/min).

The effect of groundwater usage on neighboring groundwater users will depend on the rate of usage and the distance to the neighboring well. A neighboring well close to the well field of a plant using a large amount of groundwater could experience some decline in yield. The power plants using groundwater are generally remotely located, and groundwater is not thought to be a limited resource. Conflicts that do arise should be resolvable by taking steps to restore yield of the affected water supply, such as deepening the affected wells.

In conclusion, this is a Category 1 issue for those plants using less than 0.0063 m^3/s (100 gal/min) of groundwater for potable and service water. At this usage rate, there would be no significant depletion of the groundwater supply which could impact other users. Because the cone of depression would not extend beyond the site boundary, mitigation is not warranted. However, if use exceeds 0.0063 m^3/s (100 gal/min), there is a possibility of moderate or large adverse effects, and mitigation may be warranted. Therefore, this is a Category 2 issue for those plants using more than 0.0063 m^3/s (100 gal/min) of groundwater.

4.8.1.2 Operational Dewatering Systems

Operational dewatering systems are in place at the Perry site (on a bluff overlooking Lake Erie) and the Calvert Cliffs site (on a bluff overlooking Chesapeake Bay). The Perry site is actively dewatered by pumping wells, and the water table is depressed by more than 15 m (50 ft). During construction dewatering, the cone of depression extended outward about 150 m (500 ft) (it remained inside the site boundary). Less vigorous pumping is required during operational dewatering, and the cone of depression is reduced. If pumping were discontinued, the water table would rise approximately 6 m (20 ft), groundwater would continue to drain passively through a gravity drain system, and the cone of depression would continue to shrink. The Calvert Cliffs site is passively dewatered by an underdrain system (natural gravity flow). The base of the reactor containment structure at Calvert Cliffs is more than 6 m (20 ft) below sea level, whereas the water table is maintained several feet above sea level. There is no impact to neighboring groundwater users at either of these sites.

None of the sites in low-lying areas of the Atlantic coastal plain had operational dewatering systems (i.e., Hope Creek, Millstone, Oyster Creek, St. Lucie, and Turkey Point). At St. Lucie, a construction site dewatering system [pumped at 0.80 m^3/s (13,000 gal/min)] was decommissioned before the plant was placed in operation. The St. Lucie construction/ operation case history is typical of plants in low-lying areas.

For other sites using active dewatering systems (systems in which groundwater is pumped from the aquifer), the same bounding conditions apply as for groundwater use in potable and service water systems. That is, for operational dewatering systems that do not exceed 0.0063 m^3/s (100 gal/min), impacts would be of only small significance. Because the cone of depression would not extend beyond the site boundaries, no mitigation measures beyond those implemented during the current term license would be warranted. For plants that withdraw more than 0.0063 m^3/s (100 gal/min), the significance of the groundwater withdrawal cannot be determined generically. Groundwater use through operational dewatering is a Category 2 issue.

4.8.1.3 Surface Water Withdrawals for Cooling Towers

Many plants located on small rivers have cooling towers. Rivers often supply alluvial aquifers, and large-scale withdrawals of makeup water for evaporative loss could impact an alluvial aquifer during periods of low flow. However, withdrawal from the river is regulated by local or state agencies.

For example, the withdrawal of water at Duane Arnold is restricted at low flow (Water Use Permit). Under normal flow conditions, Duane Arnold withdraws 1.6 m^3/s (27,000 gal/min) from the Cedar River as cooling tower makeup water. This plant continues to operate, at least temporarily, during low flow by withdrawing water from a standby reservoir on a tributary to Cedar River. This reservoir is used only during emergencies when low-flow conditions exist on the Cedar River.

Indirect groundwater-use conflict resulting from surface water withdrawal from a small river for use in cooling towers is a potentially important concern. Because the significance of these conflicts cannot be determined at this time, this is a Category 2 issue.

4.8.1.4 Use of Groundwater for Cooling Tower Makeup

The Ranney wells at Grand Gulf withdraw groundwater from Mississippi River alluvium at a rate of 1.5 m^3/s [24,000 gal/min (34 million gal/day)] for use as cooling tower makeup water to avoid the aquatic effects of a surface water intake. Groundwater in Mississippi River alluvium is used primarily for irrigation and catfish farming (Jamie Crawford, Mississippi Bureau of Land and Water Resources, telephone interview with W. P. Staub, ORNL, Oak Ridge, Tennessee, December 3, 1990). Generally, groundwater from the alluvial aquifer is too high is iron content to be used for municipal water supplies.

The impact of cooling water intake on groundwater at the Grand Gulf plant (the only plant employing Ranney wells) does not conflict with other groundwater uses in the area. However, conflicts could develop if other uses develop (e.g., additional catfish farms). Because it is not possible to predict whether conflicts will occur at Grand Gulf or the significance of impacts associated with Ranney well use at other plants (if they were to adopt their use), it is not possible to determine the significance of Ranney well use at this time. This is a Category 2 issue.

4.8.2 Groundwater Quality

Impairment of groundwater quality could occur at estuary and ocean site facilities that withdraw groundwater for any purpose (e.g., potable and service water systems, operational dewatering). Long-term pumping of groundwater from coastal plain aquifers by industrial and municipal facilities has contributed to saltwater intrusion in some areas of nearly every Atlantic and Gulf Coast state (USGS 1990). The saltwater intrusion issue was evaluated by examining groundwater use at selected nuclear power plants sited on estuaries and oceanic coastlines. Operational dewatering is not taking place at any of the estuaries or coastal sites.

Groundwater quality could also be impaired at inland sites where groundwater may be replaced by poorer quality river water through induced infiltration (NUREG-0777). Potential impairment of groundwater quality at facilities that have large cooling ponds is discussed in Section 4.8.3.

At this time, no licensed plant is located on a sole-source aquifer (i.e., sole or primary source of water supply for an area). If a site occupied by one of the licensed nuclear plants were in an area designated as a sole-source aquifer, NRC would cooperate with responsible agencies in making required information available. Under the provisions of the SDWA, states must establish demonstration programs for protection of critical aquifers.

Slightly elevated concentrations of tritium have been observed in groundwater adjacent to the Prairie Island plant on the Mississippi River in southern Minnesota (Minnesota Environmental Quality Board 1991; Minnesota Department of Public Service 1992). These elevated concentrations have not altered the current use of groundwater near the site. One off-site privately owned well has reported tritium concentrations ranging between 800 and 1000 pCi/L (dates of measurements are uncertain, but they are no more recent than 1991). By comparison, tritium concentrations in North American streams were about 10 pCi/L prior to the beginning of the nuclear age and about 4000 pCi/L at the end of large-scale atmospheric testing of nuclear weapons in 1963. Radioactive decay of tritium between 1963 and 1992 would produce a concentration of about 715 pCi/L (DOE 1992). If tritium concentrations at Prairie Island were as high as 1000 pCi/L in 1992, then perhaps one-third of the tritium contamination found in local groundwater might be attributable to the Prairie Island plant and the balance would be attributable to atmospheric testing. Future radioactive decay of tritium would further reduce its overall concentration in groundwater. Natural decay and tritium release to the environment at Prairie Island might be expected to reach equilibrium eventually at around 300 pCi/L. This compares with a regulatory limit of 20,000 pCi/L in drinking water.

Data were taken from appropriate FSARs and FESs pertaining to the operation of nuclear power plants. Sites having a potential impact on groundwater quality were identified; appropriate state water-use permitting agency representatives and USGS personnel were interviewed by telephone for additional information. Groundwater quality impacts are considered to be of small significance when the plant does not contribute to changes in groundwater quality that would preclude current and future uses of the groundwater. Hence, the contribution of plant operations (during the license renewal period) to the cumulative impacts of major activities on groundwater quality would be relatively small.

4.8.2.1 Potable and Service Water

Groundwater withdrawals in estuary and oceanic areas can cause saltwater intrusion into freshwater aquifers. Saltwater intrusion, where it occurs, is the cumulative effect of groundwater consumption by users in the affected region and therefore could have a cumulative impact on groundwater quality. Estuary and oceanic sites located in rural areas withdraw groundwater from confined aquifers at rates between 0.025 and 0.063 m^3/s (400 and 1000 gal/min) (e.g., for Calvert Cliffs, Crystal River, and Hope Creek–Salem). In contrast, sites located near urban areas purchase water for their potable and service water systems from municipal suppliers (e.g., Millstone, St. Lucie, and Turkey Point), which themselves use groundwater resources. Directly or indirectly, all nuclear power plants in Florida derive their potable and service water supply from groundwater. The staff considers nuclear plant contributions to saltwater intrusion to have small significance on groundwater quality where the plant's groundwater consumption is less than 10 percent of the regional total.

Withdrawal of potable and service water at nuclear power plants represents a small percentage of county-wide water supplies derived from groundwater in both urban and rural counties of Florida. According to Marella (1988, data for 1985), 2.98 and 21.3 m^3/s (68 and 486 million gal/day) of groundwater were withdrawn for all uses in semi-urban St. Lucie and urban Dade Counties where the St. Lucie and Turkey Point plants are located, respectively. Both of these plants purchase about 0.063 m^3/s [1.4 million gal/day (1000 gal/min)] from municipal sources in these counties. About 1.09 m^3/s (25 million gal/day) of groundwater were withdrawn in rural Citrus County, compared with

1.4 million gal/day withdrawn by Crystal River plant wells in that county. Nuclear plant groundwater consumption at its current rate would not contribute significantly to any future saltwater intrusion that might occur.

Ken Miller (Maryland Water Resources Administration, Water Rights Division, telephone interview with W. P. Staub, ORNL, Oak Ridge, Tennessee, November 28, 1990) believes that saltwater intrusion of the Aquia aquifer, which serves the Calvert Cliffs plant, is unlikely. He bases his conclusion on the fact that this aquifer is confined and changes to an aquitard on its downdip (seaward) side as illustrated in USGS (1988) and Chapelle and Drummond (1983).

Geologic conditions as described above are site specific. The USGS (1988) states that the Raritan-Magothy aquifer in New Jersey is susceptible to saltwater intrusion and is already contaminated in some places. However, based on data for Florida, power plant groundwater consumption ranges from about 0.3 percent to 6 percent of the total in urban and rural regions, respectively. Saltwater intrusion is more likely to occur in urban regions because of the greater demand for water, and electric power generation would be a small contributor.

The potential for inducing saltwater intrusion is considered to be of small significance at all sites because groundwater consumption from confined aquifers for potable and service water uses by nuclear power plants is a small fraction of groundwater use in all cases. Where saltwater intrusion has been a problem, the large uses have been agricultural (irrigation) and municipal groundwater consumption. Mitigation for saltwater intrusion, if needed, would likely take the form of groundwater withdrawal curtailments. Because nuclear plant water consumption represents a small fraction of total consumption, consumption curtailments of large groundwater users (i.e., municipal or agricultural users) are more likely. Consequently, groundwater use curtailments are not expected to be warranted for nuclear plants to mitigate saltwater intrusion impacts. However, even if pro-rata curtailments of groundwater consumption were required of all users, nuclear plants could accommodate most conceivable reductions without adversely affecting their operations. Therefore, this is a Category 1 issue.

4.8.2.2 Groundwater Withdrawal at Inland Sites

Grand Gulf uses large quantities of groundwater from an alluvial aquifer as described in Section 4.8.1.4. Geohydrologic modeling has predicted that groundwater would be replaced by river water of lesser quality by induced infiltration (NUREG-0777). A groundwater monitoring system is currently being installed at Grand Gulf, but no data are currently available to validate the model. Nevertheless, the model's prediction is reasonable.

The net flow of the infiltrating river water will be into the Grand Gulf Ranney well collectors. Thus, water quality change will be largely confined to the plant. Any other users of groundwater from the same formation would induce infiltration in a similar manner. The quality of Mississippi River water would not preclude the current uses of the groundwater from the alluvium. Long-term use of Ranney wells may cause groundwater quality to approach the water quality of the adjoining river. Therefore, the change in water quality resulting from use of Ranney wells would be of small significance at any site. The only possible mitigation for a plant using Ranney wells would be to construct and operate a water intake structure in the nearby water body. However, because the change in groundwater quality would not preclude current and future uses and because building a surface water intake structure would be costly and have adverse environmental effects of its own (Sect. 4.8.1.4), no mitigation measures beyond those implemented during the current term license would be warranted. This is a Category 1 issue. Because groundwater quality level would never be lower than that of the nearby Mississippi River, groundwater withdrawal for Grand Gulf's use would not contribute significantly to the cumulative impacts of water infiltration into the aquifer.

4.8.3 Groundwater Quality Impacts of Cooling Ponds

Alteration of groundwater quality in shallow, unconfined aquifers may occur at the nine nuclear power plant sites that use cooling ponds (Section 4.4.1). Irrigation and private domestic water supplies are the principal off-site uses of these groundwater resources. This issue was evaluated by examining off-site land uses and potential for shallow groundwater utilization at all nine sites. The impact on private uses of groundwater was subdivided into two sets based on current land use: (1) sites surrounded by undeveloped land, including saltwater marshes, and (2) sites adjacent to farmland. Short- and long-term potential for utilization of shallow groundwater resources depends on current land use.

Four plant sites are surrounded by undeveloped land or have large exclusion areas around them. These plants are Clinton (large exclusion area), Dresden (surrounded by undeveloped woodlands), South Texas, and Turkey Point (surrounded by saltwater marshes). Although off-site groundwater is not being used currently near these sites, its long-term use is not necessarily precluded.

The remaining five sites have relatively small exclusion areas and are adjacent to farmland. These plants are Braidwood, La Salle, Robinson, Summer, and Wolf Creek. A limited amount of off-site groundwater is being used currently or could potentially be used at these sites in the near term.

All of the cooling ponds are unlined and have surface areas that range from 637 to 2960 ha (1573 to 7310 acres). Cooling pond water has higher concentrations (than makeup water) of total dissolved solids due to evaporation, heavy metals due to contact of cooling water with plant equipment, and chlorinated organic compounds used to prevent biofouling of equipment. The average concentration of total dissolved solids in continuously recycled cooling pond water is about 2.8 times as large as that in makeup water.

Water seeping from these ponds commingles with underlying shallow groundwater and produces a groundwater mound. Groundwater spreads laterally away from this mound. The commingled groundwater will eventually reach off-site areas. At this point, groundwater quality will be between that of the cooling pond water and the quality of the naturally occurring groundwater. These groundwater contaminant plumes are not expected to alter current groundwater-use categories (as defined by various state regulatory agencies) because contaminant concentrations are not expected to rise significantly. However, groundwater quality is not routinely monitored for contaminants specific to cooling ponds.

Depending on groundwater velocity and adsorption characteristics, some contaminants (diluted by dispersion in natural groundwater) may reach off-site areas during the initial term of the license. As plant operation continues, groundwater quality at points near the site may approach the quality of the cooling pond water. If necessary, mitigation of groundwater contamination due to cooling pond operations might take the form of lining the ponds to reduce infiltration or cleaning groundwater by pumping and treating, both of which would be costly.

The extent of groundwater contamination by cooling ponds has not been documented at this time. Off-site groundwater monitoring is not standard practice at these sites, and there are no data with which to characterize the significance of potential off-site groundwater contamination. For those plants with cooling ponds located in a salt marsh (South Texas and Turkey Point), groundwater quality is not a significant concern because groundwater quality beneath salt marshes is too poor for human use. Because continued infiltration into the shallow aquifer will not change its groundwater use category (which is already restricted to industrial uses only) and because potential mitigation measures would be costly, no mitigation measures beyond those implemented during the current term license would be warranted. Therefore, for plants with cooling ponds located in salt marshes, this is a Category 1 issue. Groundwater in salt marshes is already restricted to industrial use, and there is no mechanism by which cooling pond water infiltrating into the groundwater would change its use category. The impact on groundwater quality for plants with cooling ponds that are not located in salt marshes is a Category 2 issue.

4.9 SUMMARY OF IMPACTS OF OPERATION

The conclusions about the environmental impacts of nuclear power plant operation during a license renewal term are summarized below.

Threatened and Endangered Species

- It is not possible to reach a conclusion about the significance of potential impacts to threatened and endangered species at this time because (1) the significance of impacts on such species cannot be assessed without site- and project-specific information that will not be available until the time of license renewal and (2) additional species that are threatened with extinction and that may be adversely affected by plant operations may be identified between the present and the time of license renewal. This is a Category 2 issue.

Surface Water Quality, Hydrology, and Use

- The staff examined nine aspects of water quality that might be affected by power plant operations: current patterns at intake and discharge structures, salinity gradients, temperature effects on sediment transport, altered thermal stratification of lakes, scouring from discharged cooling water, eutrophication, discharge of biocides, discharge of other chemical contaminants (e.g., metals), and discharge of sanitary wastes. Open-cycle cooling systems are more likely than other cooling systems to have such effects because they withdraw and discharge very large volumes of water; however, the impacts for each of these effects were found to be of small significance for all plants, regardless of cooling system type. For each type of impact, the staff considered potential mitigation measures but found that none were warranted because they would be costly and would have very small environmental benefits. These are Category 1 issues.

- The staff found no potential for water use conflicts or riperian plant and animal community impacts of moderate or large significance for plants with open-cycle cooling systems because they are used on large water bodies. Because the potential mitigation measures are costly and because the potential benefits are small, the staff does not consider mitigation to be warranted. These are Category 1 issues.
- The staff found that water use conflicts and the effects of consumptive water use on in-stream aquatic and riparian terrestrial communities could be of moderate significance at some plants that employ cooling-tower or cooling-pond systems because they are often located near smaller water bodies. For plants with these cooling systems, these are Category 2 issues.

Aquatic Ecology

- The staff examined 12 potential effects that nuclear power plant cooling systems may have on aquatic ecology: (1) impingement of fish; (2) entrainment of fish (early life stages); (3) entrainment of phytoplankton and zooplankton; (4) thermal discharge effects; (5) cold shock; (6) thermal plume barriers to migrating fish; (7) premature emergence of aquatic insects; (8) stimulation of nuisance organisms; (9) losses from predation, parasitism, and disease among organisms exposed to sublethal stresses; (10) gas supersaturation; (11) low dissolved oxygen in the discharge; and (12) accumulation of contaminants in sediments or biota. Except for three potential impacts (entrainment of fish and shellfish, impingement of fish and shellfish, and thermal discharge effects), each of these was found to be of small significance at all plants. Because mitigation would be costly and provide little environmental benefit, no additional mitigation measures beyond those implemented during the current license term are warranted. These are Category 1 issues. The other three impacts would be of small significance at all plants employing cooling-tower cooling systems. Because mitigation would be costly and provide little environmental benefit, no additional mitigation measures beyond those implemented during the current license term are warranted. For those plants, these are Category 1 issues. However, the impacts may be of greater significance at some plants employing open-cycle or cooling-pond systems; and these are Category 2 issues for those plants.

Groundwater Use and Quality

- The staff found that groundwater use of less than 100 gal/min is of small significance because the cone of depression will not extend beyond the site boundary. Conflicts might result from several types of groundwater use by nuclear power plants. If groundwater conflicts arose, they could be resolvable by deepening the affected wells, but no such mitigation is warranted because sites producing less than 0.0063 m^3/s (100 gal/min) would not have a cone of depression that extends beyond the site boundary. This is a Category 1 issue. Plants that extract more than 0.0063 m^3/s (100 gal/min), including plants using Ranney wells, may have groundwater use conflicts of moderate or large significance. Groundwater use is a Category 2 issue for such plants.

- Cooling system makeup water consumption may cause groundwater use conflicts. During times of low flow, surface water withdrawals for cooling tower makeup from small rivers can reduce groundwater recharge. Because the significance of such impacts cannot be determined generically, this is a Category 2 issue.
- Groundwater withdrawals could cause adverse effects on groundwater quality by inducing intrusion of lower-quality groundwater into the aquifer. The staff found that the significance of these potential impacts are of small significance in all cases. Because all plants except Grand Gulf use relatively small quantities of groundwater and surface water intrusion at Grand Gulf would not preclude current water uses, the staff found that mitigation was not warranted. This is a Category 1 issue.
- Cooling ponds leak an undetermined quantity of water through the pond bottom. Because the water in cooling ponds is elevated in salts and metals, such leakage may contaminate groundwater. The staff found that groundwater quality impacts of ponds located in salt marshes would be of small significance in all cases because salt marshes already have poor water quality. This is a Category 1 issue. Cooling ponds that are not located in salt marshes may have groundwater quality impacts of small, moderate, or large significance. This is a Category 2 issue.

Air Quality

- Small amounts of ozone and substantially smaller amounts of oxides of nitrogen are produced by transmission lines; however, ozone concentrations generated by transmission lines are too low to cause any significant effects. The minute amounts of oxides of nitrogen produced are also insignificant. Thus, air quality impacts associated with the operational transmission lines during the renewal term are expected to be of small significance at all sites. Potential mitigation measures would be very costly and are not warranted. This is a Category 1 issue.

Terrestrial Ecology

- The potential impact of cooling tower drift on crops and ornamental vegetation arising from operations during the license renewal term is expected to be of small significance for all nuclear plants. No mitigation measures beyond those implemented during the current license term are warranted because there have been no measurable effects on crops or ornamental vegetation from cooling tower drift. This is a Category 1 issue.
- The impact of cooling towers on natural plant communities would continue to be unmeasurable as a result of license renewal and will therefore be of small significance. Because the impacts of cooling tower drift on native plants are expected to be small and because potential mitigation measures would be costly, no mitigation measures beyond those during the current term license would be warranted. This is a Category 1 issue.

- Bird mortality from collision with power lines associated with nuclear plants is of small significance for all plants because bird mortality is expected to remain a small fraction of total collision mortality associated with all types of man-made objects. Because the numbers of birds killed from collision with cooling towers are not large enough to affect population stability or the ecosystem, consideration of further mitigation is not warranted. Both bird collosion with power lines and bird collision with cooling towers are Category 1 issues.
- Because no threat to the stability of local wildlife populations or vegetation communities is found for any cooling pond, the impacts are found to be of small significance. Potential mitigation measures would include excluding wildlife (e.g., birds) from contaminated ponds, converting to a dry cooling system, or reducing plant output during fogging or icing conditions. The impacts are found to be so minor that consideration of additional mitigation measures is not warranted. These effects of cooling ponds are so minor and so localized that cumulative impacts are not a concern. This is a Category 1 issue.
- Maintaining power-line ROWs causes fluctuations in wildlife populations, but the long-term effects are of small significance. The staff found that bird collision with transmission lines are of small significance. Also, transmission line maintenance and repair would have impacts of only small significance on floodplains and wetlands. In each case, the staff found that potential mitigation measures beyond those implemented during the current license term would be costly and provide little environmental benefit, and thus are not warranted. These are Category 1 issues.
- Wildlife, livestock, and plants residing in power-line EMF apparently grow, survive, and reproduce as well as expected in the absence of EMF. The potential impact of EMF on terrestrial resources during the license renewal term is considered to be of small significance for all plants. Because the impact is of small significance and because mitigation measures could create additional environmental impacts and would be costly, no mitigation measures beyond those implemented during the current term license would be warranted. This is a Category 1 issue.

Land Use

- Land use restrictions are necessary within transmission-line ROWs. The staff found these impacts to be of small significance at all sites. Mitigation beyond that imposed when ROWs were established might include relocating the transmission line. The staff concluded that such mitigation would not be warranted because it would be very costly and provide little environmental benefit. This is a Category 1 issue.

Human Health

- During the license renewal term, the radiation dose commitment to the total worker population is projected to increase less than 5 percent at nuclear power plants under the typical scenario and less than 8 percent at any plant under the conservative scenario. The present operating experience results in about 30,000 person-rem/year for all licensed plants combined. After refurbishment, routine operating conditions are expected to result in 32,000 person-rem/year for all plants combined. The risk associated with occupational radiation exposures after license renewal is expected to be of small significance at all plants. No mitigation measures beyond those implemented during the current license term are warranted because the existing ALARA process continues to be effective in reducing radiation doses. This is a Category 1 issue.

- Among the 150 million people who live within 50 miles of a U.S. nuclear power plant, about 30 million will die of spontaneous cancer unrelated to radiation exposure from nuclear power plants. This number is compared with approximately 5 calculated fatalities associated with potential nuclear-power-plant-induced cancer. The estimated annual cancer risk to the average individual is less than 1×10^{-6}. Public exposure to radiation during the license renewal term is of small significance at all sites, and no mitigation measures beyond those implemented during the current license term are warranted because current mitigation practices have resulted in declining public radiation doses and are expected to continue to do so. This is a Category 1 issue.
- The significance of potential for electrical shock from charges induced by transmission lines that may occur during the license renewal term cannot be evaluated generically because no NESC review was performed for some of the earlier licensed plants. For those that underwent an NESC review, a change in the transmission line voltage may have been made since issuance of the initial operating license, or changes in land use since issuance of the original license could have occurred. This is a Category 2 issue.
- There is no consensus among scientists on whether 60-Hz electromagnetic fields have a measurable human health impact. Because of inconclusive scientific evidence, the chronic effects of electromagnetic fields would be not be categorized as either a Category 1 or 2 issue. If NRC finds that a consensus has been reached that there are adverse health effects, all license renewal applicants will have to address it in the license renewal process.
- Occupational health questions related to thermophilic organisms, like *Legionella* sp., are currently resolved using proven industrial hygiene principles to minimize worker exposures to these organisms in mists of cooling towers. Adverse occupational health effects associated with microorganisms are expected to be of small significance at all sites. Aside from continued application of accepted industrial hygiene procedures, no additional mitigation measures beyond those implemented during the current license term are warranted. This is a Category 1 issue.
- Thermophilic organisms may or may not be influenced by operation of nuclear power plants. The issue is largely unstudied. However, NRC recognizes a potential health problem stemming from heated effluents. Public health questions require additional consideration for the 25 plants using cooling ponds, lakes, canals, or small rivers because the operation of these plants may significantly enhance the presence of thermophilic organisms. The data for these sites is not now at hand and it is impossible with current knowledge to predict the level of thermophilic organism enhancement at any given

site. Thus, the impacts are not known and are site specific. Therefore, the magnitude of the potential public health impacts associated with thermal enhancement of *N. fowleri* cannot be determined generically. This is a Category 2 issue.

Noise

- The principal noise sources at power plants (cooling towers and transformers) do not appreciably change during the aging process. Because noise impacts have been found to be small and generally not noticed by the public, noise impacts are expected to be of small significance at all sites. Because noise reduction methods would be costly, and given that there have been few complaints, no additional mitigation measures are warranted for license renewal. This is a Category 1 issue.

Socioeconomics

- The staff examined socioeconomic effects of nuclear power plant operations during a license renewal period. Five of these would be of small significance at all sites: education, public safety, social services, recreation and tourism, and aesthetics. Because mitigation measures beyond those implemented during the current license term are costly and would offer little benefit, no additional mitigation measures are warranted. These are Category 1 issues. Four of the socioeconomic effects were found to have moderate or large significance at some sites: housing, transportation, public utilities (especially water supply), and off-site land use. These are Category 2 issues. In addition the statutory requirement (National Historic Preservation Act) requires consultation; thus historic and archaeological resources are Category 2 issues.

4.10 ENDNOTES

1. For example, Coleman et al. 1989; Fulton et al. 1980; Savitz et al. 1988; Spitz and Johnson 1985; Tomenius 1986; Wertheimer and Leeper 1979; Wilkins and Koutras 1988; Feychting and Ahlbom 1993; Petridow et al. 1993.
2. Anthony and Morrison 1985; Beason et al. 1982; Bunyan and Stanley 1983; Campbell et al. 1983; Castrale 1987; Wildlife No. 235; Connor and McMillan 1988; D'Anieri et al. 1987; DeFazio et al. 1988; de Waal Malefyt 1987; Freedman et al. 1988; FWS/OBS-79/22; Gangstad and Hesser 1989; Gangstad and Phillips 1989; Ghassemi and Quinlivan 1982; Hill and Camardese 1986; Hoffman and Albers 1984; Hoffman et al. 1990; Holechek 1981; Hudson et al. 1984; Kennedy and Jordan 1985; Kirkland 1978; Lautenschlager 1986; Linder and Richman 1990; Lochmiller et al. 1991; Mayer 1976; McComb and Rumsey 1982, 1983a, 1983b; Moore 1983; Morrison and Meslow 1984a, 1984b; Newton and Knight 1981; Rands 1986; Risebrough 1986; Roberts and Dorough 1984; Santillo et al., 1989a, 1989b; Savidge 1978; Schulz et al. 1992a, 1992b; Solberg and Higgins 1993; Steele 1984; Sullivan and Sullivan 1981, 1982; Thompson et al. 1991; Voorhees 1984; Walker 1983; Warren et al. 1984; White et al. 1981.
3. Anthony and Morrison 1985; Beason et al. 1988; Bunyan and Stanley 1983; Lautenschlager 1986; McComb and Rumsey 1983a; Moore 1983; Morrison

and Meslow 1984a, 1984b; Rands 1986; Risebrough 1986; Solberg and Higgins 1993.

4. Anderson 1979; Betsill et al. 1981; Bramwell and Bider 1981; Denoncour and Olson 1984; Eaton and Gates 1981; Everett et al. 1981; Geibert 1980; Kroodsma 1984c; Meyers and Provost 1981; Morhardt et al. 1984; Niemi and Hanowski 1984; Schreiber et al. 1976.
5. Anderson 1978; Beaulaurier et al. 1984; Brown et al. 1985; Crawford 1981; Faanes 1987; Fredrickson 1983; Howard et al. 1985; Krapu 1974; ORAU-142, 1978c; Malcolm 1982; Mathiasson 1993; Meyer and Lee 1981; Rusz et al. 1986.
6. Bohm 1988; Bridges and McConnon 1987; Denoncour and Olson 1984; Fitzner 1980; Gilmer and Stewart 1983; Knight and Kawashima 1993; Lee 1990; Paton and Kneedy 1993; Postovit and Postovit 1987; Roppe et al. 1989; Smith 1985; Stahlecker 1978; Steenhof et al. 1993; Williams and Colson 1989.
7. A discussion of the International System units used in measuring radioactivity and radiation dose is given in Appendix E, Section E.A.3.

4.11 REFERENCES

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5. ENVIRONMENTAL IMPACTS OF POSTULATED ACCIDENTS

5.1 INTRODUCTION

This section discusses each aspect of postulated accidents that is normally treated in the final environmental statements (FESs) for the operation of nuclear power plants. Methodologies that estimate future risks at each existing nuclear power plant site in the United States are developed in Section 5.3.3, considering an additional 20-year period of operation beyond the current license term.

The characteristics of nuclear power plant accidents are discussed (Section 5.2.1) to acquaint the reader with (1) the sources of radiation from postulated accidents, (2) the potential pathways of radiation to the environment, and (3) the possible health effects of exposure to such accidental releases. Historical experience and observed impacts of nuclear power plant accidents are discussed next (Section 5.2.2), followed by a description of the various measures taken in the design and operation of a power plant to reduce the likelihood or consequences of an accident (Section 5.2.3).

The impacts of accident risks during a license renewal period are discussed in Section 5.3. A brief discussion of the primary concern arising from extending the operational life of nuclear power plants is provided (Section 5.3.1). This concern centers on the effects that plant aging and increasing population can have on the probability and consequences of accidents. Calculation of the estimated environmental impacts and risks due to postulated accidents during the license extension period is discussed in Sections 5.3.2 and 5.3.3. Consequences of design-basis and severe accidents are reviewed. The potential pathways for radiation release examined are (1) direct release to the atmosphere, (2) fallout on open bodies of water, and (3) groundwater. Existing severe accident analyses were reviewed and used to predict consequences at all sites. The potential economic impacts of accidents during the renewal period were also reviewed (Section 5.3.4). To maintain a perspective on the results of this analysis, a discussion of the uncertainties associated with the types of consequence analyses used in this evaluation is provided (Section 5.3.5). Finally, a discussion is given on the role of severe accident mitigation design alternatives (SAMDAs) in the license renewal process (Section 5.4).

5.2 PLANT ACCIDENTS

5.2.1 General Characteristics of Accidents

The term "accident" refers to any unintentional event outside the normal plant operational envelope that results in a release or the potential for release of radioactive materials into the environment. Generally, the U.S. Nuclear Regulatory Commission (NRC) categorizes accidents as "design basis" (i.e., the plant is designed specifically to accommodate these) or "severe" (i.e., those involving multiple failures of equipment or function and, therefore, whose likelihood is generally lower than design-basis accidents but where consequences may be higher), for which plants are analyzed to determine their response. The predominant focus in environmental assessments is on events that can lead to releases substantially in excess of permissible limits for normal operation. Normal release limits are specified in the NRC's regulations (10 CFR Part 20 and 10 CFR Part 50, Appendix I).

Many features combine to minimize the risk of accidents at nuclear power plants. These features include high-quality reactivity control and reactor cooling systems and containment and backup safety systems to respond to equipment failure. The incorporation of safety into design, construction, and operation is to a very large extent devoted to minimizing the possibility of the release of radioactive materials from their normal places of confinement within the plant. Descriptions of these safety features are provided in each licensee's final safety analysis report (FSAR) and in the NRC's safety evaluation report.

The plant design, including the types and number of safety systems, takes into consideration the specific locations of radioactive materials within the plant; their amounts; their nuclear, physical, and chemical properties; and their potential for transport into the environment and for creating health hazards.

5.2.1.1 Fission Product Characteristics

By far the largest inventory of radioactive material in a nuclear power plant is produced as a by-product of the fission process and is located in the uranium oxide fuel pellets in the reactor core in the form of fission products. During periodic refueling shutdowns, the assemblies containing these fuel pellets are transferred to a spent-fuel storage pool; the second largest inventory of radioactive material is located in this storage area. Much smaller inventories of radioactive materials are also normally present in the water that circulates in the reactor coolant system and in the systems used to process gaseous and liquid radioactive wastes in the plant.

Radioactive materials in power plants exist in a variety of physical and chemical forms. Their potential for dispersal into the environment depends not only on mechanical forces that might physically transport them, but also on their inherent properties, particularly their volatility. The majority of these materials exist as nonvolatile solids over a wide range of temperatures. Some, however, are relatively volatile solids, and a few are gaseous at normal temperatures and pressures. These characteristics have a significant bearing on the assessment of the environmental radiological impacts of accidents.

The gaseous materials include radioactive forms of the chemically inert noble gases krypton and xenon. These two gases have the highest potential for release into the atmosphere. If a reactor accident involving degradation of the fuel cladding were to occur, the release of substantial quantities of these radioactive gases from the fuel into the reactor cooling system would be virtually certain. Such accidents are low-frequency, but credible, events. For this reason, the safety analysis of each nuclear power plant incorporates a hypothetical design-basis accident that postulates the release of the entire contained inventory of radioactive noble gases from the fuel in the reactor into the containment structure. If the noble gases were further released to the environment as a result of failure to maintain the containment boundary, the hazard to individuals from these noble gases would arise predominantly through the external gamma radiation from the airborne plume.

The reactor containment structure and containment support systems are designed to minimize the possibility of this type of release.

Radioactive forms of iodine are produced in substantial quantities in the fuel by the fission process, and in some chemical forms they may be quite volatile. For these reasons, iodine has traditionally been regarded as having a relatively high potential for release from the fuel into the containment during certain design-basis accidents. Because iodine concentrates in the thyroid gland, the release of radioiodines to the atmosphere is controlled by containment and by the use of special systems (i.e., filters) designed to retain the iodine.

The chemical forms in which the fission product radioiodines are found are generally solid materials at room temperatures; hence, they have a strong tendency to condense (or "plate out") on cooler surfaces. In addition, most of the iodine compounds are quite soluble in, or are chemically reactive with, water. Although these properties do not prevent the release of radioiodines from degraded fuel, they would act to inhibit release from the containment structure that has large internal surface areas and may contain large quantities of water as a result of an accident. The same properties affect the behavior of radioiodines that may "escape" into the atmosphere. Thus, if it rains during a release, or if there is moisture on exposed surfaces (for example, dew), the radioiodines will show a strong tendency to be absorbed by the moisture.

Other radioactive materials formed during the operation of a nuclear power plant are less volatile and have a much smaller tendency to escape from degraded fuel unless the temperature of the fuel becomes very high. Such materials tend to condense quite rapidly when they are transported to a lower temperature region or to dissolve in water when it is present. This mechanism can result in production of very small particles that can be carried some distance by a moving stream of gas or air. If such particulate materials are dispersed into the atmosphere as a result of containment failure, they tend to be carried downwind and deposited on surfaces by gravitational settling (fallout) or by precipitation (washout or rainout), where they will become "contamination" hazards in the environment.

All of these radioactive materials exhibit the property of radioactive decay with half-life periods ranging from fractions of a second to many days or years. Many of the radioactive materials decay through a sequence of decay processes, and all eventually become stable (nonradioactive). The radiation emitted during these decay processes renders the radioactive materials hazardous.

5.2.1.2 Meteorological Considerations

Two separate analyses of accident sequences are performed during the licensing process for a nuclear power plant. The first analysis is the determination of the consequences for design-basis accidents and is performed for the NRC's safety evaluation report. This analysis is performed to ensure that the doses to any individual at the exclusion area boundary over a period of 2 hours, or at the outer boundary of the low population zone (LPZ) during the entire period of plume passage, will not exceed the siting dose guidelines of 25 rem to the whole body or 300 rem to the thyroid, pursuant to 10 CFR Part 100. This analysis is used to examine site suitability (10 CFR Part 100) and the mitigative capability of certain plant safety features (10 CFR Part 50). The atmospheric dispersion model for this evaluation, as described in the NRC Regulatory Guide 1.145, uses on-site meteorological data (typically, a multiyear record) considered representative of the site and vicinity to calculate relative dilutions that will be exceeded no more than 0.5 percent of the time in any one sector (22.5°) and no more than 5 percent of the time for all sectors (360°) at the exclusion area boundary and LPZ. These dilution factors, because they provide little plume spread, ensure site-specific calculated doses that could be exceeded only 5 percent of the time.

The second analysis of accident consequences is generally found in the environmental documentation for the most recently licensed nuclear plants and considers a spectrum of releases, including those for severe accidents. Actual meteorological conditions from a representative 1-year period of record of on-site data are used in this environmental analysis. A detailed description of the atmospheric dispersion model used to estimate the environmental impacts of such accidents is contained in NUREG-75/014 (formerly WASH-1400), Appendix VI.

5.2.1.3 Exposure Pathways

The radiation exposure (hazard) to individuals is determined by the individual's proximity to the radioactive materials; the duration, intensity, and type (external versus internal) of exposure; and factors that act to shield the individual from the radiation. Many of the pathways for radiation and the transport of radioactive materials that lead to radiation exposure hazards to humans are the same for accidental as for "normal" releases. These pathways are depicted in Figure 5.1. Two additional possible pathways that could be significant for accident releases are not shown in Figure 5.1. One of these pathways is the fallout of radioactivity onto open water or onto land with runoff into open water bodies. The second pathway would be unique to an accident involving temperatures high enough to cause melting of the reactor core and subsequent penetration of the reactor vessel and underlying base mat by the molten core debris. Such an occurrence would create the potential for the release of radioactive material into the hydrosphere via groundwater beneath the plant. These pathways may lead to external exposure to radiation and also to internal exposure if radioactive material is contacted, inhaled, or ingested from contaminated food or water.

It is characteristic of all these pathways that during the transport of radioactive material by wind or water, the material tends to spread and disperse—like a plume of smoke from a smokestack—becoming less concentrated in larger volumes of air or water. The result of these natural processes is to lessen the intensity of exposure to individuals downwind or downstream of the point of release, but the processes also tend to increase the number who may be exposed. For a release into the atmosphere, the degree to which dispersion reduces the concentration in the plume at any downwind point is governed by the turbulence characteristics of the atmosphere, which vary considerably with time and from place to place. This fact, taken in conjunction with the variability of wind direction and the presence or absence of precipitation, means that accident consequences depend largely upon the

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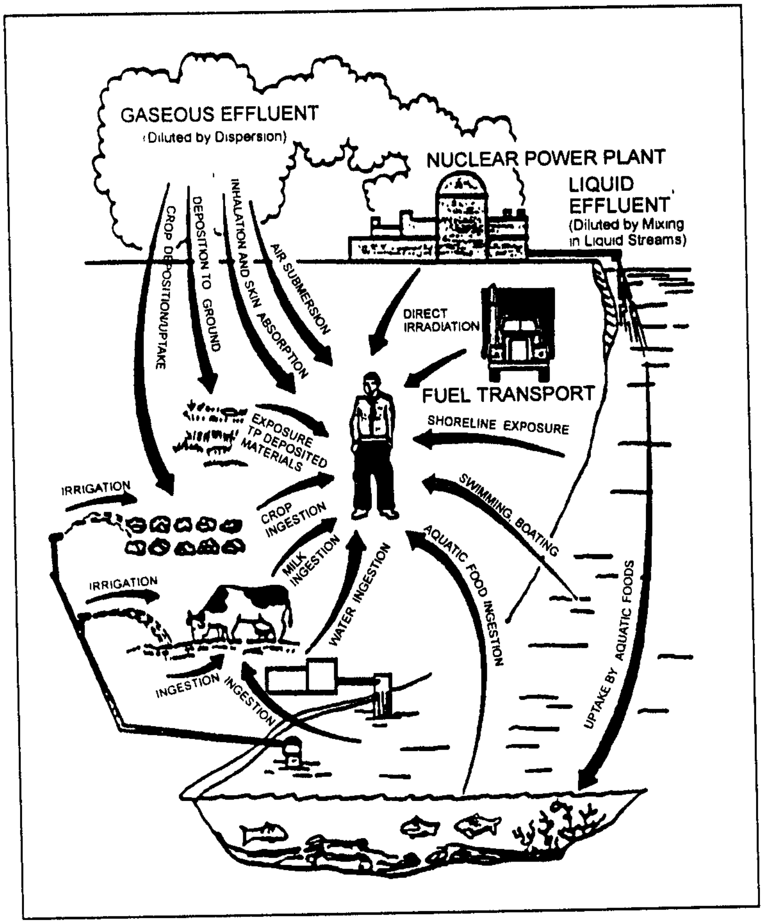

Figure 5.1 Potential exposure pathways to individuals.

weather conditions existing at the time of the accident.

5.2.1.4 Adverse Health Effects

The cause-and-effect relationships between radiation exposure and adverse health effects are quite complex. Whole-body radiation exposure resulting in a dose greater than about 25 rem over a short period of time (hours) is necessary before any physiological effects to an individual are clinically detectable[1] shortly thereafter. Doses about 10 to 20 times larger, also received over a relatively short period of time (hours to a few days), can be expected to cause some fatalities. At the severe (but extremely low probability) end of the accident spectrum, very high exposures of these magnitudes are theoretically possible for persons in proximity to the plant if measures are not or cannot be taken to provide protection, such as by sheltering or evacuation.

Lower levels of exposures may constitute a longer-term health risk. The effects of such exposures may include randomly occurring cancer in the exposed population and genetic changes in future generations after exposure of a prospective parent. Relating a given health effect to a known exposure to radiation is most often not possible because of the many other possible causes for such effects. For this reason, it is necessary to assess radiation-induced cancer effects on a statistical basis.

Occurrences of cancer in the exposed population may begin to develop only after a lapse of 2 to 15 years (latent period) from the time of exposure and continue over a period of over 40 years (plateau period). However, in the case of exposure of fetuses (in utero), occurrences of cancer may begin to develop at birth (no latent period) and end at age 10 (that is, the plateau period is 10 years). The occurrence of cancer itself is not necessarily indicative of a fatality because the ratio of mortality to incidence of cancer depends upon the cancer type and advances in medical treatment.

The estimates of health consequences used for latent fatalities in this document are the same estimators used in the development of the revised 10 CFR 20 regulations. A discussion is provided in Sections 3.8 and 4.6, and a more detailed discussion is provided in Section E.4, which details the recent developments in radiation risk estimation that lead to the health-consequence risk estimates in this section. The discussion in Section E.4 includes background information about epidemiology as well as health-effects information compiled by the United Nations Scientific Committee on the Effects of Atomic Radiation, by the National Academy of Sciences (reports of Advisory Committees on the Biological Effects of Ionizing Radiation—BEIR-I, BEIR-III, BEIR-V), and by the International Commission on Radiological Protection. The risk estimates for fatal cancers are considered to be nominally 500 per million person-rem, consistent with the risk factors described earlier (Section 3.8.1.3 and Appendix E.4). In addition, approximately 100 genetic disorders per million person-rem are projected for the succeeding generations.

5.2.1.5 Avoiding Adverse Health Effects

Radiation hazards in the environment disappear by the natural process of radioactive decay. Where the decay process is a slow one, however, and where the material becomes relatively fixed in its location as an environmental contaminant (such as in soil), the hazard can continue to exist for a long period of time—months, years, or even decades. Thus, a possible environmental societal reaction to severe accidents is avoidance of the potential health hazards by restrictions on the use of the contaminated property or contaminated foodstuffs, milk, and drinking water.

5.2.2 Accident Experience and Observed Impacts

A limited number of accidents have been recorded in the experience data of the world's nuclear programs. The United States, Great Britain, and the Soviet Union have all experienced accidents of varying magnitudes and consequences. The following paragraphs will discuss first the United States experience, followed by the British and then the Soviet accident experience.

As of September 1990, 112 commercial nuclear power reactor units were licensed for operation in the United States (Table 2.1) with power-generating capacities ranging from 72 to 1270 MW(e).

The combined experience with these operating units represents approximately 1300 reactor-years (RYs) of operation over an elapsed time of about 28 years. [An additional 6 plants, with individual generating capacities of up to 1314 MW(e), are expected to receive an operating license within the next 10 years.] Several of these facilities have experienced accidents (ORNL 1980; NUREG-0651; Thompson and Beckerley 1964), some of which have resulted in small releases of radioactive material to the environment. None is known to have caused any radiation injury or fatality to any member of the public, nor any significant contamination of the environment. Although the experience base with light-water reactors (LWRs) having containments such as those licensed in the United States is not large enough to permit reliable statistical prediction of accident probabilities, it does, however, suggest that significant environmental impacts caused by accidents are not at all likely to occur over time periods of a few decades.

Melting or severe degradation of reactor fuel has occurred in only one U.S.-licensed commercial LWR—during the accident at Three Mile Island Unit 2 (TMI-2) on March 28, 1979. It has been estimated that about 2.5 million Ci of noble gases (about 0.9 percent of the core inventory) and 15 Ci of radioiodine (about 0.00003 percent of the core inventory) were released to the environment at TMI-2 (NUREG/CR-1250).[2] No other radioactive fission products were released in measurable quantities. It has been estimated that the maximum cumulative off-site radiation dose to an individual was less than 100 mrem (NUREG/CR-1250; *President's Commission* 1979). The total population exposure has been estimated to be in the range from about 1000 to 5000 person-rem. (This range is discussed on page 2 of NUREG-0558.) This exposure could statistically produce between zero and one additional fatal cancer over the lifetime of the exposed population of approximately 2 million in the site area. The same population receives about 240,000 person-rem each year from natural background radiation, and approximately a half million cancers are expected to develop in this group over the lifetime of the population (NUREG/CR-1250; *President's Commission* 1979), primarily from causes other than radiation. Trace quantities (barely above the limit of detectability, below allowable limits, and less than that from fallout due to nuclear tests) of radioiodine were found in a few samples of milk produced in the area. No other food or water supplies were affected.

Accidents at U.S. nuclear power plants have also caused occupational injuries and a few occupational fatalities, but these were not due to radiation exposure. Individual worker exposures have ranged up to about 4 rem as a direct consequence of reactor accidents (although there have been higher exposures to individual workers as a result of other unusual occurrences). However, the collective worker exposure levels (person-rem) from accidents are a small fraction of the exposures experienced during routine operation; during the 1982–1986 time period, routine exposures ranged from 23 to 2880 person-rem/year in pressurized-water reactors (PWR) and 84 to 4080 person-rem/year in boiling-water reactors (BWR) per RY (NUREG-0713).

Accidents have also occurred at other nuclear facilities in the United States and in other countries (ORNL 1980; Bertini 1980). Reactor fuel melted in at least seven of these accidents: Fermi 1 (Lagoona Beach, Michigan), St. Laurent (France), NRX Reactor (Chalk River, Canada), Experimental Breeder Reactor 1 (Idaho), Heat Transfer Reactor Experiment Facility (Idaho), Westinghouse Reactor (Waltz Mills, Pennsylvania), and Oak Ridge Research Reactor (Tennessee). Because of inherent differences in design, construction, operation, and purpose of these other facilities, their accident record has only indirect relevance to current nuclear power plants. The most relevant accident was the one in 1966 at Enrico Fermi Atomic Power Plant Unit 1. Fermi Unit 1 was a sodium-cooled fast breeder demonstration reactor designed to generate 61 MW(e). The damages were repaired and the reactor reached full power 4 years after the accident. It operated successfully and completed its mission in 1973. The Fermi accident did not release any measurable radioactivity to the environment.

A reactor accident in 1957 at Windscale, England (renamed Seascale), released a significant quantity of radioiodine, approximately 20,000 Ci, to the environment and minor quantities of ^{137}Cs, ^{89}Sr, and ^{90}Sr (Eisenbud 1987) and ^{240}Po (Crick and Linsley 1983). This reactor, which was not operated to generate electricity, used a graphite core design and circulated air rather than water to cool the uranium fuel. During a special operation to heat the large amount of graphite in this reactor (an operation normal for this graphite-moderated reactor), the fuel overheated and radioiodine and noble gases were released directly to the atmosphere from a 123-m (405-ft) stack. Milk produced in a 518-km^2 (200-mile^2) area around the facility was impounded for up to 44 days. The United Kingdom National Radiological Protection Board (1957) estimates that the releases may have caused as many as 260 cases of thyroid cancer, about 13 of them fatal, and as many as 7 deaths from other cancers or hereditary diseases. This kind of accident cannot occur in a water-moderated and -cooled reactor like those in the U.S. nuclear power program.

On April 26, 1986, a major accident occurred at reactor 4 of the Chernobyl Nuclear Power Station in the Soviet Union. This reactor differs substantially from LWRs licensed to operate in the United States. The initiating event, a reactivity insertion, was recognized as a potential problem early in U.S. power reactor design; consequently, licensed U.S. power reactors are designed to prevent or accommodate occurrences of reactivity insertions. A major difference in safety between the U.S. designs and Chernobyl is that the Chernobyl reactor did not have a containment similar to those found on U.S. reactors. Also, the Chernobyl plant, which used graphite as a neutron moderator rather than water as with U.S. designs, had a positive power coefficient for the off-normal plant conditions that were present at the time of the accident. Thus, the accident has only indirect relevance to LWRs. The release of radioactive material from the accident was initially reported by the Soviets to be about 100 million Ci of fission products, but (except for the noble gases) that estimate included only material deposited within the European part of the Soviet Union. As a result of the accident, radionuclides were deposited throughout the Northern Hemisphere.

Of the almost 3 billion people in the Northern Hemisphere receiving Chernobyl radiation, about 800 million people account for 97 percent of the total risk increment. The remaining 3 percent of the dose commitment in Asia and North America represents a minuscule risk increment. Outside of the 30-km (19-mile) zone surrounding Chernobyl, the incremental increase in fatal cancer risk is a fraction of a percent and is not likely ever to be detected epidemiologically (DOE/ER-0332; Goldman 1987).

5.2.3 Mitigation of Accident Consequences

5.2.3.1 Design Features

All U.S. power reactors contain system features designed to prevent accidental release of radioactive fission products from the fuel and to lessen the consequences should such a release occur. Many of the design and operating specifications of these features are derived from the analysis of postulated events known as design-basis accidents. These accident-preventing and -mitigating system features are collectively referred to as "engineered safety features." Safety injection systems are incorporated to provide cooling water to the reactor core during a loss-of- coolant accident to prevent or minimize fuel damage. Heat-removal capability is provided inside the containment to prevent containment failure from overpressure. Long-term decay heat removal systems are also provided to remove decay heat from the core. All the mechanical systems mentioned above are supplied with emergency power from on-site diesel generators in the event that normal off-site station power is interrupted.

Containment structures are used as a mitigating system to provide a nearly leaktight barrier to minimize the escape of fission products to the environment in the event of a fission product release inside containment. These structures are designed to withstand the internal pressure and temperature associated with design-basis accidents.

The fuel-handling structures also have accident-mitigating systems. Spent fuel is handled and stored under water, which would tend to greatly reduce the amount of radioactive material released to the building environment in the event of fuel failure. A safety-grade exhaust air ventilation subsystem contains both charcoal and high-efficiency particulate filters. The ventilation systems are also designed to keep the area around the spent-fuel pool below the prevailing barometric pressure during fuel-handling operations to minimize the outleakage through building openings. Upon detection of high radiation, exhaust air is routed through the filter units, and radioactive iodine and particulate fission products which escaped from the spent fuel pool would be removed from the flow stream before exhausting to the atmosphere.

Much more extensive discussions of the safety features and characteristics of a particular plant may be found in the FSAR for that plant. In addition, the implementation of the lessons learned from the TMI-2 accident—in the form of improvements in design, procedures, and operator training—has significantly reduced the likelihood of a degraded-core accident that could result in large releases of fission products to the containment. These TMI-2-related requirements are specified in NUREG-0737.

5.2.3.2 Site Features

The NRC's site criteria, found in 10 CFR Part 100, require that every power reactor site have certain characteristics that tend to reduce the risk and potential impact of accidents. First, the site must have an exclusion area around the reactor. A typical exclusion area radius is about 0.8 km (0.5 mile). No residents are allowed in the exclusion area. Public transportation routes and other public activities are allowed within the exclusion area, but these routes and activities must be demonstrated to be controllable in the event of an emergency. Second, beyond and surrounding the exclusion area is an LPZ. A typical LPZ radius is about 5 km (3 miles). Within this zone, the licensee must ensure that there is a reasonable probability that appropriate protective measures could be taken on behalf of the residents and other members of the public in the event of a serious accident. Third, 10 CFR Part 100 requires that the distance from the reactor to the nearest boundary of a densely populated area containing more than 25,000 residents be at least one and one-third times the distance from the reactor to the outer bound of the LPZ.

5.2.3.3 Emergency Preparedness

Each licensee is required to establish emergency preparedness plans to be implemented in the event of an accident, including protective action measures for the public. The NRC, as well as other federal and state regulatory agencies, review the subject plans to ensure that the condition of on- and off-site emergency preparedness provides reasonable assurance that adequate protective measures can and will be taken in the event of a radiological emergency. Among the standards that must be met by these plans are provisions for two emergency planning zones (EPZs). A plume exposure pathway EPZ (requiring preplanned evacuation procedures) of about 16 km (10 miles) in radius and an ingestion exposure pathway EPZ (where interdiction of foodstuffs is planned) of about 80 km (50 miles) in radius are required. Other standards include appropriate ranges of protective actions for each of these zones; provisions for dissemination to the public of basic emergency planning information; provisions for rapid notification of the public during a serious reactor emergency; and methods, systems, and equipment for assessing and monitoring actual or potential off-site consequences in the event of a radiological emergency condition.

5.3 ACCIDENT RISK AND IMPACT ASSESSMENT FOR LICENSE RENEWAL PERIOD

5.3.1 Regulatory Interface Between License Renewal and Accident Impacts

In general, the safety and environmental issues associated with license renewal fall into two general categories: (1) effects of aging on the physical plant itself and the associated impact of these effects on accident frequency and radiological releases and (2) effects on accident consequences due to the changing environment in which the plant exists.

The potential effects of age on the physical plant are addressed through engineering and research programs. Potential deterioration of plant components and structures due to physical processes such as corrosion, erosion, mechanical wear, and embrittlement could result in the increased likelihood of component or structure failure. These increased failure rates, in turn, could lead to a higher frequency of accidents or more severe consequences. Therefore, control of these effects is necessary if the plant is to be assured of continuing to operate in a safe manner. As a result, NRC has developed the license renewal process within the context of the aging issue. The process will provide assurance that these age-related impacts are controlled and adequate protection of the health and safety of the public is maintained during the 20-year license renewal period. To supplement the control that the normal regulatory process has over the aging effects on the plant, the NRC requires that the renewal applicant specifically address the issue of age-related degradation by identifying, in an integrated plant assessment process, those structures and components which are susceptible to age-related degradation and whose functions are necessary to ensure that the facility's licensing basis is maintained. The licensee will further be required to demonstrate that the effects of aging will be adequately managed so that the intended functions of these structures and components will be maintained for the period of extended operation. The combined impact of these actions should be to provide high confidence that significant incremental increases in public risk will not result from aging effects related to the plant. A comprehensive discussion of the NRC rule, programs, and activities to provide this assurance is found in 55 *FR* 29043, dated July 17, 1990.

In assessing the impact on the environment from postulated accidents during the license renewal period, the assumption has been made that the license renewal process will ensure that aging effects on the plant are controlled and that the probability of any radioactive releases from accidents will not increase over the license renewal period.

The effects due to the changing environment around the plant during the license renewal period are less predictable, are generally not subject to regulatory controls, and could cause an increase in public risk as the plant continues to operate. These effects manifest themselves primarily by increasing the consequences of a given accident. For example, as the general population in the vicinity of a nuclear plant increases, the number of persons that could be affected by an accidental release also increases. Because these impacts are "noncontrollable," their potential for increasing risk as well as the magnitude of any such increase in risk must be specifically examined. Such an examination is presented in the following sections, which will discuss and assess the potential adverse impacts to the environment from postulated accidents during the license renewal period.

5.3.2 Design-Basis Accidents

Two classes of accidents are evaluated. The first class of accidents, design-basis accidents, is discussed in this section. The second, severe accidents, is discussed in Section 5.3.3. As noted previously, design-basis accidents are those that both the licensee and the NRC staff evaluate to ensure that the plant meets acceptable design and performance criteria. The environmental impacts of design-basis accidents are evaluated during the initial license process, and the ability of the plant to accommodate these accidents is demonstrated to be acceptable before issuance of the license. The results of these evaluations are found in license documentation such as FESs and FSARs. The licensee is required to maintain these acceptable design and performance criteria throughout the life of the plant, including any extended-life operation. The consequences for these events are evaluated for the hypothetical maximum exposed individual; as such, changes in the plant environment will not affect these evaluations. Because of the requirements that continuous acceptability of the consequences and aging management programs be in effect for license renewal, the environmental impacts as calculated for design-basis accidents should not differ significantly from initial licensing assessments over the life of the plant, including the license renewal period. In addition, any refurbishment necessary to prepare for license renewal would be done in a fashion consistent with the limits set for design-basis accidents and would not alter their consequences. Accordingly, the design of the plant relative to design-basis accidents during the extended license period is considered to remain acceptable and the environmental impacts of those accidents will not be examined further in this section.

5.3.3 Probabilistic Assessment of Severe Accidents

This section presents the staff's assessment of impacts of severe accidents during the license renewal period. Methodologies were developed to evaluate each of the dose pathways by which a severe accident may result in adverse environmental impacts and to estimate off-site costs of severe accidents.

Three pathways for release of radioactive material to the environment from severe accidents are evaluated in this section for each plant site for the license renewal period. These pathways are (1) air, (2) air to surface water, and (3) groundwater to surface water. For most plants, the air pathway represents the most likely pathway for significant dose to the public. The air to surface water pathway is significant for only a few sites that are close to large but confined bodies of water. The third pathway represents a less significant potential for dose because of reduction in radioactivity due to retention in the ground and greater flexibility and time to implement interdiction measures. Separate methodologies were developed for quantifying the potential consequences resulting from each pathway for each site. Economic impacts from severe accidents during the license renewal period are also described in this chapter.

Section 5.3.3.1 reviews the existing analyses available for use in this Generic Environmental Impact Statement (GEIS) study; Section 5.3.3.2 examines the effects of atmospheric releases, including vegetation pathways; Section 5.3.3.3 examines the effects from direct fallout onto open bodies of water; Section 5.3.3.4 reviews effects from releases to groundwater; and Section 5.3.3.5 examines the economic impacts of severe accidents. All analyses will adhere to a process that uses the results of existing analyses and site-specific information to conservatively predict the environmental impacts of severe accidents for each plant during the license renewal period.

5.3.3.1 Review of Existing Impact Assessments

The public risk due to nuclear power accidents has a range of values. The staff believes that current regulatory practices ensure that the basic statutory requirement, adequate protection of the public, is met (51 *FR* 28044). These risk estimates are representative of the magnitude of risk associated with current regulatory practices. Since the early 1970s, there have been increasing efforts to determine severe accident risks more precisely and on a plant-specific basis. The first comprehensive plant-specific examination of risk was the Reactor Safety

Study (RSS), published in 1975 (NUREG 75/014, formerly WASH-1400). The risk values calculated in RSS were later updated in NUREG-0773 and used in NRC FESs published after 1980. Later, more complex and more intensive plant-specific risk studies were developed, both by NRC and the industry. The most recent NRC studies of severe accident consequences are found in the NUREG-1150 analyses. To date, about 40 percent of the 118 operating plants and plants under construction have had some level of plant-specific risk analysis reviewed by NRC. This body of knowledge was used in the prediction of environmental impacts of severe accidents for all plants. Further details of these studies are provided in the following paragraphs.

FES reports since 1980 (Table 5.1) have provided assessments of impacts resulting from postulated severe accidents. Both the frequency and magnitude of the source terms ("source term" is a descriptive name for the releases of radioactive material to the environment under various accident conditions) for such assessments were usually taken from the rebaselined RSS (NUREG-0773). [These values are the result of updating the original RSS (NUREG-75/014, formerly WASH-1400) results using improved methods relative to the original WASH-1400 methodology.] Table 5.2 provides more information on the source-term data used in the FES analyses. These rebaselined source terms were then used with site-specific meteorological and demographic data to calculate off-site risk. A separate rebaselined set of source terms was provided for each of the two types of reactor designs, BWRs and PWRs. In most FES assessments, these same sets of data, without change, were used to evaluate off-site risks. Accordingly, the risk values provided in these FESs are based upon the plant designs analyzed in WASH-1400. As such, they do not represent plant-specific analyses for the FES plants but are sufficient to illustrate the general magnitude and types of risks that may occur from reactor accidents. There were some exceptions in that several studies included some further modification of the rebaselined RSS frequency estimates to better account for plant-specific design differences from the RSS plants. When available, other studies used plant-specific information on severe accident risks [such as probabilistic risk assessments (PRAs)]. Once the source-term data were established, all plants used the Calculation of Reactor Accident Consequences (CRAC) code to determine environmental consequences. Site-specific information regarding meteorology, population, and evacuation was used. Assumptions regarding exposure pathway, exposure limits, and plume behavior remained largely unchanged for all analyses.

The NUREG-1150 study is an NRC-sponsored risk examination of five U.S. nuclear power plants.[3] These analyses used state-of-the-art technology in evaluation of source-term release frequency, source-term characteristics, and consequence evaluation. Efforts were made to explore uncertainties in accident frequency, containment behavior, and radioactive material release and transport so that from this distribution of results, mean values of risk could be determined. Source terms and frequencies specific to the plant were determined. Advanced computer codes were used. For example, the MELCOR Accident Consequence Code System (MACCS) computer code for consequence evaluation was used instead of CRAC.

Table 5.1 Available risk analyses associated with final environmental statements

Plant	NSSS[a] vendor	Plant size [MW(e)]	Containment type	NUREG document number	NUREG date
Beaver Valley 2	W	836	Subatmospheric	1094	9-85
Braidwood 1, 2	W	1120	Large dry	1026	6-84
Byron 1, 2	W	1120	Large dry	0848	4-82
Callaway 1	W	1171	Large dry	0813	1-82
Catawba 1, 2	W	1145	Ice condenser	0921	1-83
Clinton 1	GE	933	Mark III	0854	5-82
Comanche Peak 1, 2	W	1150	Large dry	0775	9-81
Fermi 2	GE	1093	Mark I	0769	8-81
Grand Gulf 1, 2	GE	1250	Mark III	0777	9-81
Shearon Harris 1, 2	W	900	Large dry	0972	10-83
Hope Creek	GE	1067	Mark I	1074	6-84
Indian Point 2, 3	W	873/965	Large dry	*b*	*b*
Limerick 1, 2	GE	1055	Mark II	0974	12-83
Millstone 3	W	1154	Subatmospheric	1064	12-84
Nine Mile Point 2	GE	1091	Mark II	1085	5-85
Palo Verde 1, 2, 3	CE	1270	Large dry	0841	2-82
Perry 1, 2	GE	1191	Mark III	0884	8-82
River Bend	GE	936	Mark III	1073	1-85
San Onofre 2, 3	CE	1070/1080	Large dry	0490	4-81
Seabrook 1, 2	W	1198	Large dry	0895	12-82
South Texas 1, 2	W	1250/1251	Large dry	1171	8-86
St. Lucie 2	CE	830	Large dry	0842	4-82
Summer 1	W	900	Large dry	0719	5-81
Susquehanna 1, 2	GE	1050	Mark II	0564	6-81
Vogtle 1, 2	W	1101	Large dry	1087	3-85
Waterford 3	CE	1104	Large dry	0779	9-81
Wolf Creek 1	W	1170	Large dry	0878	6-82
WNP-2[c]	GE	1100	Mark II	0812	12-81

[a] NSSS = nuclear steam supply system, W = Westinghouse, GE = General Electric, CE = Combustion Engineering.
[b] Indian Point 2 and 3 consequence information was obtained from Atomic Safety and Licensing Board testimony.
[c] WNP-2 = Washington Nuclear Project 2.

Table 5.2 Source term information used for final environmental statement severe accident analyses

Plant	Source term used	Comments
Beaver Valley 2	Rebaselined Reactor Safety Study (RSS)	Pressurized-water reactor (PWR) source terms and frequencies from NUREG-0773 used
Braidwood 1, 2	Rebaselined RSS modified	PWR source terms and frequencies from NUREG-0773 modified for specific Braidwood design features
Byron 1, 2	Rebaselined RSS	Same as Beaver Valley
Callaway 1	Rebaselined RSS	Same as Beaver Valley
Catawba 1, 2	Rebaselined RSS	Same as Beaver Valley
Clinton 1	Rebaselined RSS	Boiling-water reactor (BWR) source terms and frequencies from NUREG-0773 used
Comanche Peak 1, 2	Rebaselined RSS	Same as Beaver Valley
Fermi 2	Rebaselined RSS	Same as Clinton
Grand Gulf 1, 2	Rebaselined RSS	Same as Clinton
Shearon Harris 1, 2	Rebaselined RSS	Same as Beaver Valley
Hope Creek	Rebaselined RSS	Same as Clinton
Indian Point 2, 3	Plant specific	
Limerick 1, 2	Rebaselined RSS (modified)	BWR source terms and frequencies from NUREG-0733 modified for specific Limerick design features. External events also included
Millstone 3	Plant-specific probabilistic risk analysis (PRA)	Source terms and frequencies from plant specific PRA used
Nine Mile Point 2	Limerick PRA (modified)	Source terms and frequencies from Limerick PRA modified for specific Nine Mile Point Unit 2 design features
Palo Verde 1, 2, 3	Rebaselined RSS	Same as Beaver Valley
Perry 1, 2	Rebaselined RSS	Same as Clinton

See footnote at end of table.

Table 5.2 (continued)

Plant	Source term used	Comments
River Bend	Grand Gulf RSS Methodologies Applications Program (MAP)	Source terms and frequencies from Grand Gulf RSS MAP (NUREG/CR-1659) with no modification
San Onofre 2, 3	Rebaselined RSS	Same as Beaver Valley
Seabrook 1, 2	Rebaselined RSS	Same as Beaver Valley
South Texas 1, 2	Rebaselined RSS (modified)	PWR source terms and frequencies from NUREG-0773 modified for specific South Texas design features
St. Lucie 2	Rebaselined RSS	Same as Beaver Valley
Summer 1	Rebaselined RSS	Same as Beaver Valley
Susquehanna 1, 2	Rebaselined RSS	Same as Clinton
Vogtle 1, 2	Rebaselined RSS (modified)	PWR source terms and frequencies from NUREG-0773 modified for specific Vogtle design features
Waterford 3	Rebaselined RSS	Same as Beaver Valley
Wolf Creek 1, 2	Rebaselined RSS	Same as Beaver Valley
WNP-2[a]	Rebaselined RSS	Same as Clinton

[a] Washington Nuclear Project 2.

The industry-sponsored risk assessments (e.g., Oconee 3, Seabrook, and Millstone 3) are similar in that efforts are made to reduce the degree of conservatism and to use the best information available. For these studies, source-term levels and frequencies specific to the plant are calculated.

Finally, studies exist that provide a detailed assessment of the risk due to specific types of accidents. For example, two such studies are NUREG-0440, which is a generic study of the radiological risks that could result from a severe accident that releases significant contamination into the groundwater, and NUREG-0769 (Addendum 1), which estimates the risks from direct contamination of the Great Lakes due to fallout from a severe accident at the Enrico Fermi 2 power plant. These two as well as other specific risk studies are used in this GEIS to provide a projection of risk during the license renewal period.

Severe accidents initiated by external phenomena such as tornadoes, floods, earthquakes, fires, and sabotage have not traditionally been discussed in quantitative terms in FESs. With the exception of sabotage, the NRC staff has, however, reviewed or performed detailed probabilistic assessments of external events for Zion Units 1 and 2, Indian Point Units 2 and 3, Limerick Units 1 and 2, Surry Unit 1, Peach Bottom Unit 2, and Millstone Unit 3. In most cases, the external event risks were determined to be comparable to internal event risks. However, for Zion and Limerick, the licensee's PRAs indicated that external events could be significant contributors to risk. For the Indian Point units, NRC staff evaluations also indicated that external events could significantly contribute to severe accident risk. The most recent NRC analysis of external events has been the NUREG-1150 external events assessment for Surry Unit 1 and Peach Bottom Unit 1. This analysis examined a broad range of external events and found that they could range from negligible to significant contributors to risk when compared with internal initiators. It should be noted, however, that in cases where external event risk was shown to be a significant contributor to the overall risk, the majority of the estimated risk arose from large beyond design basis earthquakes; but in all cases, the total risk (internal and external) is still small.

NRC's earthquake design standards have been conservatively developed to ensure protection of the public health and safety from earthquakes whose magnitudes are well above the most likely earthquake magnitude when considering the collective earthquakes history for specific plant sites in the United States. Therefore, earthquakes exceeding NRC seismic design standards are extremely unlikely. However, in the unlikely event of such an earthquake, there would be substantial damage to older residential structures, commercial structures, and high-hazard facilities such as dams whose seismic design standards are below nuclear seismic design standards. The societal impact due to the non-nuclear losses alone from an earthquake larger than the design basis of a nuclear plant, including property damage, injuries, and fatalities, would be major. The technology for assessing losses from such large earthquakes is a developing one, and there are several ongoing studies of this technology, including work at the United States Geological Survey. Presently there is no agreed-upon method for performing such assessments, although a recent report of the National Academy of Sciences suggests some broad guidelines (NAS 1989). The NRC has not developed a method for assessing the societal losses from large earthquakes such that the reactor contribution to accident consequences can be quantitatively compared with the non-nuclear losses. However, as supported by at least one study (Lee et al. 1979), the commission expects that the reactor accident contribution to the losses from large beyond design basis earthquakes would be small relative to the non-nuclear losses. While this in itself does not mean the reactor consequences from such an earthquake would be small, the commission concludes that even with potentially high consequences from a beyond design basis earthquake, the extremely low probability of such earthquake yields a small risk from beyond design basis earthquakes at existing nuclear power plants.

With regard to sabotage, quantitative estimates of risk from sabotage are not made in external event analyses because such estimates are beyond the current state of the art for performing risk assessments. The commission has long used deterministic criteria to establish a set of regulatory requirements for the physical protection of nuclear power plants from the threat of sabotage, 10 CFR Part 73, "Physical Protection of Plants and Materials", delineates these regulatory requirements. In addition, as a result of the World Trade Center bombing, the Commission amended 10 CFR Part 73 to provide protection against malevolent use of vehicles, including land vehicle bombs. This amendment requires licenses to establish vehicle control measures, including vehicle barrier systems to protect against vehicular sabotage. The regulatory requirements under 10 CFR part 73 provide reasonable assurance that the risk from sabotage is small. Although the threat of sabotage events cannot be accurately quantified, the commission believes that acts of sabotage are not reasonably expected. Nonetheless, if such events were to occur, the commission would expect that resultant core damage and radiological releases would be no worse than those expected from internally initiated events.

Based on the above, the commission concludes that the risk from sabotage and beyond design basis earthquakes at existing nuclear power plants is small and additionally, that the risks form other external events, are adequately addressed by a generic consideration of internally initiated severe accidents.

Although external events are not discussed in further detail in this chapter, it should be noted that the NRC is continuing to evaluate ways to reduce the risk from nuclear power plants from external events. For example, each licensee is performing an individual plant examination to look for plant vulnerabilities to internally and externally initiated events and considering potential improvements to reduce the frequency or consequences of such events. Additionally, as discussed in Section 5.4.1.2, as part of the review of individual license renewal applications, a site-specific consideration of alternatives to mitigate severe accidents will be performed in order to determine if improvements to further reduce severe accident risk or consequences are warranted.

5.3.3.2 Dose and Adverse Health Effects from Atmospheric Releases

5.3.3.2.1 Methodology for Predicting Future Risk

Summary of methodology

The assessment of environmental impacts due to the atmospheric release pathway are described in this section. This pathway includes the exposure of individuals directly from the passage of the cloud of radioactive material released from an accident and from material deposited on the ground, as well as the longer-term effects from other terrestrial pathways such as the ingestion of crops. Doses and the resulting health effects (early and latent fatalities) will be estimated for the middle year of relicense (MYR) population. The MYR is the estimated midpoint of the renewal period for a given plant rounded upward to the next year of available population data. Predictions of MYR risk were generated by taking the results of existing risk calculations (i.e., plant-specific estimates of early fatalities, latent fatalities, and dose) and regressing those values against a composite site-specific variable called the exposure index (EI). EI is a function of population surrounding the plant weighted by the site-specific wind direction frequency and, thus, is a site-specific parameter. Because meteorological patterns, including wind direction frequency, tend to remain constant over time, EI changes as populations change or become redistributed.

A straight-line regression of the total risk values (taken from FES analyses) for each plant listed in Table 5.1 versus the EI for that plant (at the date assumed in the FES analyses) was calculated. Average and 95 percent upper confidence bound values of total risk were estimated. Risks for individual plants for their license renewal period were then estimated from the upper confidence bound values based on MYR population data converted to MYR EI. In the prediction of risk using EI (discussed in the preceding paragraph), the assumption was made that future plant risk is primarily a function of population and wind direction. Secondary factors—such as terrain, rainfall, and wind stability—also have some effect on risk, but their impact was judged to be much smaller than the effects of population and wind direction.

Selection of appropriate existing analyses for use in regression

Currently, 118 nuclear plants are in operation or under active construction in the United States. These 118 plants represent 72 sites for the evaluation of air pathway consequences (74 sites are used for the other two pathway evaluations).[4] As noted previously, only a portion of these nuclear plants have severe accident analyses available for review.

The data selected for use in this GEIS analysis were taken from the FESs published since 1981. As discussed previously, these FES analyses are based upon source terms resulting from the RSS (NUREG-75/014, formerly WASH-1400) rebaselined in NUREG-0773. As such, these source terms (and the resulting risk and environmental impacts calculated using them) reflect the plant designs used in WASH-1400. However, this approach is considered conservative because the source terms developed in WASH-1400 generally reflect an "as found" (late 1970s) and, as such, do not reflect the improvements that have been made in nuclear industry plant design and operations since the early 1980s. Accordingly, the use of WASH-1400 source terms in the FESs may, in many cases, tend to overestimate the actual environmental consequences and risks.

Since the RSS study was completed, the NRC has implemented several industry-wide risk-reduction programs. These programs, such as station blackout (10 CFR 50.63), anticipated transient without scram (10 CFR 50.62), resolution of other generic safety issues, improvements resulting from the extensive reviews of the accident at Three Mile Island (NUREG-0737), and the individual plant examination and containment performance improvement programs, have served to lower the overall average values of nuclear plant risk relative to their values prior to the changes. Because the programs are implemented on an industry-wide basis, risk values should be smaller at all plants. No quantification of the overall risk reduction has been performed, but it is believed that the risk reduction is significant. As a result of the changes, the staff believes that the spectrum of risk for the entire nuclear industry shifted downward to lower overall risk values, and the average total risk for all nuclear plants is smaller than the risk estimated in the original RSS analyses. Thus, RSS risk estimates are more representative of the upper end of the total nuclear plant risk spectrum than the actual current risks.

The preceding discussion shows that the use of the FES risk values provides reasonable estimates of the actual average risk of the general nuclear plant population and that the use of the FES values in this analysis results in appropriate risk values in the GEIS. Where there were choices of methodology and the best method was not obvious, the staff chose the method that would lead to higher predicted values. The use of the 95 percent upper prediction confidence bounds from the regression in this analysis (discussed later) provides even greater assurance that the GEIS does not underestimate potential future environmental impacts.

As for use of detailed PRA analyses in the GEIS, particularly the NUREG-1150 studies, the plants represented in these detailed PRAs have had the benefit of considerable risk reduction feedback and improvement; consequently, their predicted risk values are not considered to be representative of the absolute values of the general plant population risk. However, these studies do provide significant risk information on the relative risks to the public as a function of distance from the plant. Because of the much more advanced computational tools available during the NUREG-1150 studies (which could better model secondary effects such as rainfall pattern), as well as more than 10 years of additional knowledge about severe accidents, the information on the distribution of risk at a specific plant, as estimated by the NUREG-1150 reports, is considered more realistic and representative of the actual environmental impacts due to the air pathway for severe accidents. The GEIS uses this relative risk information in its analysis process.

Enveloping of all plants with FES analyses

Many factors could potentially increase the consequences to the general public resulting from a severe-accident release. A comprehensive listing and description of factors that influence consequences are provided in the *PRA Procedures Guide* (NUREG/CR-2300). The purpose of this section is to use, to the extent possible, the available severe accident results (Table 5.3), in conjunction with those factors that are important to risk and that change with time to estimate the consequences of nuclear plant accidents for all plants for a time period that exceeds

Table 5.3 Comparison of general site characteristics. Italics indicate that the final environmental statement contains severe accident evaluations

Plant	MYR evaluation date[a]	MYR 50-mile population[b]	MYR 50-mile population in high-frequency wind direction	Rain[c]	Snow[c]	General terrain[d]
Arkansas 1	2030	245,476	20,471	51	5	3
Arkansas 2	2030	245,476	20,471	51	5	3
Beaver Valley 1	2030	4,039,282	1,177,194	36	46	3
Beaver Valley 2	2050	4,169,673	1,202,284	36	46	3
Bellefonte 1	2050	1,473,597	60,836	56	3	4
Bellefonte 2	2050	1,473,597	60,836	56	3	4
Big Rock Point	2030	228,199	61	31	111	2
Braidwood 1	2050	5,092,832	1,534,979	30	28	2
Braidwood 2	2050	5,092,832	1,534,979	30	28	2
Browns Ferry 1	2030	926,918	27,791	47	3	4
Browns Ferry 2	2030	926,918	27,791	47	3	4
Browns Ferry 3	2030	926,918	27,791	47	3	4
Brunswick 1	2030	304,703	7,703	51	2	1
Brunswick 2	2030	304,703	7,703	51	2	1
Byron 1	2050	1,141,541	29,618	18	34	2
Byron 2	2050	1,141,541	29,618	18	34	2
Callaway 1	2030	463,360	17,712	37	19	3
Calvert Cliffs 1	2030	3,481,008	256,881	41	21	1
Calvert Cliffs 2	2030	3,481,008	256,881	41	21	1
Catawba 1	2050	2,337,775	139,401	42	5	4
Catawba 2	2050	2,337,775	139,401	42	5	4
Clinton 1	2050	869,226	27,294	35	23	2
Comanche Peak 1	2030	1,654,378	54,431	31	3	1
Comanche Peak 2	2050	1,875,643	61,419	31	3	1
Cooper	2030	217,516	19,745	28	28	2
Crystal River 3	2030	655,382	0	42	0	1
D.C. Cook 1	2030	1,440,998	15	36	69	2
D.C. Cook 2	2030	1,440,998	15	36	69	2
Davis Besse	2030	2,169,925	20	32	37	2
Diablo Canyon 1	2050	419,046	4	32	0	6
Diablo Canyon 2	2050	419,046	4	32	0	6
Dresden 2	2030	7,453,539	143,593	33	30	2
Dresden 3	2030	7,453,539	143,593	33	30	2
Duane Arnold 1	2030	754,825	26,445	33	31	2
Farley 1	2030	488,464	21,412	54	0	1
Farley 2	2050	542,746	25,242	54	0	1

See footnotes at end of table.

Table 5.3 (continued)

Plant	MYR evaluation date[a]	MYR 50-mile population[b]	MYR 50-mile population in high-frequency wind direction	Rain[c]	Snow[c]	General terrain[d]
Fermi 2	2050	6,647,763	0	31	31	2
FitzPatrick	2030	804,876	12,128	34	88	2
Fort Calhoun 1	2030	887,478	14,526	30	32	2
Ginna	2030	1,112,686	0	33	86	2
Grand Gulf 1	2050	504,930	15,143	50	2	1
Haddam Neck (Connecticut Yankee)	2030	4,136,066	120,354	43	53	5
Hatch 1	2030	416,412	43,798	44	1	1
Hatch 2	2030	416,412	43,798	44	1	1
Hope Creek	2050	5,424,373	54,596	40	23	1
Indian Point 2[e]	2030	15,195,541	602,427	43	6	3
Indian Point 3[e]	2030	15,195,541	602,427	43	26	3
Kewanee 1	2030	733,618	0	28	45	2
La Salle 1	2050	1,366,307	61,875	35	28	2
La Salle 2	2050	1,366,307	61,875	35	28	2
Limerick 1	2050	7,615,980	794,765	59	20	1
Limerick 2	2050	7,615,980	794,765	59	20	1
Maine Yankee	2030	830,737	19,668	43	71	5
McGuire 1	2050	2,543,485	134,597	43	6	4
McGuire 2	2050	2,543,485	134,597	43	6	4
Millstone 1	2030	3,138,820	1,419	39	26	5
Millstone 2	2030	3,137,820	1,419	39	26	5
Millstone 3	2050	3,325,582	1,462	39	26	5
Monticello 1	2030	2,815,967	1,587,694	24	42	2
Nine Mile Point 1	2030	802,759	12,239	34	88	2
Nine Mile Point 2	2050	811,475	12,478	34	88	2
North Anna 1	2030	1,478,490	41,700	44	16	4
North Anna 2	2030	1,478,490	41,700	44	16	4
Oconee 1	2030	1,311,318	53,947	53	6	4
Oconee 2	2030	1,311,318	53,947	53	6	4
Oconee 3	2030	1,311,318	53,947	53	6	4
Oyster Creek 1	2030	4,561,213	929	41	16	1
Palisades	2030	1,337,910	9,582	36	69	2
Palo Verde 1	2050	1,974,946	2,700	13	0	3
Palo Verde 2	2050	1,974,946	2,700	13	0	3
Palo Verde 3	2050	1,974,946	2,700	13	0	3
Peach Bottom 2	2030	5,283,198	122,770	38	35	4
Peach Bottom 3	2030	5,283,198	122,770	38	35	4

See footnotes at end of table.

Table 5.3 (continued)

Plant	MYR evaluation date[a]	MYR 50-mile population[b]	MYR 50-mile population in high-frequency wind direction	Rain[c]	Snow[c]	General terrain[d]
Perry 1	2050	2,767,417	0	34	52	2
Pilgrim 1	2030	4,881,755	0	42	42	1
Point Beach 1	2030	700,257	13,275	24	45	2
Point Beach 2	2030	700,257	13,275	24	45	2
Prairie Island 1	2030	2,961,583	29,124	24	44	2
Prairie Island 2	2030	2,961,583	29,124	24	44	2
Quad Cities 1	2030	810,640	13,191	36	29	2
Quad Cities 2	2030	810,640	13,191	36	29	2
Rancho Seco 1	2030	2,589,992	303,556	17	0	6
River Bend	2050	1,105,994	15,770	54	0	1
Robinson 2	2030	991,450	30,941	45	2	4
Salem 1	2030	5,180,877	49,873	40	23	1
Salem 2	2050	5,372,611	54,002	40	23	1
San Onofre 1	2030	7,048,438	0	12	0	1
San Onofre 2	2050	7,764,644	0	12	0	1
San Onofre 3	2050	7,764,644	0	12	0	1
Seabrook 1	2050	4,452,452	344	43	75	5
Sequoyah 1	2030	1,208,316	205,182	58	4	3
Sequoyah 2	2050	1,334,579	226,371	58	4	3
Shearon Harris 1	2050	2,122,597	75,055	45	7	4
Shoreham	2050	5,692,690	170,058	47	34	1
South Texas 1	2050	382,195	29,850	42	0	1
South Texas 2	2050	382,195	29,850	42	0	1
St. Lucie 1	2030	1,036,446	41,401	32	0	1
St. Lucie 2	2050	1,245,868	49,375	32	0	1
Summer 1	2050	1,385,612	83,181	45	2	4
Surry 1	2030	2,506,022	36,210	45	10	1
Surry 2	2030	2,506,022	36,210	45	10	1
Susquehanna 1	2050	1,575,680	34,206	35	50	4
Susquehanna 2	2050	1,575,680	34,206	35	50	4
Three Mile Island 1	2030	2,294,045	263,028	38	37	3
Trojan 1	2030	2,822,894	116,369	42	7	6
Turkey Point 3	2030	4,156,261	93,491	54	0	1
Turkey Point 4	2030	4,156,261	93,491	54	0	1
Vermont Yankee	2030	1,709,869	58,938	43	60	5
Vogtle 1	2050	932,240	17,480	42	1	1
Vogtle 2	2050	932,240	17,480	42	1	1
Waterford 3	2050	2,778,959	45,309	54	0	1

See footnotes at end of table.

Table 5.3 (continued)

Plant	MYR evaluation date[a]	MYR 50-mile population[b]	MYR 50-mile population in high-frequency wind direction	Rain[c]	Snow[c]	General terrain[d]
Watts Bar 1	2050	1,367,537	56,133	53	9	3
Watts Bar 2	2050	1,367,537	56,133	53	9	3
WNP-2[f]	2050	405,235	23,692	5	18	3
Wolf Creek 1	2050	273,225	26,641	31	15	2
Yankee Rowe	2010	1,796,823	471,262	37	66	5
Zion 1	2030	8,199,956	0	32	58	2
Zion 2	2030	8,199,956	0	32	58	2

[a] MYR = Middle year of license renewal period rounded up to the next year for which population forecasts were available.

[b] 50 miles = 80 km.

[c] Annual average in inches.

[d] Terrain categories: 1 = coastal plain, 2 = central lowlands, 3 = plateaus, 4 = parallel valleys and ridges, 5 = rolling hills to high mountains, 6 = steep mountains.

[e] Severe accident information obtained from Atomic Safety and Licensing Board testimony and not from the final environmental statement.

[f] WNP-2 = Washington Nuclear Project 2.

the time frame of existing analyses. This estimation process was completed by predicting increases or decreases in consequences as the plant lifetime is extended past the normal license period by considering the projected changes in the risk factors. The primary assumption in this analysis is that regulatory controls will ensure that the physical plant condition (i.e., the predicted probability of and radioactive releases from an accident) will be maintained at a constant level during the renewal period; therefore, the frequency and magnitude of a release will remain relatively constant. In other words, significant changes in consequences will result only from changes in the plant's external environment. The most logical approach, then, would be to incorporate the most significant environmental factors into calculations of consequences for subsequent correlation with existing analyses (which use the consequence computer codes). The two parameters selected for this analysis are population and wind direction, as discussed in the following paragraphs.

Many factors can affect the amount of radiation to which the public is exposed. The magnitude of impact varies for any individual factor and generally is very specific to a particular plant or site. If the FES risk results are to be used to predict future risk values for all plants, it should be demonstrated that the FES plants provide a reasonable envelope of the more significant risk factors for all plants. Such factors include population density, meteorology, evacuation, and interdiction. Studies have shown that some factors have a greater degree of influence than others; for example, population has a very strong influence over risk (NUREG/CR-2239, NUREG-1150). Evacuation can have a significant influence on early fatality risk but a much more limited impact on latent fatality risk. Interdiction primarily reduces latent fatality risk. While particular aspects of meteorology, such as rainfall, can have a significant impact on peak risk values, mean health effect values are relatively insensitive to meteorology. When the basic reasons for the risk influence of each factor are examined, these factors can generally be reduced to three issues: (1) the number of people exposed to the severe accident release, (2) the likelihood that any given individual receives an exposure, and (3) the amount of radiation the individual receives. Consequently, site population (which reflects the number of people potentially at risk to severe accident exposure) and wind direction frequency (which reflects the likelihood of exposure) have been chosen as the primary factors affecting risks.

Although there are other secondary factors (e.g., source term and dose response relationship) that can influence risk and were not specifically analyzed on a plant-specific basis in this GEIS, these factors were not ignored as their impact is included in the FES analyses whose results are the basis for the GEIS analyses. Consequently, their effects are indirectly considered in the prediction of future risks and are reflected within the uncertainty bounds generated by the regression of the FES risk values. To ensure that the existing FES analyses cover a range of secondary factors representative of the total population of plants, the more significant secondary factors were examined as discussed below. The secondary factors examined are as follows:

- average annual precipitation,
- residential population within a 50-mile (80-km(radius of the plant,
- population [50 miles (90 km)] in highest frequency wind direction,
- general terrain, and
- emergency planning.

Average annual precipitation. After an atmospheric release caused by a severe accident, the fallout rate of the released radionuclides is generally the result of gravitational settling and, consequently, is not a rapid process. This slow fallout allows a given release to be suspended for sufficient time to allow for some radioactive decay of the shorter-lived radionuclides, resulting in lower individual doses to the public. In addition, releases are distributed over a wide area, resulting in relatively low individual doses (although the overall total population dose is not greatly affected). However, precipitation counteracts both of these effects by washing the radionuclides out of the atmosphere and not allowing time for extensive dispersion or decay. Thus, plant sites with higher levels of annual precipitation may indicate higher levels of risk for those measures that are based on individual doses.

Residential population within a 50-mile radius of the plant. This factor is a rather understandable selection in that plant sites with larger resident populations will have a larger number of persons at risk for a given severe accident release. Population projections were made based on the 1980 census data and projected growth (decline) factors derived from the U.S. Bureau of Census evaluations. A radius of 50 miles was selected for comparison purposes because existing analyses indicate a large majority (although not all) of early health effects from a severe accident release occur within 50 miles of the plant site.

Population (50 miles) in highest-frequency wind direction. This factor highlights a "higher risk" sector of the overall population around a specific plant site. The sector is 22.5° and the population is 0 to 50 miles from the plant in that sector. Higher populations combined with higher frequency of wind in that direction may indicate higher risks in that sector.

General terrain. This factor is chosen because the dispersion behavior of the plume may be influenced by the general terrain surrounding the plant (e.g., plains versus mountains). Six terrain classifications were selected as described in footnote c to Table 5.3.

Table 5.3 shows the values for these four factors for all nuclear plant sites. As can be seen, the existing severe accident analysis as provided in those FESs containing a severe accident evaluation provides a reasonable envelope for precipitation (rainfall and snowfall), 50-mile population, and 50-mile population in the direction of highest wind frequency. All six terrain classifications are also covered by referenced FES analyses. From review of these data, it is concluded that the FES plants sufficiently envelop these factors. Likewise, any plant risk projections that are developed from the FES severe accident results will reasonably account for secondary effects from these factors if the upper confidence bounding values from the projections are used to estimate the risk from atmospheric releases for plants during their license renewal period.

Emergency planning. Even in the event of a release of radioactive material from a plant, protective actions can be taken to move or shelter members of the public in the projected path of the radioactive cloud. The success of these actions in preventing exposure of members of the public to the radioactive material is dependent upon the warning time available prior to the release and the time it takes to carry out the protective actions. In general, this latter item (the time to carry out the protective action) is mostly influenced by the size of the population around the plant. Each FES that addresses severe accidents considers the effects of site-specific emergency planning in calculating exposures and risks to the public. Since the FES plants include sites with populations that reasonably cover the range of populations at all 74 sites, a range of emergency planning is considered in the data used for the predictions of early and latent fatalities during the license renewal period. Thus, this GEIS analysis should reasonably account for the effects of emergency planning.

Projections of estimates of risk

Detailed severe accident consequence (early and latent fatalities and total dose) evaluations are not available for all plants. Therefore, a predictor for these consequences was developed using correlations based upon the calculated results from the existing FES severe accident analyses. This predictor was then used to infer the future consequence level of all individual nuclear plants. Correlations were developed using two environmental parameters that are available for all plants. This correlation process is described below.

Discussion of exposure index

Population, which changes over time, defines the number of people within a given distance from the plant. Wind direction, which is assumed not to change from year to year, helps determine what proportion of the population is at risk in a given direction, because radionuclides are carried by the wind. Therefore, an EI relationship was developed by multiplying the wind direction frequency (fraction of the time per year) for each of 16 (22.5°) compass sectors times the population in that sector for a given distance from the plant and summing all products. An example calculation for an EI value for 1990 at 10 miles (16 km) is shown in Table 5.4. The EI value, as calculated in Table 5.4, can be considered to be the expected population at risk for the year 1990 out to a distance of 10 miles from the nuclear power plant. Population varies with population growth and movement, and with the distance from any given plant. As the population changes for that plant, the EI also changes (the larger the EI, the larger the number of people at risk). Thus, EI is proportional to risk and an EI for a site for a future year can be used to predict the risk to the population around that site in that future year.

Regression of FES values

Several relationships of EI versus risk were developed by regressing total early fatality, normalized total latent fatality, and normalized total dose values on various EI values for the FES plants (see Appendix G). The EI values at 10 miles were found to best correlate with early fatalities, which is to be expected because, in the FES analyses, early fatalities tend to be clustered close to the plant. The EI values at 150 miles (241 km) were found to best correlate with latent fatalities and total dose. This finding is to be expected because the magnitudes of these risk values are largely influenced by the exposure of large populations around the plant.

Table 5.4 Example calculation for exposure index (EI) value with 1990 population at 10-mile radius from plant

Direction segment	*A* (wind frequency in given direction)	*B* (1990 population within 10 miles of Plant *X*)[a]	*C* (product)
N	0.06	100	6.0
NNE	0.06	105	6.3
NE	0.02	55	1.1
ENE	0.10	20	2.0
E	0.08	25	2.0
ESE	0.08	24	1.92
SE	0.09	75	6.75
SSE	0.10	125	12.5
S	0.06	400	24.0
SSW	0.05	275	13.75
SW	0.07	100	7.0
WSW	0.06	78	4.68
W	0.06	72	4.32
WNW	0.06	40	2.40
NW	0.02	80	1.6
NNW	0.03	78	2.34
	1.00	1652	EI = 98.66

[a] 10 miles = 16 km.

Note: To calculate EI value: $A \times B = C$; EI = sum of *C*.

Because the magnitude of the source term is generally proportional to plant power for a given accident sequence, the FES estimates for total latent fatalities used in the latent fatality regression were first normalized to 1000 MW(t) to minimize the regression variance due to the differing plant sizes. A linear dose response function is used in the FES analyses, and because of the assumptions of downwind and crosswind spread, radioactive material is predicted to be widely dispersed. Thus, the larger the amount of radioactive material released, the larger the predicted latent fatality level (slightly reduced from strict linearity by the interdiction assumptions). Similar logic is applicable to normalization of total dose. Normalization was not used for early fatalities because of the highly nonlinear dose response function used in the FES analyses and the use of a threshold effect (that is, there is a dose level below which no early fatality is predicted). Nonetheless, early fatalities are also highly influenced by the amount of radioactive material released (i.e., plant size), and to help ensure that early fatality data from smaller plants do not distort the regression results for the larger plants, only the early fatality data for plants greater than 3025 MW(t) were used in the regression of early fatalities (Table 5.5, footnote f). The inability to correct fully for the effects of plant size and the dose–early fatality relationship leads to a higher dispersion in the regression estimates, which influences the upper confidence bound (UCB) as will be seen in subsequent sections.

Also, in several of the FES documents, two sets of early fatality values were provided, one set which assumed minimal medical support was available to aid the exposed population and a second set which assumed normal and expected levels of medical support were available. The regression used those early fatality values associated with expected medical support levels. The assumption there would be only minimal or no medical support after an accident was considered to be unrealistic. A detailed discussion of the regression analyses and UCB is provided in Appendix G.

5.3.3.2.2 Results

The data in Table 5.5 summarize the information for 28 nuclear plant sites that were used to develop the relationship between EI and consequences of severe accidents analysis for both PWRs and BWRs. Because of fundamental design differences between PWRs and BWRs, separate regression analyses were performed for each to better account for the BWR-PWR differences in plant failure modes and source terms. Accordingly, the PWR regression was used to determine the best fit relationship for PWR risk values and the BWR regression was used to determine the best fit relationship for FES BWR risk values. As can be seen in Figures 5.2–5.7, two lines (representing average and UCB values) result from the regression analyses for total early fatalities, total latent fatalities, and total dose. The 95 percent UCB (dashed line) was developed based on the scatter in the data. Two points need to be made about the UCB. First, two UCB values were calculated: one value assuming that the data points (i.e., early and latent fatalities and population dose) had a normal distribution about some mean and the second value assuming that the data points did not have a normal distribution about the mean. The larger of the two UCB values was then used in making plant risk projections. The second point to be noted is that because of the small number of data used in the regressions (18 PWR data points and 10 BWR data points), the scatter in the data (expressed as residuals)

Table 5.5 Information used for regression analyses for expected early, latent, and total dose at 28 nuclear plant sites for the license renewal period
Normalized values are obtained by converting nonnormalized values to the equivalent of a 1000-MW(t) plant

Plant	FES analysis[a] date of population	EI values[b] (10 miles)	EI values[b] (150 miles)	Expected early[c,d] fatalities (persons/reactor year)	Expected latent fatalities (persons/reactor year)		Expected total dose (person-rem/reactor year)	
					Nonnormalized[c]	Normalized[e]	Nonnormalized[c]	Normalized[e]
Beaver Valley 2	2010	9,195	958,330	0.002 [f]	0.022	0.0083	230	86.73
Braidwood 1, 2	2000	1,916	1,435,347	0.00038	0.0138	0.004	180	52.77
Byron 1, 2	2000	1,391	1,084,499	0.00026	0.016	0.0047	218	63.91
Callaway 1	2000	508	343,991	0.0001	0.0077	0.0022	126	35.34
Catawba 1, 2	2000	5,414	678,486	0.0011	0.0124	0.0036	170	49.84
Clinton 1	2000	658	1,272,955	0.000009 [f]	0.0191	0.0066	320	110.57
Comanche Peak 1, 2	2000	1,251	292,169	0.0001	0.0046	0.0014	58	17.00
Fermi 2	2000	4,165	1,112,272	0.00074	0.04	0.012	520	157.96
Grand Gulf 1, 2	2000	437	297,829	0.00006	0.0055	0.0014	100	26.09
Shearon Harris 1, 2	2010	1,415	550,951	0.00018 [f]	0.0088	0.0032	114	41.08
Hope Creek	2010	1,541	1,822,818	0.0003	0.07	0.021	1000	303.67
Indian Point 2, 3[g]	1990	18,325	2,743,032	0.0115 [h]	0.826[i]	0.299	10,400 [i]	3770.85
Limerick 1, 2	2000	10,307	2,455,497	0.00914	0.0957	0.029	1360	413.00
Millstone 3	2010	8,751	1,397,683	0.0008	0.05	0.015	1000	293.17
Nine Mile Point 2	2000	1,500	269,042	0.0004	0.023	0.007	300	90.28
Palo Verde 1, 2, 3	2000	67	194,928	0.0000021	0.00456	0.0012	67	17.63
Perry 1, 2	2000	4,465	920,212	0.000016	0.0285	0.008	470	131.32
River Bend	2000	1,485	334,565	0.0004 [f]	0.047	0.016	700	241.88
San Onofre 2, 3	2000	3,950	978,306	0.001	0.033	0.0097	380	112.09
Seabrook 1, 2	2000	4,090	448,066	0.0006	0.0075	0.0022	105	30.78
South Texas 1, 2	2010	236	461,241	0.0000007	0.0108	0.0028	250	65.79
St. Lucie 2	2000	8,739	540,442	0.00007 [f]	0.0064	0.0024	78	28.89
Summer 1	2000	647	627,969	0.00017 [f]	0.0094	0.0034	130	46.85
Susquehanna 1, 2	2000	3,760	1,995,580	0.00077	0.0227	0.0069	360	109.32
Vogtle 1, 2	2010	117	469,641	0.00001	0.024	0.007	310	90.88
Waterford 3	2000	4,745	285,560	0.00057	0.0059	0.0017	69	20.35
Wolf Creek 1	2000	311	289,260	0 [j]	0.00559	0.0016	99	29.02
WNP-2[k]	2000	108	100,055	0.00032	0.00487	0.0015	77	23.17

[a] The population estimates for the indicated year were used to evaluate the consequences to the public for the final environmental statement (FES).
[b] Exposure index (EI) values are given for FES analysis date of population (see note a).
[c] Values obtained from FES for the respective plant with the exception of Indian Point (See note g).
[d] Due to threshold dose effects, these estimates cannot be normalized (i.e., effects are not linear until an exposure threshold is reached).
[e] Normalized to 1000 MW(t) (see Appendix G).
[f] Plant thermal power < 3025 MW(t) and was not used in the regression for expected early fatalities.
[g] Expected risk values obtained from Atomic Safety and Licensing Board testimony and not from FES.
[h] Risk values for Indian Point 3 are listed.
[i] Risk values for Indian Point 2 are listed.
[j] Because values of zero have no meaning on log scales, this data point was not used in the regression for early fatalities.
[k] WNP-2 = Washington Nuclear Project 2.
Note: Multiply person-rem by 0.01 to find person-sieverts; multiply miles by 1.609 to find kilometers.

ORNL-DWG 95-1757

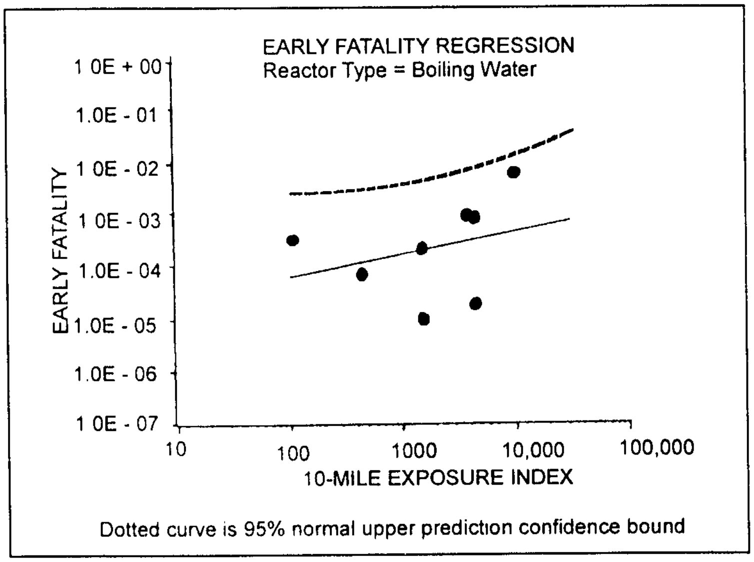

Figure 5.2 Log plot of early fatalities (average deaths per reactor-year) for final environmental statement boiling-water reactor plants, fitted regression line (solid curve), and 95 percent normal-theory upper prediction confidence bounds (dotted curve).

ORNL-DWG 95-1758

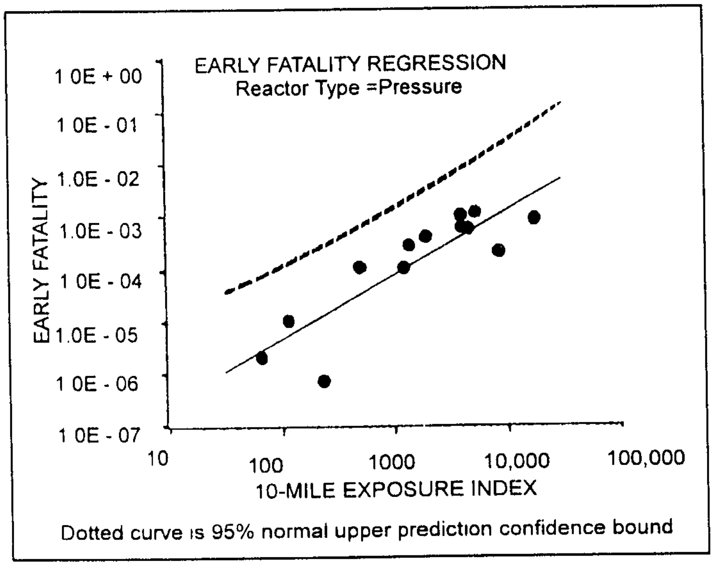

Figure 5.3 Log plot of early fatalities (average deaths per reactor-year) for final environmental statement pressurized-water reactor plants, fitted regression line (solid curve), and 95 percent normal-theory upper prediction confidence bounds (dotted curve).

ORNL-DWG 95-1759

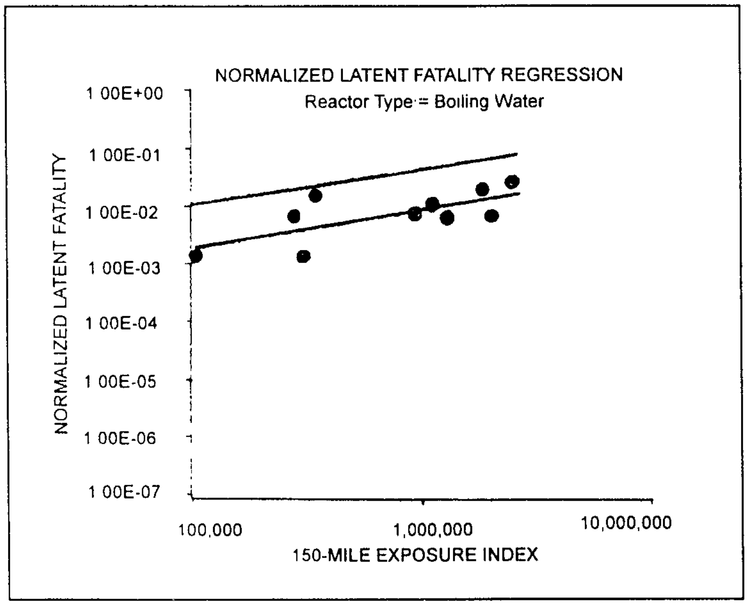

Figure 5.4 Log plot of normalized latent fatalities (average deaths per 1000 MW reactor-year) for final environmental statement boiling-water reactor plants, fitted regression line (solid curve), and 95 percent distribution-free upper prediction confidence bounds (dotted curve).

ORNL-DWG 95-1760

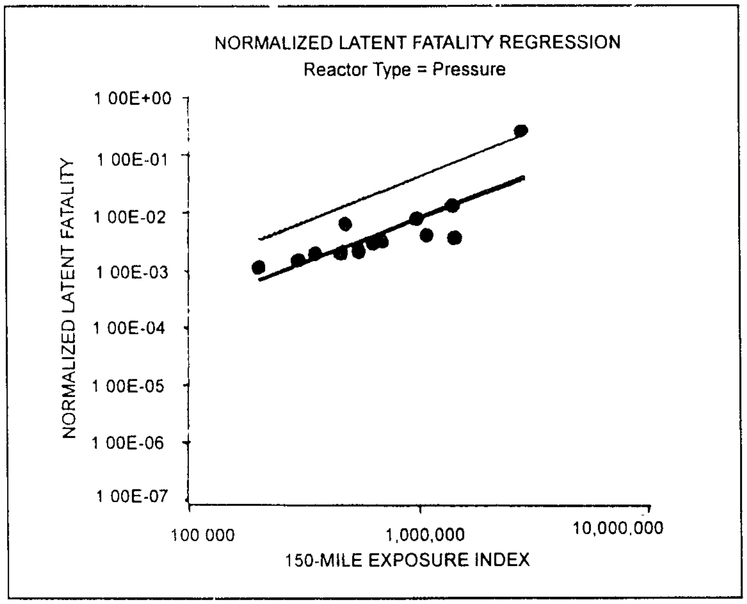

Figure 5.5 Log plot of normalized latent fatalities (average deaths per 1000 MW reactor-year) for final environmental statement pressurized-water reactor plants, fitted regression line (solid curve), and 95 percent distribution-free upper prediction confidence bounds (dotted curve).

ORNL-DWG 95-1761

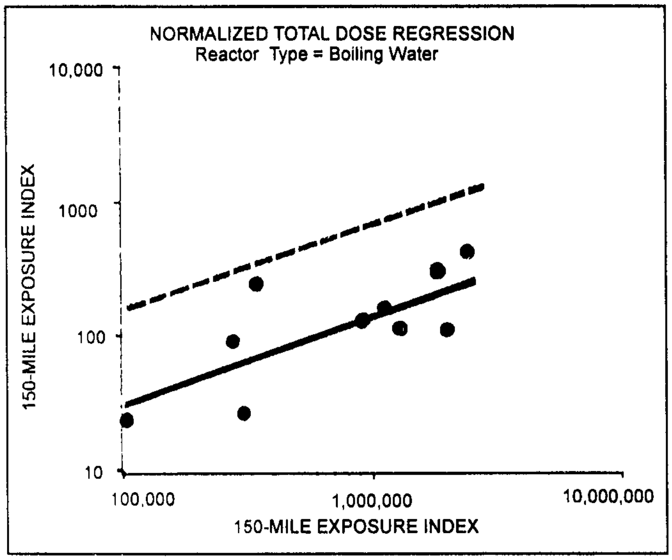

Figure 5.6 **Log plot of normalized total dose (person-rem per 1000 MW reactor-year) for final environmental statement boiling-water reactor plants, fitted regression line (solid curve), and 95 percent distribution-free upper prediction confidence bounds (dotted curve).**

ORNL-DWG 95-1762

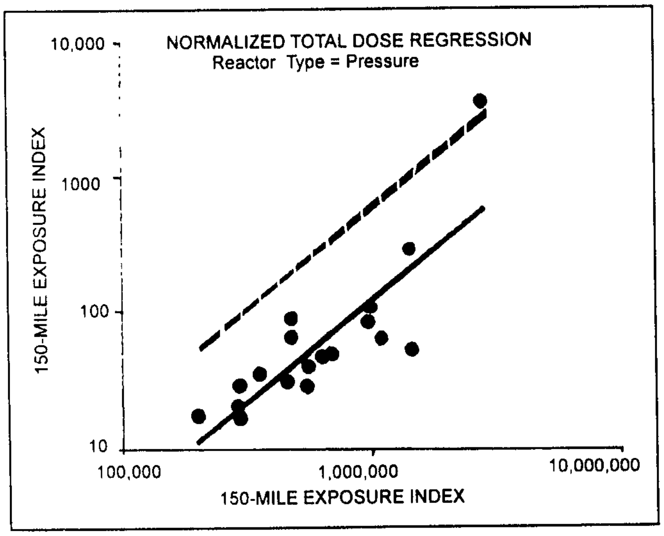

Figure 5.7 **Log plot of normalized total dose (person-rem per 1000 MW reactor-year) for final environmental statement pressurized-water reactor plants, fitted regression line (solid curve), and 95 percent distribution-free upper prediction confidence bounds (dotted curve).**

for all 28 data points was used in determining the UCB for both the PWR and BWR regressions.

Using the UCB results of the regression analysis, the values for total early fatalities, total latent fatalities, and total dose were then predicted for each site at their MYRs, rounded up to the nearest year for which projected population data are available (2010, 2030, 2050). The results of the UCB projections for early fatalities, latent fatalities, and total dose are shown in Table 5.6. The EI values corresponding to the MYR for each site, which were used to make these predictions, are shown in Tables 5.7 and 5.8. Data for the Millstone plant provide a good example of the process by which these projections were made. The EI at 10 miles for Millstone (an FES plant) is 9420 at its MYR (2050) (Table 5.7). An EI of 9420 results in a projected early fatality UCB of 0.025 fatalities/RY. This value is higher than that reported in the Millstone FES for the year 2010 (0.0008 fatalities/RY, as shown in Table 5.5) and represents a conservative projection of the increase in early fatalities that could occur as a result of increased population around the Millstone site. The effects on risk due to factors such as emergency planning, meteorology (other than the frequency of wind direction—e.g., rainfall), and topography were accounted for in the FES analyses of severe accidents and are consequently incorporated into the FES risk values. Any variation in risk resulting from variation of these secondary parameters among FES plants will be reflected in the UCB calculated by the regressions. As discussed in Section 5.3.3.2.1, the FES plants reasonably envelop these secondary effects. If the future risks for all plants are then estimated using the appropriate (BWR or PWR) regression and the MYR EI, the resulting UCB values are estimated future risks that are not expected to be exceeded.

It should be noted that the risk values for latent fatalities provided in the FESs were calculated using the CRAC computer code which used a linear-quadratic cancer model based on older, low-level radiation exposure data (BEIR-III). Recent evaluations of the EI methodology (see Section 5.3.3.2.3) have been conducted using MACCS, the current, state-of-the-art computer code for assessing risks associated with postulated severe reactor accidents. Unlike CRAC, MACCS uses a linear cancer model based on the newer BEIR-V report. These evaluations suggest that latent fatality values in the FESs are an order of magnitude too low. Therefore, to account for this, the latent fatality results predicted from the FES values have been multiplied by a factor of 10 to obtain the final predicted latent fatality results in this GEIS.

Total population dose for an accident during each plant's relicensing period was also estimated by regression analysis. This dose includes the contribution from direct exposure to the radioactive cloud at the time of release as well as the longer-term effects from ground contamination. Table 5.9 shows the results of this (in person-rem/RY) along with an estimate of the respective average individual dose, in rem/RY, for each plant. Average individual doses were estimated by distributing the UCB total dose estimates from the regression analysis over the population within 150 miles (240 km) of the plant. Because it is virtually certain that people beyond this 150-mile radius would receive some incrementally small dose from an accident, attributing the total dose to the population within 150 miles will provide a conservative average individual dose estimate. For perspective, the annual average background dose to an individual

Table 5.6 Predicted early and latent fatalities and dose estimates per reactor-year (RY) for all sites at their middle year of license renewal period, prior to incorporation of benchmark data

Plant	Predicted UCB total early fatalities/RY (95% UCB)[a]	Nonnormalized predicted latent total fatalities/RY (95% UCB)	Nonnormalized predicted total dose (person-rem/RY) (95% UCB)
Arkansas	3.3×10^{-3}	1.7×10^{-2}	238
Beaver Valley	2.5×10^{-2}	1.3×10^{-1}	1720
Bellefonte	4.0×10^{-3}	1.0×10^{-1}	1335
Big Rock Point	2.7×10^{-3}	3.2×10^{-3}	48
Braidwood	3.6×10^{-3}	3.3×10^{-1}	4418
Browns Ferry	4.3×10^{-3}	9.7×10^{-2}	1446
Brunswick	3.5×10^{-3}	4.7×10^{-2}	704
Byron	2.3×10^{-3}	2.2×10^{-1}	2867
Callaway	6.9×10^{-4}	3.6×10^{-2}	509
Calvert Cliffs	1.8×10^{-3}	2.3×10^{-1}	2995
Catawba	1.7×10^{-2}	1.4×10^{-1}	1880
Clinton	3.0×10^{-3}	1.8×10^{-1}	2549
Comanche Peak	2.3×10^{-3}	3.3×10^{-2}	466
Cooper	2.6×10^{-3}	6.3×10^{-2}	955
Crystal River	1.5×10^{-3}	5.0×10^{-2}	700
D. C. Cook	8.4×10^{-3}	1.8×10^{-1}	2311
Davis Besse	1.4×10^{-3}	1.5×10^{-1}	2021
Diablo Canyon	1.5×10^{-3}	2.5×10^{-2}	346
Dresden	4.6×10^{-3}	1.4×10^{-1}	1991
Duane Arnold	8.0×10^{-3}	3.7×10^{-2}	561
Farley	1.5×10^{-3}	2.4×10^{-2}	334
Fermi 2	6.8×10^{-3}	1.9×10^{-1}	2722
FitzPatrick	3.8×10^{-3}	5.0×10^{-2}	728
Fort Calhoun	1.7×10^{-3}	8.0×10^{-3}	111
Ginna	3.9×10^{-3}	1.5×10^{-2}	203
Grand Gulf	2.8×10^{-3}	9.7×10^{-2}	1441
Haddam Neck (Connecticut Yankee)	1.2×10^{-2}	2.0×10^{-1}	2618
Hatch	2.6×10^{-3}	5.7×10^{-2}	855
Hope Creek	4.1×10^{-3}	2.5×10^{-1}	3604
Indian Point	6.5×10^{-2}	7.7×10^{-1}	9727
Kewanee	8.9×10^{-4}	2.2×10^{-2}	303
La Salle	3.6×10^{-3}	2.0×10^{-1}	2898
Limerick	1.1×10^{-2}	3.1×10^{-1}	4461
Maine Yankee	1.8×10^{-3}	3.0×10^{-2}	414
McGuire	1.0×10^{-2}	1.4×10^{-1}	1806
Millstone	2.5×10^{-2}	3.1×10^{-1}	3988
Monticello	4.1×10^{-3}	5.0×10^{-2}	730
Nine Mile Point	3.8×10^{-3}	6.7×10^{-2}	996
North Anna	9.4×10^{-4}	1.1×10^{-1}	1496
Oconee	1.1×10^{-2}	1.0×10^{-1}	1311
Oyster Creek	7.4×10^{-3}	1.5×10^{-1}	2125
Palisades	4.2×10^{-3}	1.3×10^{-1}	1691

Table 5.6 (continued)

Plant	Predicted UCB total early fatalities/RY (95% UCB)[a]	Nonnormalized predicted latent total fatalities/RY (95% UCB)	Nonnormalized predicted total dose (person-rem/RY) (95% UCB)
Palo Verde	1.1×10^{-4}	2.6×10^{-2}	369
Peach Bottom	4.2×10^{-5}	2.0×10^{-1}	2950
Perry	6.9×10^{-3}	1.7×10^{-1}	2544
Pilgrim	3.7×10^{-3}	6.0×10^{-2}	873
Point Beach	2.5×10^{-3}	2.3×10^{-2}	309
Prairie Island	3.7×10^{-3}	1.7×10^{-2}	237
Quad Cities	4.5×10^{-3}	1.1×10^{-1}	1588
Rancho Seco	1.1×10^{-3}	1.3×10^{-1}	1723
River Bend	4.1×10^{-3}	8.0×10^{-2}	1168
Robinson	3.1×10^{-3}	7.0×10^{-2}	926
Salem	2.9×10^{-3}	5.0×10^{-1}	6059
San Onofre	1.1×10^{-2}	2.4×10^{-1}	3099
Seabrook	1.1×10^{-2}	6.0×10^{-2}	819
Sequoyah	6.6×10^{-3}	1.1×10^{-1}	1474
Shearon Harris	2.8×10^{-3}	7.3×10^{-2}	1001
South Texas	3.3×10^{-4}	8.0×10^{-2}	1065
Saint Lucie	3.2×10^{-2}	8.0×10^{-2}	1063
Shoreham	7.7×10^{-3}	6.3×10^{-2}	2724
Summer	1.3×10^{-3}	1.0×10^{-1}	1381
Surry	1.6×10^{-2}	9.0×10^{-2}	1200
Susquehanna	6.0×10^{-3}	2.8×10^{-1}	4010
Three Mile Island	2.8×10^{-2}	3.3×10^{-1}	4381
Trojan	3.7×10^{-2}	1.5×10^{-1}	1971
Turkey Point	6.0×10^{-2}	2.0×10^{-2}	278
Vermont Yankee	4.6×10^{-3}	9.0×10^{-2}	1314
Vogtle	1.6×10^{-4}	7.3×10^{-2}	983
WNP-2[b]	2.3×10^{-3}	4.3×10^{-2}	649
Waterford	1.4×10^{-2}	3.3×10^{-2}	477
Watts Bar	1.8×10^{-3}	1.2×10^{-1}	1540
Wolf Creek	4.7×10^{-4}	3.3×10^{-2}	466
Yankee Rowe	3.3×10^{-3}	6.7×10^{-2}	872
Zion	5.6×10^{-2}	1.8×10^{-1}	2379

[a] UCB = upper confidence bound. For description and explanation of these values, see Appendix G.

[b] WNP-2 = Washington Nuclear Project 2.

Note: Multiply person-rem by 0.01 to find person-sieverts.

Table 5.7 Middle year of license renewal period (MYR) evaluation date and 10-mile exposure index (EI) for each licensed nuclear plant in the U.S.
Values are given in descending order

Plant	MYR evaluation date[a]	EI[b] (10 miles)
Indian Point	2030	18,959
Turkey Point	2030	17,852
Zion	2030	16,913
Trojan	2030	12,556
St. Lucie	2030	11,447
Limerick	2050	10,709
Three Mile Island	2030	10,327
Beaver Valley	2050	9,535
Millstone	2050	9,420
Catawba	2050	7,219
Surry	2030	6,796
Duane Arnold	2030	6,283
Waterford	2050	6,163
Shoreham	2050	5,915
Oyster Creek	2030	5,584
Haddam Neck (Connecticut Yankee)	2030	5,476
Seabrook	2050	5,234
Oconee	2030	5,184
San Onofre	2050	5,179
Perry	2050	5,020
Fermi 2	2050	4,919
McGuire	2050	4,919
D. C. Cook	2030	4,163
Susquehanna	2050	3,976
Sequoyah	2050	3,471
Palisades	2030	2,421
Vermont Yankee	2030	2,408
Dresden	2030	2,345
Bellefonte	2050	2,317
Ginna	2030	2,291
Quad Cities	2030	2,228
Prairie Island	2030	2,188
Braidwood	2050	2,126
Browns Ferry	2030	2,019
Yankee Rowe	2010	1,998
Arkansas	2030	1,993
Peach Bottom	2030	1,972
River Bend	2050	1,857
Salem	2050	1,808

Table 5.7 (continued)

Plant	MYR evaluation date[a]	EI[b] (10 miles)
Robinson	2030	1,889
Monticello	2030	1,832
Hope Creek	2050	1,807
Shearon Harris	2050	1,773
Point Beach	2030	1,612
Nine Mile Point	2050	1,568
FitzPatrick	2030	1,532
Comanche Peak	2030	1,518
Byron	2050	1,468
Pilgrim	2030	1,435
La Salle	2050	1,307
Maine Yankee	2030	1,246
Watts Bar	2050	1,241
Calvert Cliffs	2030	1,232
Brunswick	2030	1,195
Fort Calhoun	2030	1,155
Crystal River	2030	1,064
Farley	2050	1,021
Diablo Canyon	2050	1,020
Davis-Besse	2030	979
Summer	2050	902
Rancho Seco	2030	835
Clinton	2050	760
North Anna	2030	704
Kewanee	2030	671
Grand Gulf	2050	562
Callaway	2030	541
Big Rock Point	2030	476
Cooper	2030	411
Wolf Creek	2050	381
Hatch	2030	372
South Texas	2050	278
Vogtle	2050	141
WNP-2[c]	2050	134
Palo Verde	2050	96

[a] The renewal period evaluation year is the estimated midpoint of the renewal period for that plant conservatively rounded upward to the next year of available population data (MYR). Dates of license expiration were obtained from Table 2.1. The maximum renewal period of 20 years was assumed.

[b] Value obtained by multiplying wind frequency in each of 16 compass sectors by population 0 to 10 miles (16 km) from plant in that compass sector, then summing all products.

[c] WNP-2 = Washington Nuclear Project 2.

Table 5.8 Middle year of license renewal period (MYR) evaluation date and 150-mile exposure index (EI) for each licensed nuclear plant in the U.S.
Values are given in descending order.

Plant	MYR evaluation date[a]	EI[b] (150 miles)
Indian Point	2030	2,863,844
Limerick	2050	2,647,224
Susquehanna	2050	2,279,528
Shoreham	2050	2,014,947
Salem	2050	1,979,840
Oyster Creek	2030	1,970,098
Hope Creek	2050	1,955,878
Three Mile Island	2030	1,928,285
Yankee Rowe	2010	1,739,663
Haddam Neck (Connecticut Yankee)	2030	1,722,399
Braidwood	2050	1,615,088
Millstone	2050	1,510,698
Calvert Cliffs	2030	1,459,323
Peach Bottom	2030	1,453,860
Clinton	2050	1,418,383
La Salle	2050	1,396,350
Fermi 2	2050	1,287,935
Vermont Yankee	2030	1,286,085
San Onofre	2050	1,284,282
Byron	2050	1,214,624
Dresden	2030	1,193,394
Zion	2030	1,107,448
Davis-Besse	2030	1,104,797
D. C. Cook	2030	1,051,654
Palisades	2030	1,041,961
Beaver Valley	2050	1,021,547
Perry	2050	1,021,049
Rancho Seco	2030	992,605
Trojan	2030	944,628
Catawba	2050	914,688
McGuire	2050	890,305
North Anna	2030	876,587
Oconee	2030	867,675
Quad Cities	2030	854,803
Summer	2050	852,405
Surry	2030	846,246
Watts Bar	2050	798,733
Sequoyah	2050	769,140
Robinson	2030	738,770
Saint Lucie	2030	727,763

Table 5.8 (continued)

Plant	MYR evaluation date[a]	EI[b] (150 miles)
Shearon Harris	2050	688,554
Bellefonte	2050	678,549
Vogtle	2050	590,283
South Texas	2050	579,617
Crystal River	2030	573,211
Seabrook	2050	523,715
Browns Ferry	2030	491,751
Monticello	2030	487,606
Pilgrim	2030	486,154
Point Beach	2030	469,985
Kewanee	2030	440,217
River Bend	2050	432,680
Cooper	2030	428,471
Maine Yankee	2030	391,929
Grand Gulf	2050	388,245
Prairie Island	2030	375,227
Callaway	2030	373,564
Waterford	2050	370,569
Comanche Peak	2030	363,530
Wolf Creek	2050	363,380
Ginna	2030	357,773
Hatch	2030	347,873
Turkey Point	2030	345,115
Farley	2050	344,405
Duane Arnold	2030	329,426
Diablo Canyon	2050	302,887
Palo Verde	2050	290,395
Nine Mile Point	2050	273,322
FitzPatrick	2030	270,532
Arkansas	2030	265,479
Brunswick	2030	256,923
Fort Calhoun	2030	242,370
Big Rock Point	2030	136,942
WNP-2[c]	2050	132,195

[a] The renewal period evaluation year is the estimated midpoint of the renewal period for that plant conservatively rounded up to the next year of available population data (MYR). Dates of license expiration were obtained from Table 2.1. The maximum renewal period of 20 years was assumed.

[b] Value obtained by multiplying wind frequency in each of 16 compass sectors by population 0 to 150 miles (240 km) from plant in that compass sector, then summing all products.

[c] WNP-2 = Washington Nuclear Project 2.

Table 5.9 Predicted dose estimate (total and average individual) per reactor-year (RY) for all sites at their middle year of license renewal (MYR)

Plant	Predicted UCB total dose 95% UCB[a] (person-rem/RY)	150-mile MYR population (in millions)	Predicted UCB average individual dose 95% UCB[b] (person-rem/RY)
Arkansas	238	4.1	6×10^{-5}
Beaver Valley	1720	15.6	1×10^{-4}
Bellefonte	1335	12.3	1×10^{-4}
Big Rock Point	48	2.3	2×10^{-5}
Braidwood	4418	20.5	2×10^{-4}
Browns Ferry	1446	8.6	2×10^{-4}
Brunswick	704	5.2	1×10^{-4}
Byron	2867	17.8	2×10^{-4}
Callaway	509	6.6	8×10^{-5}
Calvert Cliffs	2995	20.8	1×10^{-4}
Catawba	1880	13.8	1×10^{-4}
Clinton	2549	18.6	1×10^{-4}
Comanche Peak	466	8.8	5×10^{-5}
Cooper	955	5.4	2×10^{-4}
Crystal River	700	10.6	7×10^{-5}
D.C. Cook	2311	20.1	1×10^{-4}
Davis-Besse	2021	20.6	1×10^{-4}
Diablo Canyon	346	5.7	6×10^{-5}
Dresden	1991	18.9	1×10^{-4}
Duane Arnold	561	6.0	9×10^{-5}
Farley	334	5.7	6×10^{-5}
Fermi 2	2722	21.3	1×10^{-4}
FitzPatrick	728	6.1	1×10^{-4}
Fort Calhoun	111	3.6	3×10^{-5}
Ginna	203	5.8	4×10^{-5}
Grand Gulf	1441	6.2	2×10^{-4}
Haddam Neck (Connecticut Yankee)	2618	32.4	8×10^{-5}
Hatch	855	5.8	1×10^{-4}
Hope Creek	3604	35.5	1×10^{-4}
Indian Point	9727	35.7	3×10^{-4}
Kewanee	303	7.4	4×10^{-5}
La Salle	2898	19.1	2×10^{-4}
Limerick	4461	39.3	1×10^{-4}
Maine Yankee	414	7.6	5×10^{-5}
McGuire	1806	14.3	1×10^{-4}
Millstone	3988	32.6	1×10^{-4}

See footnotes at end of table.

Table 5.9 (continued)

Plant	Predicted UCB total dose 95% UCB[a] (person-rem/RY)	150-mile MYR population (in millions)	Predicted UCB average individual dose 95% UCB[b] (person-rem/RY)
Monticello	730	5.9	1×10^{-4}
Nine Mile Point	996	6.2	2×10^{-4}
North Anna	1496	14.7	1×10^{-4}
Oconee	1311	14.1	1×10^{-4}
Oyster Creek	2125	34.0	6×10^{-5}
Palisades	1691	20.4	8×10^{-5}
Palo Verde	369	4.9	8×10^{-5}
Peach Bottom	2950	33.1	9×10^{-5}
Perry	2544	19.7	1×10^{-4}
Pilgrim	873	13.9	6×10^{-5}
Point Beach	309	7.4	4×10^{-5}
Prairie Island	237	6.5	4×10^{-5}
Quad Cities	1588	15.0	1×10^{-4}
Rancho Seco	1723	16.5	1×10^{-4}
River Bend	1168	7.9	1×10^{-4}
Robinson	926	11.9	8×10^{-5}
Salem	6059	36.1	2×10^{-4}
San Onofre	3099	23.6	1×10^{-4}
Seabrook	819	14.7	6×10^{-5}
Sequoyah	1474	12.9	1×10^{-4}
Shearon Harris	1001	11.8	8×10^{-5}
Shoreham	2724	36.0	8×10^{-5}
South Texas	1065	10.2	1×10^{-4}
Saint Lucie	1063	12.0	9×10^{-5}
Summer	1381	12.6	1×10^{-4}
Surry	1200	12.9	9×10^{-5}
Susquehanna	4010	36.0	1×10^{-4}
Three Mile Island	4381	29.3	1×10^{-4}
Trojan	1971	9.4	2×10^{-4}
Turkey Point	278	6.9	4×10^{-5}
Vermont Yankee	1314	20.9	6×10^{-5}
Vogtle	983	9.4	1×10^{-4}
WNP-2[c]	649	2.5	3×10^{-4}
Waterford	477	6.8	7×10^{-5}
Watts Bar	1540	13.4	1×10^{-4}
Wolf Creek	466	6.3	7×10^{-5}

Table 5.9 (continued)

Plant	Predicted UCB total dose 95% UCB[a] (person-rem/RY)	150-mile MYR population (in millions)	Predicted UCB average individual dose 95% UCB[b] (person-rem/RY)
Yankee Rowe	872	25.0	3×10^{-5}
Zion	2379	18.1	1×10^{-4}

[a] UCB = upper confidence bound. For description and explanation of these values see Appendix G.
[b] Obtained by dividing total fatalities by 150-mile population.
[c] WNP-2 = Washington Nuclear Project 2.
Note: Multiply person-rem by 0.01 to find person-sieverts; 150 miles = 240 km.

from all other causes, including radon, is estimated as 3×10^{-1} rem per year.

5.3.3.2.3 Benchmark Evaluations of the EI Methodology

Values for the consequences associated with nuclear power plant severe accidents have been taken from the FESs and used to establish the regressions and corresponding 95 percent UCBs presented in this chapter. As described previously, the FES values were calculated using the CRAC computer model. Using these regressions and the site-specific EI, UCB estimates for early and normalized latent fatalities and normalized total dose were obtained. As a means of assessing the performance of the EI methodology, two additional studies have been performed (Yambert and Linn 1992 and Tingle 1993). The primary goal of these studies was to demonstrate the accuracy of the EI methodology in predicting consequences associated with severe nuclear power plant accidents. In addition, insight gained from these evaluations was used to adjust values estimated using the EI regressions to reflect current, state-of-the-art calculation techniques.

The most direct means to perform this benchmarking would be to compare the outputs from CRAC used in the FESs with the output of the MACCS code, given identical inputs, for each of the FES plants. However, CRAC has undergone numerous revisions and a working version of the code used for the FES calculations is not available. Also, because the original CRAC input files for the FES plants were no longer available, detailed MACCS input files reflecting the FES plant inputs could not be created. Consequently, a direct comparison of the FES and MACCS output could not be made.

To bridge the gap between the FES values upon which the GEIS results were based and the MACCS code, CRAC2S was used to evaluate 72 hypothetical nuclear power plants. The first effort was to determine if CRAC2S would be an adequate surrogate for CRAC. Then CRAC2S and MACCS would be used to evaluate the 72 hypothetical sites and the results would be compared.

Benchmarking the CRAC2S code

A benchmark run was made using CRAC2S in order to verify its ability to satisfactorily reproduce the CRAC results found in the FESs. This was done by trying to match the input data sets for Indian Point Units 1 and 2 (Acharya and Blond n.d.). The data used in the CRAC2S main input file were identical to those used for the Indian Point CRAC main input file. However, the on-site meteorological data file used in the original Indian Point CRAC calculations was not available. In its place, meteorological data from the nearest monitoring station location, New York City, were used. The results of the benchmark found the early fatalities at Indian Point as calculated by the CRAC2S code were almost five times lower than the values calculated by CRAC. The values for latent cancers and total dose were almost identical. From these results, the staff concluded that the CRAC2S code could be used as a reasonable surrogate for CRAC in benchmarking it against the MACCS code.

Comparison of CRAC2S results to EI results for the hypothetical sites

Yambert and Linn (1992) created 72 hypothetical reactor sites. These sites were constructed by combining projected year 2030 population data for 9 existing reactor sites (5 PWR and 4 BWR) with actual meteorological data taken from 8 stations located across the U.S. The meteorological data were independent of the population data sites. Reactor locations for which population data were selected were chosen such that areas with high, medium, and low populations were represented. Similarly, the meteorological data were selected to represent a wide range of weather patterns (i.e., wet site, dry site, calm site, windy site, etc.). Values for early and normalized latent fatalities, and normalized total dose were then calculated for each of these hypothetical PWR and BWR sites using the CRAC2S computer code.[5] These values were then compared to estimates obtained by applying the EI methodology to the 72 hypothetical sites.

Comparison of the two sets of estimates showed that in all cases, the consequence values calculated using CRAC2S fell below the corresponding 95 percent UCB limit predicted using the EI methodology. In the case of early fatalities, CRAC2S calculated values for PWRs averaged about 2 to 3 times lower than expected values predicted using the fitted EI regression line. This difference was greater for hypothetical BWR sites where CRAC2S calculated values averaged an order of magnitude less than the corresponding expected values from the EI regression. In addition, for a hypothetical site with a very low EI value (less than 100), the CRAC2S predictions were 4 orders of magnitude lower than the EI regression line. This large variability was attributed to the sensitivity of the CRAC2S code results to the number of persons located near the site, particularly in the 0 to 2 mile radius from the facility. The CRAC2S values for both normalized latent fatalities and normalized total dose were nearly identical to the EI fitted regression line for BWRs and were slightly below the regression line for PWRs.

The preceding paragraphs showed that the CRAC code can be adequately represented by the CRAC2S code and that the EI methodology (which is derived from values calculated by the CRAC code) predicts higher or equal consequences for all combinations of population and meteorology compared with the CRAC2S results. The final step was to compare the CRAC2S computations with the latest consequence code to determine if the CRAC2S values, and by inference, the EI methodology values, conservatively overpredict consequences when compared to the state-of-the-art consequence models and computation techniques.

A study was conducted at Brookhaven National Laboratory (Tingle 1993) which compared predictions made by the CRAC2S code to those of the MACCS code. MACCS is the consequence code currently supported by NRC for estimating consequences associated with severe reactor accidents. The Brookhaven study used MACCS to analyze the 72 hypothetical reactor sites (Yambert and Linn 1992).

Early fatality values calculated using MACCS for PWR sites were about a factor of 2 higher than those calculated by CRAC2S. For BWR sites the MACCS values were about a factor of 10 to 20 higher. Consequently, CRAC2S underpredicted MACCS early fatality values by a factor of 2 for PWR sites and a factor of 10 to 20 for BWR sites. However, the EI regression values overpredict the values for early fatality estimates from the CRAC2S code (which are based on CRAC analyses performed for the plants' FES) by factors of 3 for PWRs and 10 for BWRs. These results show that the early fatalities values estimated using the most advanced consequence computer code, MACCS, can be adequately predicted using the fitted EI regression methodology and are well within the 95 percent UCB determined by the EI regression. Consequently, the early fatality regression values shown in Table 5.10 are conservative estimates of this potential impact.

The values for total dose calculated by MACCS and CRAC2S were nearly identical, differing by no more than a factor of 2. This was the same result in comparing the CRAC2S and EI regression values. Thus, the EI regression can be used as an adequate predictor of population total dose due to a severe accident release.

For latent fatalities, the study showed some significant differences between the values predicted by the two codes. MACCS estimates for latent fatalities were consistently factors of 5–15 higher than estimates from the CRAC2S code. Since the CRAC2S values for latent fatalities were very close to the expected EI regression values, the EI regressions underestimate the current best estimates for latent fatalities by approximately a factor of 10. In order to enable the EI methodology to be an adequately conservative predictor of latent fatalities, this information was incorporated by taking the 95 percent UCB values as estimated from the EI regressions and increasing the values by a factor of 10. It is these increased values which are used in the GEIS. The adjusted latent fatality estimates are shown in Table 5.11.

5.3.3.2.4 Conclusion

As can be seen from the data in Tables 5.10 and 5.11, the risk of early and latent fatalities from individual nuclear power plants is small. It represents only a small fraction of the risk to which the public is exposed from other sources. Even if the predicted early and latent fatalities from all 118 plants were considered (that is, the risk to the population of the United States from all 118 nuclear power plants), this would only result in a predicted risk of approximately one additional early fatality per year and approximately 30 additional latent fatalities per year, which is still a small fraction of the approximately 100,000 early and 500,000 latent cancer fatalities per year from other sources.

Table 5.10 Predicted early fatality estimates per reactor-year (RY) for all sites at their middle year of license renewal

Plant	Predicted UCB total early fatalities/RY (95% UCB)[a]
Arkansas	3.3×10^{-3}
Beaver Valley	2.5×10^{-2}
Bellefonte	4.0×10^{-3}
Big Rock Point	2.7×10^{-3}
Braidwood	3.6×10^{-3}
Browns Ferry	4.3×10^{-3}
Brunswick	3.5×10^{-3}
Byron	2.3×10^{-3}
Callaway	6.9×10^{-4}
Calvert Cliffs	1.8×10^{-3}
Catawba	1.7×10^{-2}
Clinton	3.0×10^{-3}
Comanche Peak	2.3×10^{-3}
Cooper	2.6×10^{-3}
Crystal River	1.5×10^{-3}
D. C. Cook	8.4×10^{-3}
Davis-Besse	1.4×10^{-3}
Diablo Canyon	1.5×10^{-3}
Dresden	4.6×10^{-3}
Duane Arnold	8.0×10^{-3}
Farley	1.5×10^{-3}
Fermi 2	6.8×10^{-3}
FitzPatrick	3.8×10^{-3}
Fort Calhoun	1.7×10^{-3}
Ginna	3.9×10^{-3}
Grand Gulf	2.8×10^{-3}
Haddam Neck	1.2×10^{-2}
Hatch	2.6×10^{-3}
Hope Creek	4.1×10^{-3}
Indian Point	6.5×10^{-2}
Kewanee	8.9×10^{-4}
La Salle	3.6×10^{-3}
Limerick	1.1×10^{-2}
Maine Yankee	1.8×10^{-3}
McGuire	1.0×10^{-2}
Millstone	2.5×10^{-2}
Monticello	4.1×10^{-3}
Nine Mile Point	3.8×10^{-3}

See footnotes at end of table.

Table 5.10 (continued)

Plant	Predicted UCB total early fatalities/RY (95% UCB)[a]
North Anna	9.4×10^{-4}
Oconee	1.1×10^{-2}
Oyster Creek	7.4×10^{-3}
Palisades	4.2×10^{-3}
Palo Verde	1.1×10^{-4}
Peach Bottom	4.2×10^{-3}
Perry	6.9×10^{-3}
Pilgrim	3.7×10^{-3}
Point Beach	2.5×10^{-3}
Prairie Island	3.7×10^{-3}
Quad Cities	4.5×10^{-3}
Rancho Seco	1.1×10^{-3}
River Bend	4.1×10^{-3}
Robinson	3.1×10^{-3}
Salem	2.9×10^{-3}
San Onofre	1.1×10^{-2}
Seabrook	1.1×10^{-2}
Sequoyah	6.6×10^{-3}
Shearon Harris	2.8×10^{-3}
Shoreham	3.3×10^{-3}
South Texas	3.2×10^{-3}
Saint Lucie	7.7×10^{-2}
Summer	1.3×10^{-4}
Surry	1.6×10^{-2}
Susquehanna	6.0×10^{-3}
Three Mile Island	2.8×10^{-2}
Trojan	3.7×10^{-2}
Turkey Point	6.0×10^{-2}
Vermont Yankee	4.6×10^{-3}
Vogtle	1.6×10^{-4}
WNP-2[b]	2.3×10^{-3}
Waterford	1.4×10^{-2}
Watts Bar	1.8×10^{-3}
Wolf Creek	4.7×10^{-4}
Yankee Rowe	3.3×10^{-3}
Zion	5.6×10^{-2}

[a] UCB = upper confidence bound. For description and explanation of these values, see Appendix G.

[b] WNP-2 = Washington Nuclear Project 2.

Table 5.11 Predicted latent fatality estimates per reactor-year (RY) for all sites at their middle year of license renewal (MYR)

Plant	Nonnormalized predicted UCB total latent fatalities/RY (95% UCB)[a]
Arkansas	1.7×10^{-1}
Beaver Valley	1.3×10^{0}
Bellefonte	1.0×10^{0}
Big Rock Point	3.2×10^{-2}
Braidwood	3.3×10^{0}
Browns Ferry	9.7×10^{-1}
Brunswick	4.7×10^{-1}
Byron	2.2×10^{0}
Callaway	3.6×10^{-1}
Calvert Cliffs	2.3×10^{0}
Catawba	1.4×10^{0}
Clinton	1.8×10^{0}
Comanche Peak	3.3×10^{-1}
Cooper	6.3×10^{-1}
Crystal River	5.0×10^{-1}
D. C. Cook	1.8×10^{0}
Davis-Besse	1.5×10^{0}
Diablo Canyon	2.5×10^{-1}
Dresden	1.4×10^{0}
Duane Arnold	3.7×10^{-1}
Farley	2.4×10^{-1}
Fermi 2	1.9×10^{0}
FitzPatrick	5.0×10^{-1}
Fort Calhoun	8.0×10^{-2}
Ginna	1.5×10^{-1}
Grand Gulf	9.7×10^{-1}
Haddam Neck (Connecticut Yankee)	2.0×10^{0}
Hatch	5.7×10^{-1}
Hope Creek	2.5×10^{0}
Indian Point	7.7×10^{0}
Kewanee	2.2×10^{-1}
La Salle	2.0×10^{0}
Limerick	3.1×10^{0}
Maine Yankee	3.0×10^{-1}
McGuire	1.4×10^{0}
Millstone	3.1×10^{0}

See footnotes at end of table.

Table 5.11 (continued)

Plant	Nonnormalized predicted UCB total latent fatalities/RY (95% UCB)[a]
Monticello	5.0×10^{-1}
Nine Mile Point	6.7×10^{-1}
North Anna	1.1×10^{0}
Oconee	1.0×10^{0}
Oyster Creek	1.5×10^{0}
Palisades	1.3×10^{0}
Palo Verde	2.6×10^{-1}
Peach Bottom	2.0×10^{0}
Perry	1.7×10^{0}
Pilgrim	6.0×10^{-1}
	2.3×10^{-1}
Point Beach	
Prairie Island	1.7×10^{-1}
Quad Cities	1.1×10^{0}
Rancho Seco	1.3×10^{0}
River Bend	8.0×10^{-1}
Robinson	7.0×10^{-1}
Salem	5.0×10^{0}
San Onofre	2.4×10^{0}
Seabrook	6.0×10^{-1}
Sequoyah	1.1×10^{0}
Shearon Harris	7.3×10^{-1}
Shoreham	8.0×10^{-1}
South Texas	8.0×10^{-1}
St. Lucie	6.3×10^{-1}
Summer	1.0×10^{0}
Surry	9.0×10^{-1}
Susquehanna	2.8×10^{0}
Three Mile Island	3.3×10^{0}
Trojan	1.5×10^{0}
Turkey Point	2.0×10^{-1}
Vermont Yankee	9.0×10^{-1}
Vogtle	7.3×10^{-1}
WNP-2[b]	4.3×10^{-1}
Waterford	3.3×10^{-1}
Watts Bar	1.2×10^{0}
Wolf Creek	3.3×10^{-1}
Yankee Rowe	6.7×10^{-1}
Zion	1.8×10^{0}

[a] UCB = upper confidence bound. For description and explanation of these values, see Appendix G.

[b] WNP-2 = Washington Nuclear Project 2.

In addition, the prediction technique used was designed to overestimate the risk from reactor accidents. Table 5.12 illustrates this point by comparing—for the five NUREG-1150 plants—the early and latent risk values obtained from Tables 5.10 and 5.11 versus those from the NUREG-1150 analyses. In all cases the NUREG-1150 analyses predict lower risk values (one to five orders of magnitude) than the GEIS prediction technique. Although some of the difference can be attributed to the fact that the NUREG-1150 results incorporated plant modifications discovered and corrected as a result of the NUREG-1150 analyses, some can also be attributed to the conservatism of the prediction technique used versus the more recent detailed analyses used for NUREG-1150.

Table 5.12 Comparison of predicted early and latent fatality estimates to NUREG-1150 findings

	Early fatalities		Latent fatalities	
Plant	Table 5.10	NUREG-1150	Table 5.11	NUREG-1150
Grand Gulf	2.8×10^{-3}/RY	1×10^{-8}/RY	9.7×10^{-1}/RY	9×10^{-4}/RY
Peach Bottom	4.2×10^{-3}/RY	3×10^{-8}/RY	2.0×10^{0}/RY	4×10^{-3}/RY
Sequoyah	6.6×10^{-3}/RY	3×10^{-5}/RY	1.1×10^{0}/RY	1×10^{-2}/RY
Surry	1.6×10^{-2}/RY	2×10^{-6}/RY	9.0×10^{-1}/RY	5×10^{-3}/RY
Zion	5.6×10^{-2}/RY	3×10^{-5}/RY	1.8×10^{0}/RY	8×10^{-3}/RY

Note: RY = reactor-year.

5.3.3.3 Dose and Adverse Health Effects from Fallout onto Open Bodies of Water

5.3.3.3.1 Methodology

Following a severe accident, a radiation hazard may exist from the deposition of airborne, radioactive fallout onto open bodies of water. Depending on the type of water body, this hazard may lead to internal exposure from the ingestion of contaminated water or from consuming contaminated aquatic fauna. External exposure may result from swimming in the contaminated water or from recreational activities on the shoreline. The extent of the hazard is largely determined by the proximity of individuals to the reactor, the areal extent of contamination, and the ability for interdiction to reduce the exposure hazard. The risk from this exposure at plants sited on all types of water bodies is compared with that of the Fermi plant, located on Lake Erie, for which an analysis has been completed for an uninterdicted dose (NUREG-0769, Addendum 1). The potential risk is also discussed for a dose with interdiction.

This section examines such radiation exposure risk at nuclear power reactors in the event of a severe reactor accident in which radioactive contaminants are released into the atmosphere and subsequently deposited onto open bodies of water. The drinking-water pathway is treated separately from the aquatic food, swimming, and shoreline pathways. The latter three pathways are addressed collectively, and the rationale for selecting only the aquatic food pathway for analysis is presented. In the case of the drinking-water pathway, environmental parameters at representative sites are compared with such parameters at the Enrico Fermi Atomic Power Plant, Unit 2, to arrive at some indication of comparative, uninterdicted hazard.

For the aquatic food pathway, the methodology in the Fermi analysis was used with site-specific data to arrive at a comparative population dose. The Fermi analysis applied the completely mixed lake model bottom sedimentation, so that sedimentation processes are accounted for in the residence times. Population dose estimates for both the drinking-water and aquatic food pathways are compared with estimates from the atmospheric pathway. Analysis of the drinking-water pathway precedes that of the aquatic food pathway.

For the drinking-water pathway, sites adjacent to bodies of fresh water that can be used as a source of drinking water are considered. One estuarine site, which is not used as a source of drinking water, is examined for comparison purposes only. Direct deposition onto the surface water is the only pathway evaluated. The contamination of surface water bodies by the land erosion of atmospherically deposited radionuclides is not considered. One study concludes that risk from such a pathway is small compared with that of the atmospheric and terrestrial pathways (Helton et al. 1985). The study indicates that the contribution to latent facility from runoff to a great lake is less than 15 percent of what would be expected by direct deposit onto the lake. For both a great lake and a river, the expected latent facilities are only a small fraction of the latent fatalities predicted from land contamination. (Terrestrial pathways, including ingestion of crops, are considered in the atmospheric pathway in Section 5.3.3.2.)

Radioactive material released to the atmosphere tends to spread and disperse in air and dilute in water. The concentration of the contaminated material is thus related to the volume of contaminated air and water and meteorological and hydrological conditions at the time of release. These dilution processes reduce the intensity of the hazard downwind and downstream from the point of release but tend to increase the areal extent of the exposure hazard.

Several studies provide partial benchmarks that can be used to comparatively evaluate the surface water ingestion pathway at reactors located adjacent to bodies of fresh water. The Liquid Pathway Generic Study (LPGS) (NUREG-0440) examines surface water contamination via groundwater transport following a severe accident at a generic small river site, large river site, Great Lakes site, estuary site, coastal site, and dry site. Transport via groundwater to surface water bodies, however, is not directly applicable to the direct deposition pathway examined here. Results of the LPGS study indicate that the maximum individual total body dose associated with a severe core-melt accident for the small river site was one to two orders of magnitude higher than for the large river and Great Lakes site. The high values for the small river site were related to lower flow rates. Uninterdicted population drinking-water dose estimates calculated in the LPGS are as follows: large river site, 1.08×10^5 person-rem; small river site,

8.87×10^6 person-rem; and Great Lakes site, 2.34×10^6 person-rem.

Two analyses establish precedent for the direct-deposition, surface-water ingestion pathway. One (NUREG-0769, Addendum 1) is an estimate of risk performed for the Enrico Fermi Atomic Power Plant Unit 2. This assessment indicates that estimated individual and societal uninterdicted doses from the surface water pathway are of the same order of magnitude as interdicted doses from the airborne pathway. A whole body dose to an individual after a 3-year period of exposure was estimated at 0.8 rem. Interdiction comparable to that for the terrestrial pathway could substantially reduce this dose estimate and is equally likely. A second study for the Indian Point reactors (Codell 1985) developed empirical models based on considerations of radionuclide data associated with fallout from atmospheric weapons tests. A maximum 194 person-rem/RY whole-body uninterdicted dose via drinking water was estimated and compared with a maximum 2610 person-rem/RY whole-body dose from the direct airborne pathways. Although both latent and early fatality risks are associated with direct airborne pathways, only latent risks were found to be associated with the liquid (drinking-water) pathway because doses were well below the predicted rate and threshold for early fatalities or radiation illness.

Analyses in environmental documents prepared subsequent to the Fermi and Indian Point studies and the LPGS used results of these three studies as benchmarks. Representative conclusions from these documents are summarized here. Using site-specific parameters for the Perry plant (NUREG-0884), individual and societal latent cancer fatality risks from unrestricted use of Lake Erie were found to be about twice the risks from the Fermi reactor but the same order of magnitude as the air and ground pathways. For the Limerick plant (NUREG-0974), the small surface area of the nearby receiving water body (the Schuylkill River) relative to the total area of fallout is cited as the basis for concluding that the surface water pathway would be of small importance compared with the land pathway. The analysis for the Vogtle plant (NUREG-1087) qualitatively compares site-specific characteristics with those from both the Fermi and Indian Point studies and concludes that the surface water pathway would be of little importance compared with the results from atmospheric fallout onto land.

Environmental parameters important for input in performing the above analyses, and for use in analyses of additional sites, are the surface area of the receiving body, the volume of water in the body, and the flow rate. In the absence of a rigorous site-specific analyses, these data can provide estimates of the extent of contamination in the receiving water body and the residence time of the contaminant in the affected water body. Comparing these estimates and site environmental parameters with those for Fermi can provide some indication of the comparative hazard associated with drinking contaminated surface water among sites and the need for site-specific analyses. Accounting for population and meteorological data in the comparison can provide further indication of relative risk among sites.

The method used for evaluating the direct-deposition surface water ingestion pathway compares water body surface area, volume, and flow rate data at plants for which analyses have not been performed with similar data used in the Fermi 2 analysis. Table 5.13 lists all plants by adjacent water body category. Type of plant site categories have been assigned consistent with the LPGS analysis. Plants

Table 5.13 Nuclear power plants by water body category

Estuary or coastal	Great lakes	Small river or impoundment		Large river
Diablo Canyon	Zion	Bellefonte	Vogtle	Grand Gulf
Crystal River	Fermi	Haddam Neck	Clinton	Trojan
Maine Yankee	Ginna	Braidwood	Quad Cities	WNP-2[a]
Seabrook	Perry	Dresden	Monticello	River Bend
Salem	Big Rock Point	Duane Arnold	Cooper	
South Texas	Palisades	Waterford	Shearon Harris	
San Onofre	Nine Mile Point	Prairie Island	Limerick	
St. Lucie	Kewaunee	Fort Calhoun	Three Mile Island	
Calvert Cliffs	Cook	McGuire		
Hope Creek	FitzPatrick	Peach Bottom	Catawba	
Shoreham	Davis-Besse	Browns Ferry	Summer	
Surry	Point Beach	Arkansas	Oconee	
Millstone		Hatch	Sequoyah	
Turkey Point		Byron Station	Vermont Yankee	
Pilgrim		La Salle		
Oyster Creek		Wolf Creek	Connecticut Yankee	
Brunswick		Yankee Rowe		
Indian Point		Callaway	Robinson	
Shoreham		Beaver Valley	Watts Bar	
		Susquehanna	North Anna	
		Farley		

[a] WNP-2 = Washington Nuclear Project 2.

were selected for analysis to represent the spectrum of environmental characteristics found at all plants; those not evaluated are considered to possess environmental characteristics within the range of those evaluated.

Nine Mile Point and Zion were selected to include Great Lakes other than Lake Erie. Zion was selected because, of those plants located near Lake Michigan, Zion's location near the southwestern shore of the lake would enable a large portion of a plume to be deposited onto the lake near a highly populated area. Trojan and Grand Gulf were selected to represent each of the two large rivers adjacent to plants. Because the LPGS analysis indicates higher population dose estimates for small rivers (NUREG-0440), a larger number of small river sites have been evaluated. Small river sites were selected to represent (1) a range of flow rates, (2) proximity to small rivers that are the only affected water body, and (3) proximity to small rivers where other water bodies are also affected. An estuary site, in which the principal water body is not used as a source of drinking water, is included for comparison purposes only.

Great Lakes data as presented in the Fermi analysis are used in this evaluation. The assumptions used for determining river width, depth, and flow rate throughout the affected river reach are as follows: (1) large rivers and small rivers are uniformly 6- and 3-m (20- and 10-ft) deep, respectively, (2) river width at the reactor site is the same throughout the affected area, and (3) reported flow rate at the site is assumed throughout. Surface area and volume data for small lakes and reservoirs were obtained from federal and state agencies. In those cases in which part of a small lake is included in the affected area, the entire surface area and volume of the lake are included. As in the Fermi analysis, contaminant is assumed to be thoroughly mixed in the water body.

For the purposes of this analysis, it is assumed that essentially all atmospheric fallout occurs within 80 km (50 miles) of the reactor. For river sites, the "potentially" affected area includes all surface water bodies within 80 km (50 miles) of the reactor while the "likely" affected area assumes that only a limited portion of the potentially affected area is affected. (The likely affected area includes water body surface areas and volumes within 80 km of the reactor site and within 6 of the 22.5° compass sectors toward which the wind blows the greatest percentage of time.) All major surface water bodies are assumed to be sources of drinking water at the evaluation year (MYR). For Great Lakes and the estuary site, it is assumed that the adjacent water body is both the potentially and likely affected area. The potentially and likely affected populations at the MYR are obtained as above for the affected area. Data are presented in Tables 5.14a and 5.14b.

To facilitate comparison of environmental parameters and analysis of those parameters among sites, selected data in Tables 5.14a and 5.14b are presented in histograms in Figures 5.8 through 5.11. The data included in the figures and a brief description of types of information provided by the figures follow. Figure 5.8 compares surface areas and water volumes of potentially affected areas. In addition to illustrating the smaller surface area of rivers available to receive fallout compared with the Great Lakes, these data provide some indication of relative dilution capacity (water volume) of the bodies of water. Figure 5.9 compares surface areas and water volumes of likely affected areas. These data further illustrate the smaller affected surface area and dilution capacity of rivers compared with the Great Lakes. Figure 5.10 depicts the three-order-of-magnitude spread in water body flow rate that contributes to additional dilution over longer time periods. Figure 5.11 compares estimated contaminant residence times in the likely affected water bodies and the surface-area-to-volume ratios to provide some indication of the relative level of contamination per unit of water. The data in this figure (obtained by simple computation from data presented in previous figures) are the principal basis for comparison with the Fermi plant.

In addition to examining the drinking-water pathway, NUREG-0769 (1981) considers the aquatic food, shoreline, and swimming exposure pathways for the Fermi reactor. Since the principal uninterdicted, whole-body population dose in the Fermi analysis is derived from aquatic food (8×10^7 person-rem), as compared to drinking water (4×10^6 person-rem), shoreline (2×10^6 person-rem), and swimming (6×10^3 person-rem), the uninterdicted aquatic food pathway is examined. Particularly in the case of estuaries, aquatic food consumption constitutes the principal pathway of exposure.

The process for examining the aquatic food pathway began with a comparison of edible aquatic food harvest data from major eastern U.S. and Gulf Coast estuaries,

Table 5.14a Comparison of Fermi 2 site data with data from other representative nuclear plants

Plant	Type of site[a]	Potentially affected surface area (m^2)	Potentially affected water volume (m^3)	Likely affected surface area (m^2)[b]	Likely affected water volume (m^3)[b]	Average flow rate (m^3/year)
Fermi	Lake	2.57×10^{10}	4.58×10^{11}	2.57×10^{10}	4.58×10^{11}	1.75×10^{11}
Beaver Valley	Small river	9.44×10^{7}	2.83×10^{8}	6.74×10^{7}	2.02×10^{8}	3.31×10^{10}
Braidwood	Small river	2.27×10^{7}	6.82×10^{7}	1.28×10^{7}	3.58×10^{7}	3.47×10^{9}
Browns Ferry	Small river	5.19×10^{8}	2.45×10^{9}	2.38×10^{8}	1.16×10^{9}	3.82×10^{10}
Byron Station	Small river	2.12×10^{7}	6.36×10^{7}	4.85×10^{6}	1.46×10^{7}	4.42×10^{9}
Callaway	Small river	1.24×10^{8}	3.73×10^{8}	6.41×10^{6}	1.92×10^{7}	1.17×10^{10}
Catawba	Small river	6.99×10^{7}	4.25×10^{8}	6.79×10^{7}	3.65×10^{8}	3.47×10^{9}
Clinton	Small river	1.03×10^{8}	4.71×10^{8}	3.20×10^{7}	1.33×10^{8}	2.21×10^{8}
Dresden	Small river	2.27×10^{7}	6.82×10^{7}	6.41×10^{6}	1.92×10^{7}	3.78×10^{9}
Duane Arnold	Small river	4.27×10^{7}	1.18×10^{8}	4.27×10^{7}	1.18×10^{8}	2.68×10^{9}
Grand Gulf	Large river	1.19×10^{8}	7.15×10^{8}	1.19×10^{8}	7.15×10^{8}	6.02×10^{11}
Hope Creek	Estuary	2.07×10^{9}	3.45×10^{10}	2.07×10^{9}	3.45×10^{10}	3.71×10^{11}
Limerick	Small river	6.03×10^{7}	1.81×10^{8}	1.28×10^{7}	3.85×10^{7}	1.70×10^{9}
McGuire	Small river	3.80×10^{8}	2.15×10^{9}	2.72×10^{8}	1.48×10^{9}	2.37×10^{9}
Monticello	Small river	5.46×10^{8}	3.45×10^{9}	5.46×10^{8}	3.45×10^{9}	4.10×10^{9}
Nine Mile Point	Lake	1.97×10^{10}	1.64×10^{12}	1.97×10^{10}	1.64×10^{12}	2.09×10^{11}
North Anna	Small river	6.59×10^{7}	6.81×10^{8}	6.08×10^{7}	6.66×10^{8}	3.15×10^{8}
Oconee	Small river	3.46×10^{8}	5.86×10^{9}	3.46×10^{8}	5.86×10^{9}	9.46×10^{8}
Prairie Island	Small river	5.70×10^{8}	3.53×10^{9}	5.70×10^{8}	3.53×10^{9}	1.34×10^{10}
Quad Cities	Small river	6.24×10^{7}	1.87×10^{8}	4.33×10^{7}	1.30×10^{8}	4.23×10^{10}
Robinson	Small river	9.40×10^{7}	5.08×10^{8}	1.51×10^{7}	5.63×10^{7}	1.58×10^{8}
Shearon Harris	Small river	1.17×10^{8}	1.11×10^{9}	8.64×10^{7}	1.01×10^{9}	2.78×10^{9}
Summer	Small river	3.33×10^{8}	3.35×10^{9}	6.79×10^{7}	4.19×10^{8}	5.36×10^{9}
Three Mile Island	Small river	4.71×10^{7}	1.41×10^{8}	4.71×10^{7}	1.41×10^{8}	3.04×10^{10}
Trojan	Large river	8.73×10^{7}	5.24×10^{8}	8.73×10^{7}	5.24×10^{8}	3.85×10^{11}
Vermont Yankee	Small river	6.20×10^{7}	1.86×10^{8}	6.20×10^{7}	1.86×10^{8}	7.73×10^{9}
Wolf Creek	Small river	1.50×10^{8}	6.41×10^{8}	7.04×10^{7}	2.05×10^{8}	1.42×10^{9}
Yankee Rowe	Small river	1.97×10^{8}	1.87×10^{9}	1.48×10^{7}	4.43×10^{7}	6.62×10^{8}
Zion	Lake	5.80×10^{10}	4.87×10^{12}	5.80×10^{10}	4.87×10^{12}	1.58×10^{11}

[a] As designated in Liquid Pathway Generic Study analysis (NUREG-0440).

[b] In the likely affected water body.

Note: Multiply square meters by 1.20 to find square yards; multiply cubic meters by 1.307 to find cubic yards.

Table 5.14b Comparison of Fermi 2 site data with data from other representative nuclear plants

Plant	Type of site[a]	Residence time (years)[b]	Surface area to volume ratio[b]	Potentially affected population[c]	Percentage of population likely to be affected	Average annual wind velocity (mph)	Average annual precipitation (inches)	
							Rain	Snow
Fermi	Lake	2.6×10^{0}	5.6×10^{-2}	6,647,763	41	8.9	31	31
Beaver Valley	Small river	6.1×10^{-3}	3.3×10^{-1}	4,169,673	48	9.3	36	46
Braidwood	Small river	1.1×10^{-2}	3.3×10^{-1}	5,092,832	43	10.3	30	24
Browns Ferry	Small river	3.0×10^{-2}	2.1×10^{-1}	926,918	13	8–12	47	3
Byron Station	Small river	3.3×10^{-3}	3.3×10^{-1}	1,141,541	38	9.9	18	34
Callaway	Small river	1.6×10^{-3}	3.3×10^{-1}	463,360	11	10.3	37	19
Catawba	Small river	1.1×10^{-1}	1.9×10^{-1}	2,337,775	13	6.9	42	56
Clinton	Small river	6.0×10^{-1}	2.4×10^{-1}	869,226	6	11.4	35	23
Dresden	Small river	5.1×10^{-3}	3.3×10^{-1}	7,453,539	17	9.7	33	37
Duane Arnold	Small river	4.4×10^{-2}	3.6×10^{-1}	754,825	46	8.0	33	31
Grand Gulf	Large river	1.2×10^{-3}	1.7×10^{-1}	504,930	18	7.7	50	2
Hope Creek	Estuary	9.3×10^{-2}	6.0×10^{-2}	5,424,373	26	8.9	40	23
Limerick	Small river	2.3×10^{-2}	3.3×10^{-1}	7,615,980	37	9.1	59	20
McGuire	Small river	6.2×10^{-1}	1.8×10^{-1}	2,543,485	23	6.9	43	6
Monticello	Small river	8.4×10^{-1}	1.6×10^{-1}	2,815,967	82	NA	24	42
Nine Mile Point	Lake	7.8×10^{0}	1.2×10^{-2}	811,475	9	10.0	34	88
North Anna	Small river	2.1×10^{0}	9.1×10^{-2}	1,478,490	61	6.8	44	16
Oconee	Small river	6.0×10^{0}	5.9×10^{-2}	1,311,318	20	7.6	53	NA
Prairie Island	Small river	2.6×10^{-1}	1.6×10^{-1}	2,961,583	79	6.3	25	44
Robinson	Small river	3.6×10^{-1}	2.7×10^{-1}	991,450	28	6.2	33	NA
Shearon Harris	Small river	3.6×10^{-1}	8.6×10^{-2}	2,122,597	49	4.6	36	NA
Summer	Small river	7.8×10^{-2}	1.6×10^{-1}	1,385,612	27	NA	45	2
Trojan	Large river	1.4×10^{-3}	1.7×10^{-1}	2,822,894	91	8.2	42	7
Vermont Yankee	Small river	2.4×10^{-2}	3.3×10^{-1}	1,709,869	45	7.8	43	60
Wolf Creek	Small river	1.4×10^{-1}	3.4×10^{-1}	273,225	35	10.3	31	15
Yankee Rowe	Small river	6.7×10^{-2}	3.3×10^{-1}	1,796,823	38	NA	NA	100
Zion	Lake	3.1×10^{1}	1.2×10^{-2}	8,199,956	10	NA	32	58

[a] As designated in Liquid Pathway Generic Study analysis (NUREG-0440).

[b] In the likely affected water body.

[c] Population projected for the middle year of license renewal (Table 5.5); 80-km (50-mile) radius from the site.

NA = Data not available.

Note: To convert mph to kph, multiply by 1.61; to convert inches to centimeters, multiply by 2.54.

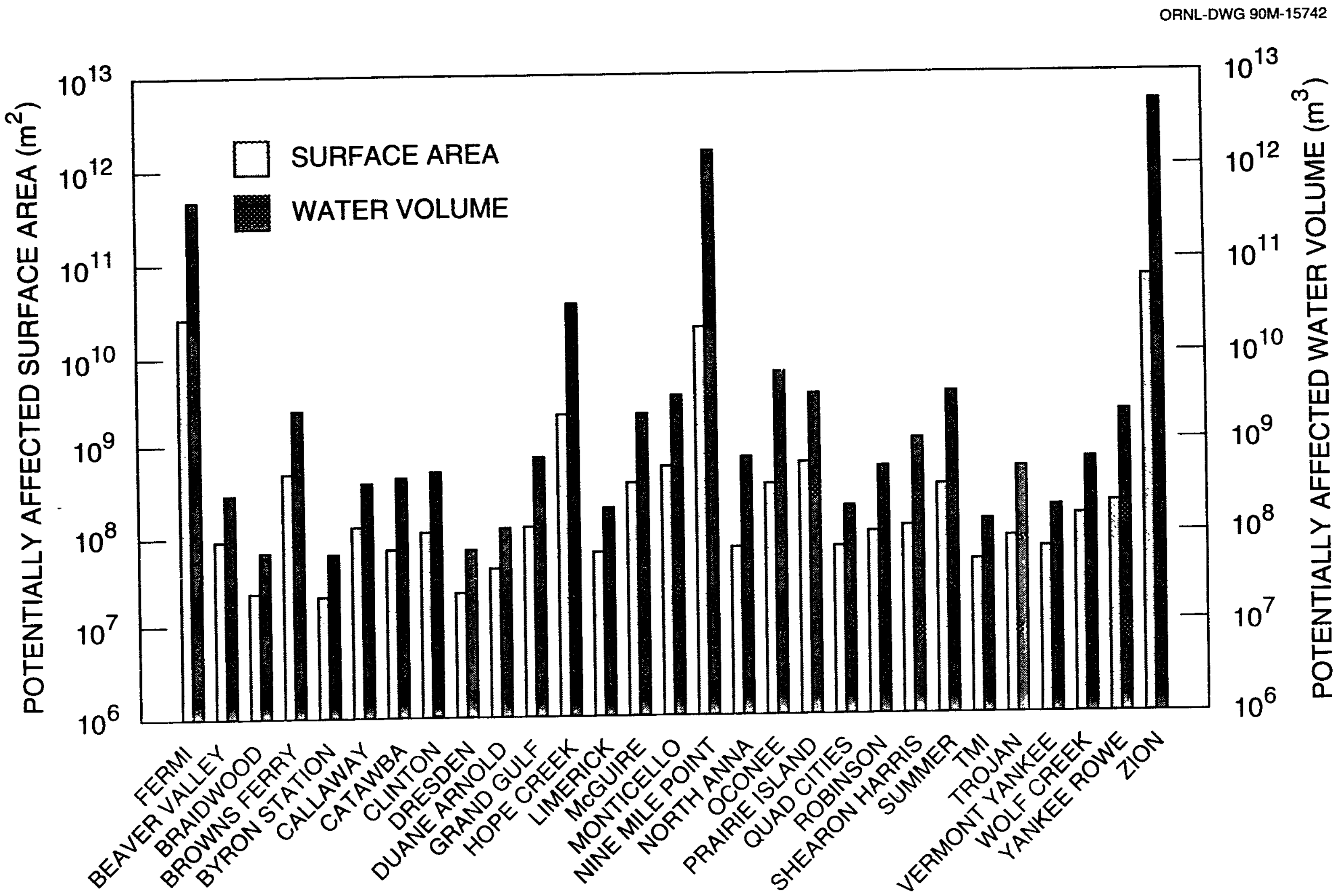

Figure 5.8 Water body surface areas and volumes within 80 km (50 miles) of representative nuclear power plant sites (potentially affected water bodies).

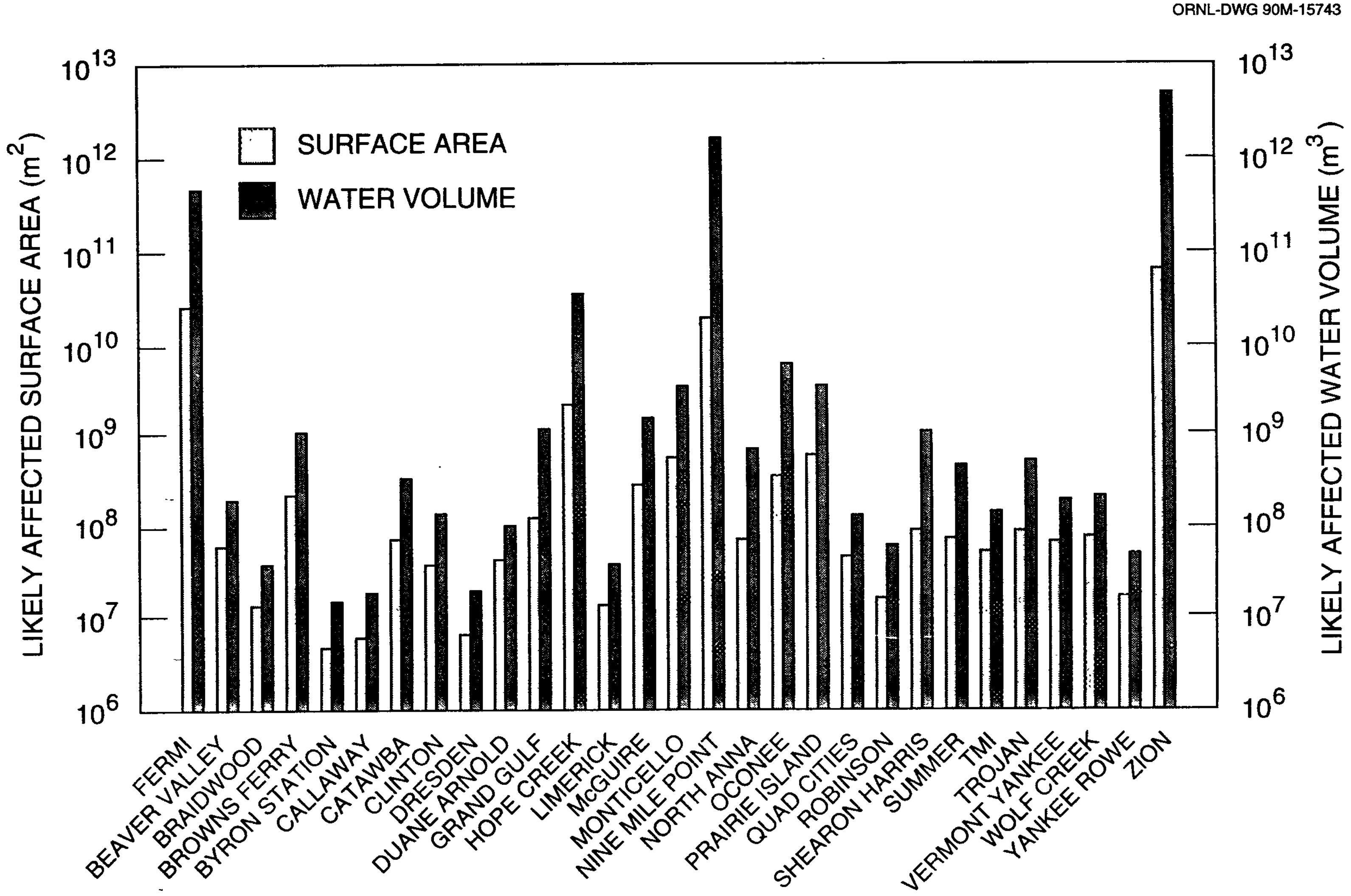

Figure 5.9 Water body surface areas and volumes within 80 km (50 miles) of the reactor site and within six of the 22.5° compass sectors that exhibit the greatest percentage of time for which the wind blows toward that compass direction (likely affected water bodies).

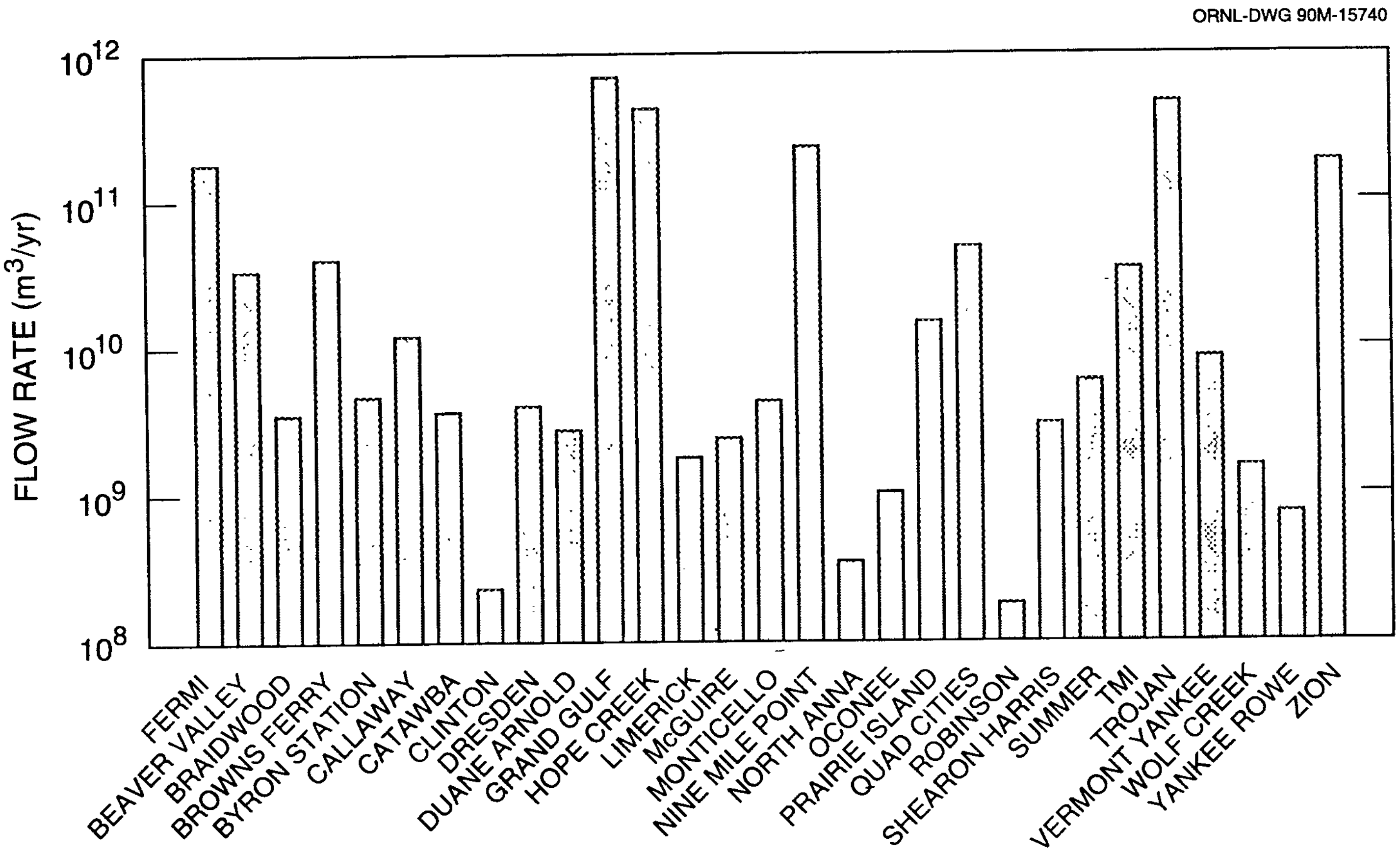

Figure 5.10 Water body flow rate at representative nuclear power plant sites.

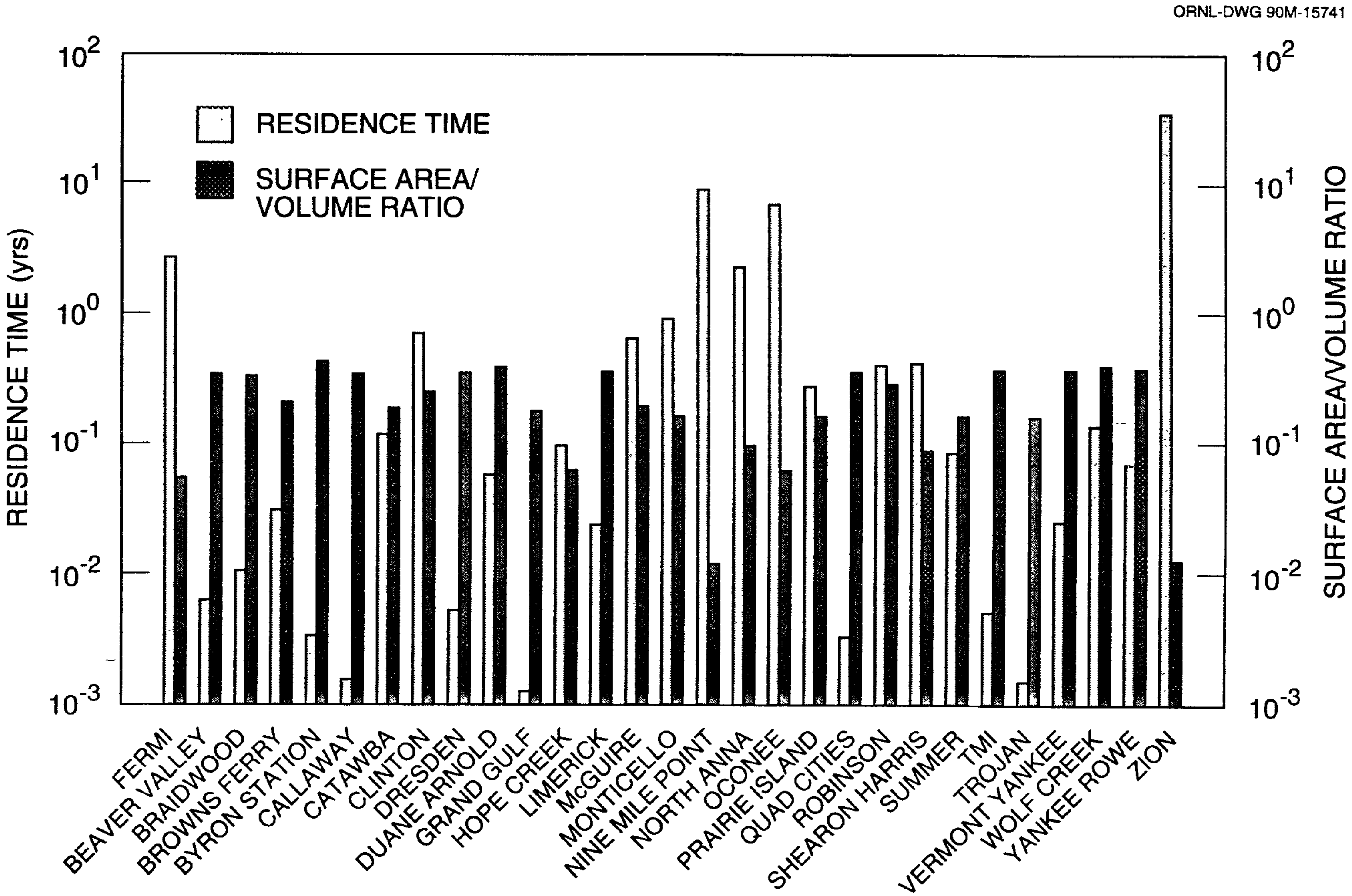

Figure 5.11 Contaminant residence time (flushing rate) and surface area–volume ratios for water bodies within an 80-km (50-mile) radius of selected nuclear power plants.

three Great Lakes, and generic large and small rivers. Sites were selected to include major aquatic food producing water bodies adjacent to plant sites. Data for East Coast estuaries, the eastern Gulf Coast, and the Great Lakes sites were obtained from the U.S. Department of Commerce (1980) and NUREG-0056. In the absence of site-specific data for river sites, generic aquatic harvest data from LPGS (NUREG-0440) were applied to a representative large and small river site. It is recognized that the quantity of aquatic food harvested from a water body varies temporally with the environmental quality of the water body. As in LPGS, it is assumed that 53 percent of the round weight of marine fish, 26 percent of the crustacea, and 28 percent of the freshwater fish are edible by humans. Mollusc data are reported in weight of edible meat. Recreational harvest data for molluscs and crustacea are unavailable and not included. While aquacultural harvests may be large locally [as much as about 3000 kg/ha in 1971 (2700 lbs/acre)], potential dose from this aquatic food source, like commercial harvests, is readily interdicted, and aquaculture harvest data are not included.

Many commercially and recreationally important marine fauna depend on the estuarine waters of the eastern Atlantic and Gulf Coasts for some portion of their life cycle. These include summer and winter flounder, striped bass, bluefish, alewives, black and rock sea basses, butterfish, croaker, weakfish, kingfish, shad, spot, menhaden, blackfish, mackerel, and shrimp. The presence of these fauna in an affected estuary for a few months and their subsequent migration from the estuary for later harvest elsewhere is acknowledged, although their contribution to the food pathway cannot be reasonably quantified and accommodated in the present analysis. However, compared with those organisms that are harvested in the estuary, the contribution of migratory fauna to estimates of dose and population risk is considered to be relatively small.

The modeling methodology in the Fermi analysis accounts for changes in radioactive nuclide concentrations in both sediment and surface water. The sediment model accounts for both the removal of radionuclides through sedimentation, as well as leaching back of the radionculides from the sediment into the water column. Surface water transport models are used to determine dispersing waterborne concentration functions, resulting in time-dependent water concentrations. The bioaccumulation approach is considered to be appropriate when the organisms have been in a reasonably constant concentration field for a period of sufficient duration for trophic and biological exchange processes to approach equilibrium. Since the time frame of interest for aquatic food concentrations extends up to 1 year, utilization of the various time-dependent waterborne radionuclide concentrations, when divided into periods of reasonably constant concentration, will provide reliable determinations of aquatic food concentrations of radioactive nuclides. A detailed discussion of the use of the bioaccumulation factor is provided in Appendix C of NUREG-0440, *Liquid Pathway Generic Study.*

Annual aquatic harvest data are compared with similar data used in the Fermi analysis to arrive at comparative estimates of whole-body population dose (assuming a constant source term among sites). From these data, estimates of population exposure and individual latent cancer fatality risk per RY are calculated as in the Fermi analysis. It is assumed that all of the edible aquatic harvest is consumed by humans, and a linear relationship between edible aquatic food harvest and population dose is assumed using data in the Fermi analysis for comparison.

Population exposure values are computed as the product of the projected population dose (scaled using the Fermi analysis), an assigned probability for an atmospheric release (about 2×10^{-5}; consistent with the Fermi analysis), and the probability of the wind blowing toward the water body. Probability estimates of deposition onto the water body are obtained from site-specific meteorological data, which provide the fraction of time the wind is blowing toward the water body.

5.3.3.3.2 Results

Results for the aquatic food pathway follow those for the drinking-water pathway. In the case of the drinking-water pathway, comparisons of each type of environmental data with those at Fermi and the implications of those comparisons with respect to surface water contamination are presented. Great Lakes and the estuarine site comparisons precede those for river sites.

For all sites evaluated, average annual precipitation and wind data are similar to those at Fermi, which suggests no appreciably different effects from meteorological conditions on fallout among sites. The surface areas of the estuarine and Great Lakes sites evaluated are the same order of magnitude or less than those of the Fermi plant, which indicates that these sites would receive less than or essentially the same proportion of contaminant as Fermi. For the other Great Lakes sites evaluated, water volume values nearly one order of magnitude greater than those of Fermi would result in significantly greater dilution. Because water volume is one order of magnitude lower for the estuarine site, less dilution would occur. Similar flow rates for the Great Lakes sites would not alter the comparative dilution capacity. A flow rate that is greater by an apparent factor of two for the estuarine site would suggest an increase in dilution. While it is acknowledged that the contribution of tidal flow to the overall flow rate is large, tidal flow may incompletely remove contaminants, and a reasonable means of accommodating that phenomenon in the analysis is not available. Therefore, tidal flow is simply included with other flow data. Nine Mile Point exhibits a contaminant resident time that is a factor of 3 longer than that of Fermi; Zion has a residence time that is an order of magnitude greater than that of Fermi, and Hope Creek's is nearly 2 orders of magnitude less. Surface-area-to-volume ratios about a factor of 5 lower for Nine Mile Point and Zion suggest lower contaminant concentrations for these sites. Essentially the same surface-area-to-volume ratio for Hope Creek indicates a contaminant concentration similar to that of Fermi.

Comparisons of the estuary and Great Lakes site data with Fermi data indicate that contamination of these sites is of the same order of magnitude as Fermi. In the case of the Great Lakes sites, effects from longer comparative residence times are countered by lower surface-area-to-volume ratios (lower contaminant concentrations). Comparisons of those parameters for the estuarine site indicates much lower residence times than for Fermi and essentially the same contaminant concentration.

In the case of the river sites, the data corroborate the assumption that the surface area of the water body available to receive fallout is small compared with

Fermi. Compared to Fermi, however, 2- to 3-orders-of-magnitude-lower water volumes for both small and large rivers result in a significantly reduced capacity for dilution in that portion of the river that receives fallout. Factors of 2 to 3 higher comparative flow rates for large rivers increase dilution capacity, whereas comparative 1- to 3-orders-of-magnitude-lower flow rates for small rivers contribute to further reduced dilution capacity. The ability of many river sites to remove contaminants rapidly is evident in the residence time data, the values of which are measured in days or weeks rather than years, as for the Great Lakes sites. Longer residence times for some small rivers are attributed to low flow rates or proximity to small lakes. Comparatively higher surface-area-to-volume ratios for river sites indicate higher concentrations of contaminant in the affected portion of the river.

In contrast to the estuarine and Great Lakes sites evaluated—in which the data are amenable to direct interpretative comparison with the Fermi analysis—a direct comparison between river and Great Lakes systems does not yield viable results. Therefore, combinations of characteristics are utilized in arriving at data interpretations for river sites. While comparatively small portions of rivers may receive fallout, the concentration of contaminant in all river sites evaluated is essentially the same as or exceeds that of Fermi by as much as a factor of 6. Residence times for large rivers are more than 3 orders of magnitude less than for Fermi, while small river values vary from nearly 3 orders of magnitude less to more than a factor of 2 greater than for Fermi. Examination of the data in Table 5.14b indicates that certain small river sites could result in a combination of residence time and concentration that would exceed Fermi by a factor of 2 to 3; however, the potentially affected population is much smaller than at Fermi.

River sites that may receive relatively high concentrations of contaminant but which exhibit flow rates sufficient to enable the removal of contaminants within short periods of time (hours to several days) would reduce potential contaminant exposure time such that risk at these sites is likely to be bound by the Fermi analysis. However, such is not the case at all river sites, and they may not be bound by the Fermi analysis. These small river sites include the 13 (Table 5.15) with the following combined characteristics: (1) low on-site average annual flow rates, (2) comparatively long residence times, and (3) comparatively large surface-area-to-volume ratios.

However, particularly for these 13 sites, an estimate of the uninterdicted population dose per RY from drinking water may be made by considering the Fermi value (4×10^6 person-rem). Using an estimated value of 2×10^{-5}/RY for the likelihood of release and a 0.445 probability of the wind blowing over the lake results in an estimated 36 person-rem/RY for Fermi. Assuming a 25 percent MYR increase in population, the uninterdicted person-rem per RY value would be approximately 45, which is less than 2 percent of the value from the atmospheric pathway (Table 5.6). Because combined residence time and surface-area-to-volume ratios for the 13 small river sites in Table 5.15 exceed values at Fermi by less than a factor of 3, and these sites have populations lower than Fermi by at least a factor of 2, the population dose at these sites would be expected to remain a small fraction of the value estimated for the atmospheric pathway. In addition, these sites are considered to be at least as amenable to interdictive measures as

Table 5.15 Reactor sites that may not be bound by the Fermi 2 surface water analysis

Catawba	Clinton	North Anna
McGuire	Monticello	Robinson
Oconee	Prairie Island	Wolf Creek
Shearon Harris	Summer	
Yankee Rowe	Duane Arnold	

Fermi, which would further reduce population dose.

Results of the uninterdicted aquatic food pathway analysis are presented in Table 5.16, which compares estimated annual aquatic food harvest, population dose, and population exposure among sites. Because of conservative assumptions in several steps in the analysis, these values are considered to constitute upper bound value estimates. It is also assumed that the entire harvest is consumed by humans, which results in maximum population dose to those sites with the greatest harvest, independent of population. This assumption implies a linear relationship between harvest and population dose.

It can be seen in Table 5.16 that those sites with the greatest aquatic harvest result in the highest values of population exposure per RY. For most sites, population exposure estimates are well below those estimated for the atmospheric pathway (Table 5.6). For those with values that exceed the atmospheric pathway value, it is reasonable to expect that dose reduction would occur as a result of interdiction. Interdiction has the potential to reduce the dose by factors of from 2 to 10 (NUREG-0769, Addendum I; NUREG-0440, Table 7.3.2); accordingly, values of population exposure for all sites would be essentially the same as or significantly less than values from the atmospheric pathway.

Interdiction could consist of preventing use of the water or making contaminated food difficult to obtain. Thus, limiting people's contact with contamination through such measures as preventing or confiscating catches of recreational and commercial fish and shellfish, prohibiting water-based recreation, and eliminating surface water as a drinking-water source would have to be employed.

This type of interdiction might have to be long term because the residence times could be long in certain situations. The food pathway of ocean and estuarine sites would be the hardest in which to effect interdiction. Not only are the physical transport mechanisms of these systems complex, but many of the important recreational and commercial organisms are highly mobile. Thus, the ability of humans to obtain these organisms would need to be controlled.

5.3.3.3.3 Conclusion

Analyses for both the drinking water and aquatic food pathways have been performed with and without considering interdiction. In the case of the drinking-water pathway, the Great Lakes and the estuarine sites are bound by the Fermi

Table 5.16 Comparison of aquatic food harvest, uninterdicted population dose and exposure among representative sites

Plant	Water body	Annual edible aquatic food harvest (kg)[a]	Estimated population dose—whole body (person-rem)[b]	Population exposure per reactor-year (person-rem)[c]
Calvert Cliffs	Chesapeake Bay	3.0×10^8	7.1×10^8	5500
Crystal River	Gulf Coast	6.4×10^7	1.5×10^8	1400
Fermi	Lake Erie	6.7×10^7	1.6×10^8	1400
Hope Creek	Delaware Bay	8.1×10^7	2.0×10^8	270
Millstone	Long Island Sound	5.8×10^7	1.4×10^8	500
Nine Mile Point	Lake Ontario	1.8×10^7	4.2×10^7	300
Seabrook	Gulf of Maine	7.4×10^7	1.7×10^8	2100
Zion	Lake Michigan	2.7×10^7	6.4×10^7	650
Small river	Generic	2.2×10^4	5.2×10^4	0.4
Large river	Generic	2.0×10^4	4.7×10^4	0.4

[a] Includes combined commercial and recreational harvest estimates.

[b] Assumes linear relationship between aquatic harvest and population dose using data in Fermi analysis (NUREG-0769) as basis for comparison.

[c] Derived as in the Fermi analysis (NUREG-0769) using site-specific data to obtain wind probability values. For the river sites, meteorological data from those sites in the drinking-water pathway analysis with the highest likely/potentially affected surface area ratios were used.

Note: Multiply by 2.2 to convert kilograms to pounds; multiply by 0.01 to convert person-rem to person-sieverts.

analysis while small river sites with relatively low annual flow rates, long residence times, and large surface-area-to-volume ratios may potentially not be bound by the Fermi analysis. In all cases, however, interdiction can reduce relative risk to levels at or below that of Fermi and significantly below that for the atmospheric pathway. River sites that may have relatively high concentrations of contaminants but which remove contaminants within short periods of time (hours to several days) are amenable to short-term interdiction. A similar level of reduced risk can be achieved at those sites with longer residence times (months) by more extensive interdictive measures.

For the aquatic food pathway, population dose and population exposure per RY are directly related to aquatic food harvest. For river sites, uninterdicted population exposure is orders of magnitude lower than that for the atmospheric pathway. For Great Lakes sites, the uninterdicted population exposure is a substantial fraction of that predicted for the atmospheric pathway but is reduced significantly by interdiction. For estuarine sites with large annual aquatic food harvests, dose reduction of a factor of 2 to 10 through interdiction provides essentially the same population exposure estimates as the atmospheric pathway.

For these reasons, population dose for the drinking-water pathway is found to be a small fraction of that for the atmospheric pathway. Risk associated with the aquatic food pathway is found to be small relative to the atmospheric pathway for most sites and essentially the same as the atmospheric pathway for the few sites with large annual aquatic food harvests.

5.3.3.4 Possible Releases to Groundwater

5.3.3.4.1 Methodology

This section discusses the potential for radiation exposure from the groundwater pathway as the result of postulated severe accidents at a nuclear reactor during the license-renewal period. Severe accidents are the only accidents capable of producing significant groundwater contamination.

For this pathway, the core is postulated to "melt down," breach the reactor vessel, and fall onto the reactor building floor. As a result of chemical energy and decay heat, the melted fuel reacts with the concrete floor. The basemat of the containment building is eventually breached, and molten core debris and radioactive water penetrate strata beneath the plant. The soluble radionuclides in the debris can be leached and transported with groundwater and contaminated reactor water to downgradient domestic wells used for drinking water or to surface water bodies used for drinking water, aquatic food, and recreation. In reality, the probability of such an accident is small. In general, the probable frequency of core melt is less than 10^{-4}/RY; however, some plants may have core damage frequencies that slightly exceed this value. From NUREG-1150, the conditional probability of basemat melt-through ranges from 0.05 to 0.24 occurrences per core melt. Therefore, it is reasonable and conservative to assume a 10^{-4} probability of occurrence of basemat melt-through per reactor-year for this analysis.

In this analysis, site-specific information on groundwater travel time; retention-adsorption coefficients; distance to surface water; and soil, sediment, and rock characteristics is compared with previous groundwater contamination analyses. Previous analyses are contained in LPGS and FESs.

First, uninterdicted doses received through the groundwater pathway are compared; however, the effects of interdiction are discussed later in this section.

Groundwater contamination due to severe accidents has been evaluated generically in LPGS (NUREG-0440). LPGS assumes that core melt and subsequent basemat melt-through occur and evaluates the consequences. LPGS examines six generic sites using typical or comparative assumptions on geology, adsorption factors, etc. Twenty-seven sites (hereafter called current sites) of the 74 nuclear power plant sites performed groundwater pathways analyses for FES and compared the results with the conclusions in LPGS. These comparisons indicate whether the current plant sites present significantly larger population doses than those calculated in LPGS. For the other 47 sites (hereafter called earlier sites) for which no groundwater pathway analyses were performed, this study compares the physical characteristics of each site with both the generic sites used in the LPGS study and the current sites.

The LPGS results are believed to provide generally conservative uninterdicted population dose estimates in the six generic plant-site categories. Five of these categories are site groupings in common locations adjacent to small rivers, large rivers, the Great Lakes, oceans, and estuaries. In a severe accident, contaminated groundwater could reach nearby surface water bodies and the population could be exposed to this source of contamination through drinking of surface water, ingestion of finfish and shellfish, and shoreline contact. Exposure by drinking contaminated groundwater is considered to be minor or nonexistent in these five categories because of a limited number of drinking-water wells. The sixth category is a "dry" site located either at a considerable distance from surface water bodies or where groundwater flow is away from a nearby surface water body. In this case, the only population exposure results from drinking contaminated groundwater. In each LPGS category, the generic site is a PWR that produces 1150 MW(e) and is located 457 m (1500 ft) from the nearest surface water (or from the boundary of the exclusion area in the dry site case).

In LPGS, five of the site categories (the dry site is the one exception) have the same generic groundwater characteristics. The groundwater velocity is 2.04 m/day (6.7 ft/day) and travel time to the nearest surface water is 0.61 year. The adsorption-retention factors (the products of these factors and the groundwater travel time are travel times of each isotope) for ^{90}Sr and ^{137}Cs are 9.2 and 83, respectively, and the corresponding amounts of each isotope reaching surface water (taking into account their radioactive decay rates) are 88 percent and 31 percent of the core-melt inventory, respectively. The groundwater velocity and travel time to the exclusion boundary of the dry site are 1.32 m/day (4.35 ft/day) and 0.95 year, respectively. In this case, the adsorption-retention factors (retardation coefficients) for ^{90}Sr and ^{137}Cs are 28 and 253, respectively. All LPGS parameters were taken from the WASH-1400 study (NUREG-75/014).

A summary of uninterdicted population doses for LPGS generic wet sites is provided in Table 5.17. The largest LPGS drinking-water dose to the population is attributed to the small river site (8.9×10^6 person-rem). The largest total population dose is attributed to the estuarine site (1.8×10^8 person-rem), which is more than an order of magnitude greater than the next largest total population dose (9.9×10^6 person-rem) for the small river site.

In the following comparisons, current FES results are tabulated separately and by generic category for ease of comparison. A major objective of these comparisons is to establish whether the generic LPGS or current FES severe accident liquid pathway analyses provide conservative uninterdicted population dose estimates in each site category. According to LPGS (NUREG-0440), the generic liquid pathway uninterdicted dose estimates are one or more orders of magnitude lower than those attributed to the atmospheric pathway. Therefore, if the 27 current site FES dose estimates do not significantly exceed those of LPGS, the liquid pathway may also be considered an insignificant contributor to the population dose that could result from a severe accident for the plants. The remaining 47 earlier sites are then placed into the appropriate categories and their physical characteristics are compared with those of the selected largest dose estimate site to determine if they also represent comparatively insignificant contributors to population dose.

Table 5.17 Summary of surrogate uninterdicted population doses for Liquid Pathway Generic Study base cases

Generic site[a]	Drinking-water dose (person-rem)[b]	Seafood ingestion dose (person-rem)	Shoreline exposure (person-rem)	Total (person-rem)
Large river	1.08×10^5	6.83×10^3	7.457×10^3	1.228×10^5
Small river	8.865×10^6	6.563×10^5	3.577×10^5	9.88×10^6
Great Lakes	2.34×10^6	6.369×10^5	4.066×10^5	3.540×10^6
Estuary	0	1.463×10^7	1.626×10^8	1.772×10^8
Coastal	0	5.348×10^5	2.36×10^3	5.372×10^5

[a] Data for the dry site are not provided.

[b] Multiply person-rem by 0.01 to find person-sieverts.

Source: NUREG-1054.

Note: These doses should not be accepted at face value, but should be used only for comparison with other sites.

5.3.3.4.2 Small River Sites

Table 5.18 compares results of current small-river plant sites (i.e., those with groundwater pathway analyses in their FESs) with the LPGS results. Beneath the name of each plant is its location, a brief description of the groundwater pathway, surface water bodies affected, and average stream flow rates past each plant site. Numerical tabulations include the estimated percentages of radionuclides ^{90}Sr and ^{137}Cs reaching the nearest downgradient surface water body as well as groundwater travel times and radionuclide adsorption-retention factors, which—together with radionuclide decay rates—were used to calculate these percentages. Also included are estimates of the magnitude of three potential uninterdicted population dose sources: drinking-water, finfish- and shellfish-ingestion, and shoreline-swimming exposure.

Population dose-estimate ratios (plant/LPGS) for drinking water, ingestion, and shoreline exposures are presented in the right-hand column of Table 5.18. These dose-estimate ratios are also based on the assumption of no interdiction. At face value, the majority of these dose-estimate ratios are several orders of magnitude less than 1. However, these dose-estimate ratios are sometimes based on parameters that may be nonconservative. There was also a lack of population dose information in FES's. Therefore, dose estimate ratios must be inferred from the percentage of radionuclides reaching surface water. At several sites, these ratios are near unity (i.e., the site and LPGS dose estimates are the same order of magnitude); at two sites (Byron Station and Clinton), ingestion dose ratios are significantly larger than unity (i.e., the site seafood ingestion dose is more than an order of magnitude greater than the corresponding LPGS dose).

Table 5.18 Current small river site severe accident liquid pathway analyses compared with Liquid Pathway Generic Study (LPGS) results

Average on-site flow rates less than 2830 m^3/s (100,000 ft^3/s)

Plant	Location and ground-water pathway	Distance from reactor to nearest downgradient surface water (m) [a]	Groundwater velocity (m/d) [a]	Groundwater travel time from reactor to surface water (years)	Adsorption-retention factor (Sr/Cs)	% radio-nuclide reaching surface water (Sr/Cs)	Drinking-water population ($\times 10^6$)	Annual aquatic food catch ($\times 10^6$ kg) [b]	Annual shoreline user rate (user-h $\times 10^6$)	Dose-estimate ratios. drinking water, ingestion, direct contact
LPGS	20 km SW of Oak Ridge, Tenn.—soil and weathered limestone to Clinch River, then to Tennessee, Ohio, and Mississippi rivers. Average flow rate is 50 m^3/second. [c]	457	2.04	0.6	9.2/83	88/31	0.62	1.2	110	1, 1, 1
Beaver Valley	40 km [d] NW of Pittsburgh, Pa.—terrace alluvial aquifer to Ohio River, then to Mississippi River Average on-site flow rate of river is 1,050 m^3/second.	~137	0.03	12.3	9.2/83 [e]	6/0	NP [f]	NP	NP	~0.01 (combined)
Braidwood	38 km SSW of Joliet, Ill.—pleistocene till and Pennsylvanian sandstone to Mazon River, then to Kankakee, Illinois, and Mississippi rivers. Average on-site flow rate of river is 110 m^3/second.	5940 (Strip-mine area)	0.01	1780	1/1 [g]	0/0	NP	NP	NP	~0 (combined)
Byron Station	27 km SW of Rockford, Ill.—through limestone to springs discharging to tributaries of Rock River, then to the Mississippi River. Average on-site flow rate of river is 140 m^3/second.	1100	0.12	24.7	1/1 [g]	56/57	2.1	9.6	110	1.3, 24, 3
Callaway	16 km SE of Fulton, Mo.—shallow limestone-sandstone aquifer to tributary of Mud Creek, then to the Missouri and Mississippi rivers. Average on-site flow rate of river is 2000 m^3/second.	~760	0.03	68.5	7.1/14.5	<1/~0	NP	NP	NP	<< 1 (combined)

See footnotes at end of table.

Table 5.18 (continued)

Plant	Location and groundwater pathway	Distance from reactor to nearest downgradient surface water (m) [a]	Groundwater velocity (m/d) [a]	Groundwater travel time from reactor to surface water (years)	Adsorption-retention factor (Sr/Cs)	% radionuclide reaching surface water (Sr/Cs)	Drinking-water population ($\times 10^6$)	Annual aquatic food catch ($\times 10^6$ kg) [b]	Annual shoreline user rate (user-h $\times 10^6$)	Dose-estimate ratios, drinking water, ingestion, direct contact
Catawba	10 km NNW of Rock Hill, S.C.—through shallow fractures in granite to Lake Wylie, then to Catawba River and a set of lakes near Charleston, S.C. Average on-site flow rate of river is 110 m^3/second.	210	0.61	1.0	6/560	88/~0	0.43	3.0	NP	0.7, 1.8, 0
Clinton	10 km E of Clinton, Ill.—sand lenses in glacial till to Lake Clinton, then to Salt Creek, Sangamon, Illinois, and Mississippi rivers. Average on-site flow rate of river is 7 m^3/second.	NP	NP	0.5	17/211 [h] 68/960 [i]	82/10 42/~0	2.1	7.0	NP	0.6, 23 [h] NP 0.3, 1.3 [i] NP
Harris	32 km SW of Raleigh, N.C.—fractures in diabase (volcanic) rocks to cooling water reservoir, then to Cape Fear River and Atlantic Ocean. Average on-site flow rate of river is 88 m^3/second.	730	0.30	6.6	49/480	0.1/~0	NP	NP	NP	<< 1 (combined)
Limerick	34 km NW of Philadelphia, Pa.—shallow fractures in sandstone/siltstone to Shuylkill River, then to the Delaware River, Delaware Bay and Atlantic Ocean. Average on-site flow rate of river is 54 m^3/second.	240	0.20	3.3	20/193	18/~0	1.9	NP	NP	~1, NP, NP

See footnotes at end of table.

Table 5.18 (continued)

Plant	Location and ground-water pathway	Distance from reactor to nearest downgradient surface water (m) [a]	Groundwater velocity (m/d) [a]	Groundwater travel time from reactor to surface water (years)	Adsorption-retention factor (Sr/Cs)	% radio-nuclide reaching surface water (Sr/Cs)	Drinking-water population ($\times 10^6$)	Annual aquatic food catch ($\times 10^6$ kg) [b]	Annual shoreline user rate (user-h $\times 10^6$)	Dose-estimate ratios. drinking water, ingestion, direct contact
South Texas	19 km S of Bay City, Tex.—wetlands to the Colorado River and the Gulf of Mexico (could have been classified as an estuary site).	4900 (Wetlands)	0.21	62.6	9.2/83 [c]	-0/-0	NP	NP	NP	<< 1 (combined)
Summer	42 km NW of Columbia, S.C.—shallow fractures in igneous and metamorphic rocks to the Broad River, then to the Congaree River and Lakes Marion and Moultrie, then marshes and estuaries to the Atlantic Ocean. Average on-site flow rate of river is 170 m^3/second.	NP	NP	7.4	8.6/154	19/-0	-0.62	3.5	NP	0.9, 2.0, -0
Susquehanna	11 km NE of Berwick, Pa.—lateral flow in fractured shale and Pleistocene-Holocene alluvium to a tributary of Lake Took-A-While, then to the Susquehanna and Delaware rivers to Delaware Bay and the Atlantic Ocean. Average on-site flow rate of river is 380 m^3/second.	NP	NP	9.2	35/500	0.2/-0	NP	NP	NP	<< 1 (combined)
Vogtle	42 km SE of Augusta, Ga.—construction backfill to shallow limestone, discharge to springs feeding Mathes Pond, then to the Savannah River and Atlantic Ocean. Average on-site flow rate of river is 340 m^3/second.	850	0.15	15.3	21.5/165	0.05/-0	0.06	< 1.2	NP	10^{-5}, 10^{-4}, 0

See footnotes at end of table.

Table 5.18 (continued)

Plant	Location and ground-water pathway	Distance from reactor to nearest downgradient surface water (m) [a]	Groundwater velocity (m/d) [a]	Groundwater travel time from reactor to surface water (years)	Adsorption-retention factor (Sr/Cs)	% radio-nuclide reaching surface water (Sr/Cs)	Drinking- water population (× 10^6)	Annual aquatic food catch (× 10^6 kg) [b]	Annual shoreline user rate (user-h × 10^6)	Dose-estimate ratios. drinking water, ingestion, direct contact
Wolf Creek	6 km NE of Burlington, Kans.—shallow limestone to cooling water reservoir, then to Neosho River (presumably), then through a series of Lakes to the Arkansas and Mississippi rivers. Average on-site flow rate is 45 m^3/second	790	0.006	356	9.2/83 [c]	-0/-0	NP	NP	NP	<< 1 (combined)

[a] Multiply by 3.28 to convert to ft or ft/d.
[b] Multiply by 2.20 to convert to pounds.
[c] Multiply by 35.3 to convert to ft^3/second.
[d] Multiply by 0.625 to convert to miles.
[e] Assumed same value as used in the LPGS.
[f] NP = not provided.
[g] Highly conservative estimate (no adsorption).
[h] Conservative estimate.
[i] Realistic estimate.

However, the seafood ingestion dose at the generic small river site is only about 6 percent of the total generic population dose as shown in Table 5.17, and Byron Station's total population dose is about three times that of the LPGS generic site for small rivers. The dose-estimate ratios in Table 5.18 suggest that the Byron Station FES severe accident liquid pathway analysis provides the highest population dose groundwater pathway for sites located along small rivers. However, Byron Station's groundwater pathway population dose is less than an order of magnitude greater than the LPGS dose. Therefore, the FES groundwater pathway population dose for the small river category does not exceed that of the atmospheric pathway.

At 11 of the 27 current sites, the population doses were found to be essentially zero. In these cases, percentages of ^{90}Sr and ^{137}Cs reaching surface water are generally low, based on long groundwater travel times, large adsorption-retention factors, or both. In some cases, the liquid pathway analysis was terminated without calculating population dose estimates. Most current FESs refer to Isherwood (1977), NUREG/CR-1596, or Parsons (1962) for representative adsorption data instead of acquiring site-specific data.

In contrast, the Byron Station liquid pathway analysis (citing a lack of site-specific adsorption data) used the highly conservative assumption that neither ^{90}Sr nor ^{137}Cs was adsorbed and that these isotopes would be transported at the same velocity as groundwater. As a result, the analysis shows that more than half the Byron Station severe accident inventory of ^{90}Sr and ^{137}Cs would reach surface water. Consequently, dose sources and estimates were found to be high.

In NUREG-1054, Codell recommends caution in using adsorption data to characterize the groundwater pathway through fractured rock. In cases involving groundwater pathways in open fractures that were not accounted for, the adsorption-retention factors and groundwater velocity may have been significantly overestimated and underestimated, respectively, leading to nonconservative (low) population dose estimates. Current FESs for Callaway, Harris, Limerick, Summer, Vogtle, and Wolf Creek all cite low groundwater velocities (site-specific data) or large adsorption-retention factors (literature values as cited previously) as well as groundwater pathways in fractured rock. Therefore, because it was not clear whether these sites were bound by the Byron Station population dose estimates, they were investigated further. However, the Summer and Vogtle sites have much smaller drinking-water populations and seafood catches than Byron Station. So, even if no adsorption were assumed for these two sites, their dose estimates would not be likely to exceed those of Byron Station.

The Callaway, Harris, Limerick, Summer, Vogtle, and Wolf Creek FSARs contain liquid pathway analyses for a postulated rupture of a liquid radioactive waste tank. Each of these plants is discussed further in the following paragraphs.

In four cases (Callaway, Harris, Limerick, and Vogtle), the FSAR findings are compatible with those of corresponding FESs. Furthermore, it is clear from the Limerick FSAR that the fracture pathway is not a significant liquid conduit (runoff water from Hurricane Agnes had to be pumped from the Limerick open excavation because it did not drain through the fractured rock). It is assumed in the Vogtle FSAR that fractured limestone drains freely, but it has been adequately demonstrated that radionuclides are sufficiently retained by an extensive construction fill between the radioactive waste tank and the limestone. Fractured volcanic rocks have been identified as groundwater conduits in the Harris FSAR, but the groundwater velocity and radionuclide retardation values for these rocks are not significantly different from those listed in the FES; and in the Callaway FSAR, unfractured sandstone, rather than a fractured limestone, has been identified as the primary groundwater pathway.

In one case (Summer), the FSAR analysis is inconsistent with that of FES. The Summer FSAR identifies the groundwater pathway as weathered rock without clay minerals and gives no credit for cation exchange (adsorption-retention factor = 1); however, in FES, adsorption-retention factors are 8.6 and 154 for strontium and cesium, respectively. Based on FSAR's conservative adsorption estimate, 77 percent of the strontium and cesium would reach surface water (about 50 percent more radionuclides than at Byron Station), rather than 19 percent strontium and < 1 percent cesium as estimated in the FES. Based on FSAR data, Summer's plant–LPGS drinking-water dose ratio would be between 3 and 4, rather than 0.9 as listed in Table 5.18. However, the drinking water population and aquatic catch estimates are less than those of Byron Station by about a factor of 3. Therefore, the conservative analysis for Summer and LPGS result in roughly similar population doses that are less than that at Byron Station.

In one case (Wolf Creek), the FSAR analysis is not sufficiently detailed to permit a direct comparison with FES. The Wolf Creek FES groundwater velocity estimate is extremely low compared with those of other small river sites [0.006 m/day (0.0065 yd/day) compared with 0.01 to 0.6 m/day (0.012 to 0.65 yd/day) for other sites]. All but one site reported groundwater velocities at least an order of magnitude greater than that at Wolf Creek. Therefore, Wolf Creek's estimated groundwater velocity may be unreasonably low. Based on this low groundwater velocity, FES concludes that less than 1 percent of the radionuclide inventory in a core-melt accident would reach surface water.

The Wolf Creek liquid pathway dose estimates have been recalculated, based on a higher groundwater velocity. It was assumed that the groundwater velocity at Wolf Creek may be similar to that at South Texas [0.21 m/day (0.23 yd/day)] where the terrain is similarly flat. If one assumes no retardation of radionuclides at Wolf Creek, 80 percent of the radioactive strontium would reach surface water before decaying—about 1.5 times more than at Byron Station. However, Byron Station has a larger downstream population dose (St. Louis and Memphis for Byron Station compared with Fort Smith and Little Rock, Arkansas, for Wolf Creek). The Mississippi River between St. Louis and its confluence with the Arkansas River has a greater fish catch. Therefore, for this Wolf Creek analysis, population dose is considered to be comparable to that at Byron Station (the largest groundwater pathway population dose estimate for small rivers).

In general, sites that are located on a floodplain or on glacial till may be expected to produce dose estimates that are lower than those for the LPGS case, assuming that the melted reactor core does not reach bedrock beneath the site (resulting in a groundwater pathway through fractured rock). Low groundwater gradients on floodplains and low hydraulic conductivity in glacial till (with the exception of glacial outwash deposits) generally result in low groundwater velocities. Furthermore, significant percentages of clay minerals are generally available for radionuclide adsorption in both floodplain deposits and glacial till. Beaver Valley, Braidwood, Clinton, South Texas, and possibly Susquehanna are representative of sites on floodplains or glacial till.

Table 5.19 compares earlier small river sites (i.e., sites without FES groundwater pathway analyses) with the Byron Station and LPGS generic small river sites. Because no severe accident pathway analyses were provided for the earlier sites, reactor size, distance from the reactor to the nearest downgradient surface water, and river flow rates are the only parameters directly comparable to the current site analysis. The total downstream population at risk (all municipalities along the river from the plant-site to the sea) is an indicator of potential drinking-water, ingestion, and shoreline exposures for these sites. No groundwater travel times or adsorption-retention factors are available for these sites.

Cooper, Farley, Fort Calhoun, Hatch, and Quad cities are sites listed in Table 5.19 that most likely would not exceed the Byron Station or LPGS dose estimates because of their locations on thick floodplain or coastal plain sediments. Groundwater pathways through fractured rock or Pleistocene outwash deposits are unlikely at these sites. Floodplains and coastal plains are expected to have low groundwater velocities (because of low groundwater gradients) or relatively high adsorption-retention factors (because of high clay content), or both.

The other sites in Table 5.19 have large populations downstream at risk and are located on either fractured rock or a Pleistocene aquifer (suggesting the presence of outwash deposits) or have a groundwater pathway that is not well known. Groundwater velocities may be higher than those at Byron Station, and adsorption cannot be relied upon to delay entry of ^{90}Sr and ^{137}Cs into nearby surface water. Therefore, uninterdicted doses at some of these sites may significantly exceed those at Byron Station. It is uncertain whether all small river site groundwater pathway population doses without interdiction would be less than that of the atmospheric pathway.

5.3.3.4.3 Large River Sites

Table 5.20 compares current large river plant sites with the LPGS generic large river site. The format for this table is the same as that for Table 5.18. The Grand Gulf and River Bend plants are located far from the Mississippi River shoreline but on its floodplain where the groundwater velocity is expected to be low and floodplain sediments would be expected to adsorb radionuclides to some extent. The River Bend site analysis was based on conservative estimates of adsorption-retention factors, and the resulting plant–LPGS population dose ratio is 0.39. The adsorption-retention factors for Grand Gulf are higher; however, using the same adsorption-retention factors for Grand Gulf as for River Bend would not have produced significantly higher doses. Therefore, the dose-estimate ratios

Table 5.19 **Earlier small river sites without severe accident liquid pathway analyses compared with Byron Station and Liquid Pathway Generic Study (LPGS) results**
Average on-site flow rates are less than 2830 m^3/second (100,000 ft^3/second)

Plant	Location and groundwater pathway	Reactor size [MW(e)]	Distance from reactor to nearest downgradient surface water (m)[a]	Average on-site river flow rate (m^3/second)[b]	Downstream population at risk × 10^6 (1988)
LPGS	20 km[c] SW of Oak Ridge, Tenn.—soil and weathered limestone and shale to Clinch River; then to Tennessee, Ohio, and Mississippi rivers.	1150	457	50	3.7[d]
Byron Station	27 km SW of Rockford, Ill.—through limestone to springs discharging to tributaries of Rock River, then to the Mississippi River.	1120	1100	140	6.1
Arkansas Nuclear	112 km E of Fort Smith, Ark.—weathered rock and soil to Lake Dardanelle on Arkansas River, then to Mississippi River.	908	~150	1020	2.5
Arnold	13 km NW of Cedar Rapids, Iowa—Pleistocene-Holocene aquifers toward Cedar River, then to Iowa and Mississippi rivers. Also, toward Cedar Rapids groundwater resources.	538	300-600	85	5.8
Bellefonte	11 km ENE of Scottsboro, Ala.—residual soil and shallow fractures in limestone to Town Creek Embayment of Guntersville Reservoir on the Tennessee River, then to downstream reservoirs and the Ohio and Mississippi rivers.	1314	~610	1090	3.2
Browns Ferry	48 km W of Huntsville, Ala.—weathered limestone and soil to Wheeler Reservoir on the Tennessee River, then to downstream reservoirs and the Ohio and Mississippi rivers.	1065	~150	1210	3.1
Connecticut Yankee (Haddem Neck)	16 km SE of Middletown, Conn.—presumably Pleistocene sediments and Holocene soil to Connecticut River, then to Long Island Sound.	582	~150	470	<0.1
Cooper	SE corner of Nebr.—alluvial sands to Missouri River, then to Mississippi River.	778	~60	880	7.2
Dresden	80 km SW of downtown Chicago, Ill.—Pleistocene aquifer to Illinois River, then to Mississippi River. At low flow the Illinois River is mostly sewage effluent.	794	~610	120	6.0
Farley	26 km east of Dothan, Ala.—coastal plain sediments to the Chattahoochee River.	829	<300	300	<0.1
Fort Calhoun	30 km N of Omaha, Nebr.—alluvial sediments to the Missouri River, then to the Mississippi River.	482	~150	765	7.9
Hatch	~110 km W of Savannah, Ga.—a few wells; coastal plain sediments to streams and ponds, eventually to the Altamaha River and Atlantic Ocean.	780	~300	370	<0.1

See footnotes at end of table.

Table 19 (continued)

Plant	Location and groundwater pathway	Reactor size [MW(e)]	Distance from reactor to nearest downgradient surface water (m)[a]	Average on-site river flow rate (m^3/second)[b]	Downstream population at risk × 10^6 1988
La Salle	120 km SW of downtown Chicago—glacial deposits to South Kickapoo Creek, to Illinois River (8 km N), then to Mississippi River.	1081	150 to 300	310	6.0
McGuire	27 km NW of Charlotte, N.C.—weathered rock and soil to Catawba River, then to a series of lakes in S.C., then Wateree and Congaree rivers, more lakes and wetlands to Atlantic Ocean.	1180	~600	75	1.7
Monticello	48 km NW of Minneapolis, Minn.—alluvium to headwaters of the Mississippi River; groundwater resources in alluvium.	545	~150	130	8.7
North Anna	64 km NW of Richmond, Va.—soil and weathered rock to Lake Anna, to North Anna River, then to York Estuary and Chesapeake Bay.	907	150 to 300	10	<0.1
Oconee	48 km W of Greenville, S.C.—residual soil and fractured shallow bedrock to Lake Keowee, Keowee River to Seneca River (11 km downstream), then to Hartwell Lake on the Savannah River.	886	<300	30	<0.1
Peach Bottom	30 km S of Lancaster, Pa.—weathered rock to Conowingo Pond, a reservoir on the Susquehanna River, then to Delaware Bay and the Atlantic Ocean.	1065	~90	1020	<0.1
Prairie Island	64 km SE of Minneapolis, Minn.—some groundwater resources; alluvial soils to Sturgeon Lake on Vermillion River, adjacent to Mississippi River.	530	~150	425	6.3
Quad Cities	48 km NE of Moline, Ill.—alluvial soils to Mississippi River.	789	~180	1340	6.1
Robinson	48 km NW of Florence, S.C.—alluvium, coastal plain sediments and Tuscaloosa sand to Lake Robinson on Black Creek, a tributary of Lynches River, then to Pee Wee Estuary on Atlantic Ocean; also groundwater users.	700	~180	5	0.2

See footnotes at end of table.

Table 19 (continued)

Plant	Location and groundwater pathway	Reactor size [MW(e)]	Distance from reactor to nearest downgradient surface water (m)[a]	Average on-site river flow rate (m^3/second)[b]	Downstream population at risk × 10^6 (1988)
Sequoyah	29 km NE of downtown Chattanooga, Tenn.—terrace alluvium and weathered rock to Chicamauga Reservoir on the Tennessee River, then through a series of reservoirs to Ohio and Mississippi rivers.	1148	Unknown	930	3.7
Three Mile Island	16 km SE of Harrisburg, Pa.—Susquehanna alluvium to Susquehanna River (the facility is on an island in the river), then to Delaware Bay and the Atlantic Ocean.	819	~180	965	<0.1
Vermont Yankee	8 km SE of Brattleboro, Vt. and 72 km N of Springfield, Mass.—Pleistocene glacial deposits to Vernon Pond on the Connecticut River, then to Long Island Sound; some groundwater users.	514	~60	245	1.7
Watts Bar	11 km SE of Spring City, Tenn. and 4 km downstream from Watts Bar Dam—limestone and river alluvium to Chickamauga Reservoir on the Tennessee River, then through a series of reservoirs to the Ohio and Mississippi rivers.	1170	~300	750	3.7
Yankee Rowe	34 km NE of Pittsfield, Mass.—groundwater pathway unknown, but Deerfield River (the receiving surface water body) is a tributary of the Connecticut River, then to Long Island Sound and the Atlantic Ocean.	175	90	21	1.7

[a] Multiply by 3.28 to convert to ft.
[b] Multiply by 35.3 to convert to ft^3/second.
[c] Multiply by 0.625 to convert to miles.
[d] Similar to Watts Bar.

Table 5.20 Current large river site severe accident liquid pathway analyses compared with Liquid Pathway Generic Study (LPGS) results
Average on-site flow rates greater than 2830 m^3/second (100,000 ft^3/second)

Plant	Location and groundwater pathway	Distance from reactor to nearest downgradient surface water (m)[a]	Ground-water velocity (m/d)[a]	Groundwater travel time from reactor to surface water (year)	Adsorption-retention factor (Sr/Cs)	% radionuclide reaching surface water (Sr/Cs)	Drinking-water population (× 10^6)	Annual aquatic food catch (× 10^6 kg)[b]	Annual shoreline user rate (user-h × 10^6)	Dose-estimate ratios drinking water, ingestion, direct contact (plant/LPGS)
LPGS	On the lower Mississippi River. On-site flow rate is 13,900 m^3/second.[c]	457	2.04	0.61	9.2/83	88/31	0 10	0.07	6	1, 1, 1
Grand Gulf	40 km[d] S of Vicksburg, Miss.—fractures in Catahoula Formation to Pleistocene terrace alluvium, then to oxbow lakes which flush into the Mississippi River during floods. Average flow rate is 19,100 m^3/second.	2230	0.46	13.3	29/990	0.3/~0	1.35	4.41	NP[e]	0.007, 0.013, 0
River Bend	38 km NNW of Baton Rouge, La.—terrace and alluvial aquifers to Mississippi River. Average flow rate is 12,700 m^3/second.	3050	1.04	8.06	15/144	4.4/~0	1.20	NP	NP	0.39, 0, 0
WNP-2[f,g]	19 km NW of Richland, Wash.—flow in unconfined glacio-fluvial aquifer to Columbia River, then to Pacific Ocean (many nearby water wells, but none are used for public water consumption). Average flow rate is 3250 m^3/second.	4880	2.13	6.26	1400/8400	0/0	NP	NP	NP	0, 0, 0
WNP-2[h]		4880	2.13	6.26	15/144	11/< 1	1.20	4.41	6	1.1, 3.1, 0.03, (1.5)[i]

[a] Multiply by 3.28 to convert to ft or ft/d.
[b] Multiply by 2.20 to convert to pounds.
[c] Multiply by 35.3 to convert to ft^3/second.
[d] Multiply by 0.625 to convert to miles.
[e] NP = not provided.
[f] Final environmental statement of the nonconservative liquid pathway analysis (NUREG-0440).
[g] WNP-2 = Washington Nuclear Project 2.
[h] Staff's conservative analysis replacing the final environmental statement adsorption-retention estimates with more conservative values and WNPs population doses assumed to be similar to Grand Gulf and River Bend.
[i] Total population dose.

in Table 5.20 suggest that the LPGS generic site analysis provides the largest uninterdicted population dose estimate for large rivers, at least for sites with locations similar to those of Grand Gulf and River Bend.

The Washington Nuclear Project 2 (WNP-2) site in Table 5.20 differs from the other two sites in that the assumed groundwater velocity is higher than that used in LPGS. However, the adsorption-retention factors for WNP-2 appear to be nonconservative. If conservative adsorption-retention factors similar to those of Grand Gulf and River Bend are used for WNP-2, an estimate of the population dose can be made (Portland, Oregon, is downstream of the WNP-2 site). The staff's conservative analysis for WNP-2 (using adsorption and drinking-water dose from River Bend and aquatic catch from Grand Gulf) yields a total population dose of 1.5 times that of the LPGS for large rivers. The difference in the conservative WNP-2 and LPGS groundwater pathway population doses is small in comparison with the order of magnitude greater atmospheric pathway population dose.

Table 5.21 compares the only earlier large river plant site (Trojan) with the LPGS generic large river site. This site is located much closer to the nearest downgradient surface water (the Columbia River) than is the generic site, and fractured rock underlies the site, suggesting that the groundwater travel time may be less than that of the LPGS. Therefore, the uninterdicted dose from the Trojan Plant would probably be less than that of the LPGS study.

Table 5.21 Earlier large river sites without severe accident liquid pathway analyses compared to the Liquid Pathway Generic Study (LPGS) results
Average on-site flow rates greater than 2830 m^3/second (100,000 ft^3/second)

Plant	Location and ground-water pathway	Reactor size [MW(e)]	Distance from reactor to nearest downgradient surface water (m)[a]	Average on-site/river flow rate (m^3/second)[b]	Downstream population at risk x 10^6 (1988)
LPGS	On the lower Mississippi River.	1150	457	13,900	1.9
Trojan	48 km[c] NW of Portland, Oreg.—soil and shallow fractured rock to the Columbia River, then to the Pacific Ocean.	1130	~90	12,200	0.1

[a] Multiply by 3.28 to convert to ft.
[b] Multiply by 35.3 to convert to ft^3/second.
[c] Multiply by 0.625 to convert to miles.

5.3.3.4.4 Great Lakes Sites

Table 5.22 compares current Great Lakes plant sites with the LPGS generic Great Lakes site. These sites are all located on or adjacent to flat Pleistocene lake bed sediments which underlie modern lake sediments and shorelines. These sediments generally have a high clay and silt content. Groundwater passing through fractured rock must also pass through these lake-bed sediments before reaching the lake. Therefore, groundwater gradients and groundwater velocities are expected to be low, and adsorption-retention factors are expected to be high relative to those of the generic site. However, the current sites have larger populations at risk (the generic site is on Lake Ontario, the farthest downstream of the string of Great Lakes) and are closer to the shoreline than the Great Lakes generic site. Taking all these factors into account yields dose-estimate ratios between 0 for Nine Mile Point and 1.4 for Fermi (the latter site has, by far, the largest drinking water population). Therefore, the severe accident liquid pathway analysis for the Fermi site provides the largest uninterdicted population doses for current FES sites adjacent to the Great Lakes. The differences between groundwater population doses for the Fermi and LPGS sites are small in comparison with differences in atmospheric pathway doses for the sites.

Table 5.23 compares earlier Great Lakes sites with the Fermi and LPGS generic Great Lakes sites. Populations at risk at sites near standing bodies of water (lakes, estuaries, and oceans) are defined as all people living within 80 km (50 miles) of the site, rather than as all people living downstream from a river site. Geologic conditions at these sites are similar to those of the current plant sites described in Table 5.22. Although some of these sites have groundwater pathways through Pleistocene outwash and fractured rock, groundwater must also pass through lake-bed sediments before reaching the lake. The Zion site is comparable to Fermi in size, distance from shoreline, and population within 80 km. Therefore, Zion's population doses would probably be similar to those of Fermi. All other sites would have population doses lower than those of Fermi, based on smaller reactor sizes, greater distances to shoreline, and lower populations within 80 km. Therefore, groundwater pathway population doses at all Great Lakes sites are expected to be less than or equal to that of the Fermi site.

5.3.3.4.5 Ocean Sites

Table 5.24 compares current ocean plant sites with the LPGS generic ocean site. The Seabrook severe accident liquid pathway analysis has the largest estimated uninterdicted population doses for sites adjacent to the ocean. Based on short groundwater travel time and low adsorption-retention factors, nearly all the strontium inventory (94 percent) and more than half the cesium inventory (58 percent) reaches the Gulf of Maine, compared with LPGS generic estimates of 88 percent and 31 percent, respectively. These percentage comparisons suggest that a severe accident at Seabrook has the potential for producing a larger maximum individual dose than that of the LPGS generic ocean site. In consideration of the large annual seafood catch and shoreline user rates, the uninterdicted total population dose estimate for Seabrook is 6 times that of the LPGS generic ocean site. Seabrook's estimated groundwater pathway population dose is still below that of the atmospheric

Table 5.22 Current Great Lakes site severe accident liquid pathway analyses compared with Liquid Pathway Generic Study (LPGS) results

Plant	Location and groundwater pathway	Distance from reactor to nearest downgradient surface water (m)[a]	Ground-water velocity (m/d)[a]	Groundwater travel time from reactor to surface water (years)	Adsorption retention factor (Sr/Cs)	~% radionuclide reaching lake (Sr/Cs)	Drinking-water population (× 10^6)	Annual aquatic food catch (× 10^6 kg)[b]	Annual shoreline user rate (user-h × 10^6)	Dose-estimate ratios drinking water, ingestion, direct contact (plant/LPGS)
LPGS	On Lake Ontario, the far downstream lake.	457	2.04	0.6	9.2/83	88/31	2.0	12.1	560	1,1,1
Fermi	48 km[c] SW of Detroit, Mich.—shallow fractures in vugular dolomite to Lake Erie, then to Lake Ontario.	140	0.19	2.0	23/219	30/0	14.0	NP	NP[c]	1.4, NP, ~0
Nine Mile Point	10 km NE of Oswego, N.Y. (collocated with FitzPatrick)—"Pulaski/Whetstone" confined aquifer to Lake Ontario.	183	0.08	6.3	245/9065	0/0	NP	NP	NP	~0, ~0, ~0
Perry	(11 km NE of Painesville, Ohio—Man-made underdrain to Lake Erie, then to Lake Ontario. Realistic and conservative dose estimates are for water table by natural flow and artificially depressed pumping down, respectively.	~366	NP	NP	NP/NP	67/69	4.12	18.2	218	0.1 (realistic) 1.2 (conservative) both combined

[a] Multiply by 3.28 to convert to ft or ft/d.
[b] Multiply by 2.20 to convert to pounds.
[c] NP = not provided.
[d] Multiply by 0.625 to convert to miles.

Table 5.23 Earlier Great Lakes sites without severe accident liquid pathway analyses compared to the Fermi and Liquid Pathway Generic Study (LPGS) Great Lakes sites

Plant	Location and groundwater pathway	Reactor size [MW(e)]	Distance to nearest downgradient surface water (m)[a]	Population within 80 km[b] × 10^6	
				1990	2030
LPGS	On Lake Ontario, the far downstream lake.	1150	457	----	----
Fermi	48 km SW of Detroit, Mich.—shallow fractures in vugular dolomite to Lake Erie, then to Lake Ontario.	1093	140	5.4	6.2
Big Rock Point	Near Charlevoix, Mich. (northern lower Michigan)—unknown groundwater pathway to Lake Michigan.	69	Unknown	Low	Low
Cook	SW corner of Mich.—Pleistocene sands to Grand Marais Embayment of Lake Michigan.	1100	<150	1.3	1.4
Davis-Besse	34 km E of Toledo, Ohio—fractured and cavitose dolomite to Lake Erie (site located in the wetland).	906	~915	1.9	2.2
Ginna	24 km NE of Rochester, N.Y.—poorly described, but probably through shallow fractures in bedrock and Pleistocene sediments to Lake Ontario.	470	~150	1.1	1.1
FitzPatrick	Co-located with Nine Mile Point nuclear power station, 10 km NE of Oswego, N.Y. and 58 km NE of Syracuse, N.Y.—Oswego Sandstone, Pleistocene till, and lacustrine deposits to Lake Ontario; a few wells in the vicinity.	816	~300	0.8	0.8

See footnotes at end of table.

Table 5.23 (continued)

Plant	Location and groundwater pathway	Reactor size [MW(e)]	Distance to nearest downgradient surface water (m)[a]	Population within 80 km[b] × 10^6	
				1990	2030
Kewaunee	43 km SE of Green Bay, Wisc.—Pleistocene glacial outwash and fractured dolomite to Lake Michigan.	545	~150	0.6	0.7
Palisades	56 km W of Kalamazoo, Mich.—lake sediments and glacial till to Lake Michigan.	805	~90	1.2	1.3
Point Beach	48 km SE of Green Bay and 80 miles N of Milwaukee, Wisc.—Pleistocene glacial outwash and fractured dolomite to Lake Michigan.	497	~150	0.6	0.7
Zion	10 km N of Waukegan, Illinois and 5 km S of the Wisc. state line—hydraulically connected glacial drift and fractured limestone aquifers to Lake Michigan.	1040	~200	7.5	8.2

[a] Multiply by 3.28 to convert to ft.

[b] Multiply by 0.625 to convert to miles.

Table 5.24 Current ocean site severe accident liquid pathway analyses compared with Liquid Pathway Generic Study (LPGS) results

Plant	Location and groundwater pathway	Distance from reactor to nearest downgradient surface water (m)[a]	Groundwater velocity (m/d)[a]	Groundwater travel time from reactor to surface water (years)	Adsorption-retention factor (Sr/Cs)	% radio-nuclide reaching ocean (Sr/Cs)	Annual aquatic catch (× 10^6 kg)[b]	Annual shoreline user rate (user-h × 10^6)	Dose-estimate ratios ingestion, direct contact (plant/LPGS)
LPGS		457	2.04	0.61	9.2/83	88/31	24.7	15.0	1,1
Millstone	5 km[c] SSW of New London, Conn.—through pipeline backfill to Niantic Bay, then to Long Island Sound and the Atlantic Ocean.	305	0.15	5.5	28/268	3/0	86.5	10.8	0.03, ~0
San Onofre	8 km SE of San Clemente, Calif.—San Mateo Sandstone to Gulf of Santa Catalina and the Pacific Ocean.	~150	0.76	0.55	31/2200	70/0	56.8	NP[d]	<1, ~0
Seabrook	21 km SSW of Portsmouth, N.H.—fractured quartzite and granite and soil to a nearby marsh and Browns River Estuary, then to Hampton Harbor and the Gulf of Maine on the Atlantic Ocean.	110	0.61	0.49	5/50	94/58	104	40.5	6 (combined)
St. Lucie	11 km SE of Fort Pierce, Fla.—beach sand to Big Mud Creek/Indian River to the Atlantic Ocean.	213	0.02	27.4	9.5/86	0.13/0	34.6	NP	0.008, ~0

[a] Multiply by 3.28 to convert to ft or ft/d.

[b] Multiply by 2.20 to convert to pounds.

[c] Multiply by 0.625 to convert to miles.

[d] NP = not provided.

pathway but at a reduced level of confidence.

Table 5.25 compares earlier ocean plant sites with both the LPGS generic and Seabrook ocean sites. The Seabrook reactor is the largest in Table 5.25. This reactor is also closest to the shoreline and has a large nearby population comparable to that of the Pilgrim site. However, the Pilgrim reactor is little more than half the size of Seabrook and, thus, may have a population dose roughly half that of Seabrook. The Diablo Canyon reactor is roughly comparable to Seabrook in size and distance from shore but has only one-tenth the population within 80 km. Furthermore, the sandstones and volcanic rocks at Diablo Canyon may have higher adsorption-retention factors than the quartzite and granite at Seabrook. Therefore, Diablo Canyon's potential population dose is expected to be at least 1 order of magnitude less than that of Seabrook and also less than that of the LPGS generic ocean site. Turkey Point is located on a flat coastal plain where the groundwater gradient is expected to be low; hence, groundwater velocity and travel time are expected to be correspondingly low and high, respectively, with respect to Seabrook. The Turkey Point reactor is located about the same distance from the shoreline as is the LPGS generic site and four times farther inland than Seabrook. However, a barge canal is less than 50 m (164 ft) from Unit 3. Interdiction at Turkey Point could be accomplished by closing off or filling in the barge canal. Thus, based on the above site-specific assumptions, it can be concluded that Seabrook represents the largest uninterdicted population dose at ocean sites other than Turkey Point.

5.3.3.4.6 Estuarine Sites

Table 5.26 compares current FESs for which groundwater pathway analysis is available with the LPGS generic estuarine site. There is only one estuarine site (Hope Creek) for which a current FES is available. However, a detailed severe accident liquid pathway analysis is also available for the Indian Point site (ConEd 1982).

Hope Creek's estimated uninterdicted total population dose is less than 1 percent of the LPGS generic dose for estuaries. The LPGS annual aquatic catch and shoreline use are 3 and 83 times, respectively, as large as Hope Creek's. Even if 100 percent of Hope Creek's strontium inventory reaches surface water, the LPGS population dose would not be exceeded.

Indian Point's estimated uninterdicted population doses vary from insignificant to 0.44 times that of the LPGS, depending upon the magnitude of the assumed strontium and cesium adsorption-retention estimates. The first Indian Point estimates in Table 5.26 are from Consolidated Edison (ConEd) (1982). These dose ^{5} estimates are very low (from 1.5 × 10 to 4.9 × 10) compared with the LPGS ^{8} generic estuarine dose estimate (1.8 × 10) in Table 5.26. ConEd's adsorption-retention factors for strontium and cesium are 270 and 1626, respectively, compared with 9.2 and 83 for the LPGS case. The very large adsorption-retention factors at Indian Point are based on the assumption that groundwater flow is through intergranular pore spaces in rock with very low porosity (0.5 percent). ConEd's groundwater flow assumption may be nonconservative because flow is more likely to occur through open fractures rather than intergranular pore spaces. Other

Table 5.25 Earlier ocean sites without severe accident liquid pathway analyses compared to Seabrook

Plant	Location and groundwater pathway	Reactor size [MW(e)]	Distance from reactor to nearest downgradient surface water (m)[a]	Population within 80 km[b] × 10^6	
				1990	2030
Seabrook	21 km SSW of Portsmouth, N.H.—fractured quartzite and granite and soil to a nearby marsh and Brown's River Estuary, then to Hampton Harbor and the Gulf of Maine on the Atlantic Ocean.	1150	110	3.8	4.2
Diablo Canyon	19 km W of San Luis Obispo, Calif.—not well documented, presumably Miocene Monteray Formation (interbedded sandstones and volcanics) and soils to Diablo Cove and the Pacific Ocean.	1100	~150	0.3	0.4
Pilgrim	56 km SE of Boston, Mass.—glacial outwash to Cape Cod Bay and the Atlantic Ocean.	655	~150	4.4	4.8
Turkey Point	40 km S of Miami, Fla.—permeable limestone to a barge canal, then to Biscayne Bay and the Atlantic Ocean.	693	~50	2.7	4.2

[a] Multiply by 3.28 to convert to ft.
[b] Multiply by 0.625 to convert to miles.

Table 5.26 Current estuary site severe accident liquid pathway analyses compared with Liquid Pathway Generic Study (LPGS) results

Plant	Location and groundwater pathway	Distance from reactor to nearest downgradient surface water (m)[a]	Ground-water velocity (m/d)[a]	Groundwater travel time from reactor to surface water (years)	Adsorption-retention factor (Sr/Cs)	% radio-nuclide reaching estuary (Sr/Cs)	Annual aquatic catch (× 10^6 kg)[b]	Annual shoreline user-rate (user-h × 10^6)	Dose-estimate ratios ingestion, direct contact (plant/LPGS)
LPGS		457	2.04	0.61	9.2/83	88/31	15.7	330	1,1
Hope Creek	Co-located with the Salem nuclear power station on an artificial island, about 13 km[c] SW of Salem, N.J.—fine to coarse-grained sand and gravel (Vincentown Formation) to Delaware Estuary, then to Delaware Bay and the Atlantic Ocean.	290	0.40	2.03	12/127	56/< 1	4.7	4	0.007 (combined)
Indian Point[d,e]	40 km N of New York City—fractured limestone to Hudson estuary.	145	0.76	0.52	270/1626	2/0	10.5	324	1×10^{-3} (combined)
Indian Point[d,f]		145	0.076	5.2	13.5/82	17/< 1	10.5	324	0, 1.1, 0.4, 0.44[g]

[a] Multiply by 3.28 to convert to ft or ft/d.

[b] Multiply by 2.20 to convert to pounds.

[c] Multiply by 0.625 to convert to miles.

[d] The largest reactor at Indian Point produces 965 MW(e).

[e] ConEd, nonconservative analysis; assumes flow through porous media, porosity = 0.005, limestone density = 2.7 g/cm^3, distribution coefficients for Sr and Cs are 0.5 and 3.0 cm^3/g, respectively, hydraulic conductivity = 0.061 m/d, hydraulic gradient = 0.062.

[f] Staff's conservative analysis; assumes flow through fractured media, porosity = 0.10, hydraulic conductivity = 0.122 m/d, all other parameters are the same as those presented by ConEd.

[g] Total population dose—the sum of drinking water, aquatic ingestion, and shoreline exposure doses.

parameters (reactor size, groundwater travel time, aquatic catch, and shoreline user-hours) are roughly comparable for Indian Point and the LPGS.

The second set of Indian Point estimates in Table 5.26 is based on a conservative assumption used in this analysis. Indian Point's reactor foundations are located on highly fractured (brecciated) limestone, and some of these fractures are open (ConEd). If the primary groundwater flow is through open fractures, the effective porosity of the fractured rock may range between 0 percent and 20 percent. Assuming that the effective porosity is 10 percent, adsorption-retention factors for strontium and cesium are about 13.5 and 82, respectively. These Indian Point adsorption-retention factors are comparable to those for the LPGS case and those for Seabrook (Table 5.25), which is also located on fractured rock. The staff analysis also uses ConEd's most conservative value of the hydraulic conductivity (0.122 m/day). Indian Point's aquatic, shoreline, and total population doses are 1.1, 0.38, and 0.44 times the respective LPGS generic estuary doses based on this second analysis.

Table 5.27 compares earlier FESs with the LPGS generic site for estuaries. The Salem reactor adjoins Hope Creek, and its estimated population dose is expected to be similar. All other sites have smaller reactors, have smaller nearby populations, or are located farther from surface water. All but Maine Yankee and Indian Point are located on coastal plains or alluvial sediments having at least some clay minerals in them, and coastal plain sites have low groundwater velocities and relatively high adsorption-retention factors. None of these sites should exceed the LPGS population dose for estuaries.

5.3.3.4.7 Dry Sites

Table 5.28 compares current dry plant sites with the LPGS generic dry site. Only one site (Palo Verde) provides significant information on which a comparison could be based. Palo Verde is located in a desert valley where the groundwater gradient and velocity are expected to be low. Alluvium in the groundwater pathway should have adsorption-retention factors comparable to those of the LPGS (if not greater, as indicated in Table 5.28). In contrast, the LPGS generic site is on the Snake River plain above the Snake River Canyon. Fractured volcanic rocks and Pleistocene glacial and alluvial sediments underlie the LPGS generic site. Accordingly, the groundwater gradient and velocity at the LPGS site are extraordinarily high, and the groundwater travel time is low. Even without adsorption, strontium would require five times as long to reach the Palo Verde site boundary as in the LPGS generic case. Because of its location on the Snake River plain, the LPGS site's uninterdicted population dose is believed to represent the largest dose for dry sites. Therefore, all dry sites are expected to have significantly lower groundwater pathway population doses than those of the atmospheric pathway.

Table 5.29 compares the only earlier dry site (Rancho Seco) with the Palo Verde and LPGS generic dry sites. As seen in the table, the Rancho Seco and Palo Verde sites are strikingly similar. The only significant difference is that the Rancho Seco reactor is only three-fourths as large as those of Palo Verde. Therefore, a severe accident at Rancho Seco is expected to produce a population dose similar to or less than that at Palo Verde.

Table 5.27 Earlier estuary sites without severe accident liquid pathway analyses compared with Liquid Pathway Generic Study (LPGS) results

Plant	Location and groundwater pathway	Reactor size [MW(e)]	Distance from reactor to nearest downgradient surface water (m)[a]	Population within 80 km[b] × 10^6	
				1990	2030
LPGS		1150	457	—	—
Brunswick	30 km S of Wilmington, N.C.—coastal plain sediments to Walden Creek, then to Cape Fear River and the Atlantic Ocean.	790	<150 to Walden Creek ~2300 to Cape Fear River	0.2	0.3
Calvert Cliffs	64 km S of Annapolis, Md.—coastal plain sediments to Chesapeake Bay and the Atlantic Ocean.	845	< 150	3.0	3.5
Crystal River	11 km NW of Crystal River, and 120 km N of Clearwater, Fla.—cavitose limestone and coastal plain sediments to surrounding wetlands and Salt Creek, then to the Gulf of Mexico.	825	< 90 wetlands ~1500 Gulf of Mexico	0.4	0.7
Maine Yankee	61 km NE of Portland, Maine—glacial till and shallow fractured granite to Back River, then to Montsweag Bay and the Atlantic Ocean.	840	< 150	0.6	0.8
Oyster Creek	13 km S of Tom's River, N.J.—coastal plain sediments to wetland; then to Oyster Creek, South Branch of Forked River, Barnegat Bay, and the Atlantic Ocean.	660	~150 to wetlands ~300 to river	4.0	4.6
Salem	Adjoining Hope Creek nuclear reactor, 13 km SW of Salem, N.J.—artificial island construction fill and coastal plain sediments (sand and gravel of the Vincentown Formation) to Delaware Estuary, then to Delaware Bay and the Atlantic Ocean.	918	90 to 150	4.8	5.2
Surry	13 km S of Williamsburg, Va.—coastal plain sediments to the James River, then to Chesapeake Bay and the Atlantic Ocean.	789	~610	1.9	2.5

[a] Multiply by 3.28 to convert to ft.

[b] Multiply by 0.625 to convert to miles.

Table 5.28 Current dry site severe accident liquid pathway analyses compared with Liquid Pathway Generic Study (LPGS) results

Plant	Location and groundwater pathway	Distance from reactor to exclusion boundary (m)[a]	Groundwater velocity (m/d)[a]	Groundwater travel time to exclusion boundary (years)	Adsorption-retention factor (Sr/Cs)	% radionuclide reaching exclusion boundary (Sr/Cs)	Drinking water population (per km^2)[b]	Dose-estimate ratio drinking water (plant/LPGS)
LPGS	Snake River Plain of SE Idaho—fractured and brecciated volcanic rock and Pleistocene glacial and alluvial deposits to groundwater resources.	457[c]	1.32	0.95	28/253	Unknown	3.9	1
Comanche Peak[d]	64 km[e] SW of Fort Worth, Tex.—groundwater is contained on-site; groundwater mound beneath cooling water reservoir prevents backflow to river; no downgradient wells identified.	NP[f]	NP	NP	NP	NP	NP	0
Palo Verde	54 km W of Phoenix, Ariz.—Lateral along water table in upper alluvial unit.	790	0.016	140	89/NP	~0/NP	4.2	~0
Waterford[g]	32 km W of New Orleans, La.—away from Mississippi River toward surrounding wetlands (the river channel is confined by natural levees and under normal flow conditions the elevation of the river's surface is above that of the surrounding wetlands).	NP	NP	17	>> 1/>> 1	NP	80	10^{-2} to 10^{-3}

[a] Multiply by 3.28 to convert to ft or ft/d.

[b] Multiply by 2.56 to convert to population per square mile.

[c] Provided by NUREG-0841.

[d] No credible groundwater pathway identified; no further information provided.

[e] Multiply by 0.625 to convert to miles.

[f] NP, not provided.

[g] Although Waterford is not located at a "dry site," for the purpose of this groundwater pathway analysis its groundwater travel characteristics behave like a dry site since flow is away from the Mississippi River. Accordingly, for analysis purposes it was classified as a dry site.

Table 5.29 **Earlier dry sites with no severe accident liquid pathway analyses compared with Palo Verde and Liquid Pathway Generic Study (LPGS) sites**

Plant	Location and groundwater pathway	Reactor size [MW(e)]	Distance from reactor to exclusion boundary (m)[a]	Groundwater velocity (m/day)[a]	Groundwater travel time to exclusion boundary (years)
LPGS	Southeastern Idaho Snake River Plain—groundwater flow is in highly permeable fractured volcanic rock, Pleistocene gravel, and sand.	1150	457	1.32	0.95
Palo Verde	54 km[b] W of Phoenix, Ariz.—lateral along the water table in an upper alluvial unit.	1270	790	0.016	140
Rancho Seco	40 km SE of Sacramento, California—sand and gravel zones in the Mehrten Formation (presumably alluvium); flow is west toward the Sacramento Basin, and the nearest public water supply wells are 22 km to the west.	918	800	0.019[c]	115

[a] Multiply by 3.28 to convert to ft or ft/day.

[b] Multiply by 0.625 to convert to miles.

[c] Calculated by Oak Ridge National Laboratory staff from data provided in Rancho Seco environmental impact statement.

5.3.3.4.8 Results

Table 5.30 summarizes sites having uncertain groundwater pathway population doses compared with the LPGS study or other FES groundwater analyses. All but two of these sites are along small rivers. Uncertain groundwater pathways were the greatest concern.

Fractured rock, solution cavities in limestone, weathered rock, incompletely described geologic conditions, and the uncertain character of glacial or Pleistocene deposits are important geologic concerns. Several sites have large nearby populations, one is unusually close to surface water, and another is close to a stream with very low average flow rate.

The above liquid pathway analyses can be considered representative of uninterdicted population doses from a severe accident during the initial 40-year operating term. Liquid pathway population dose estimates at MYR would be smaller for a few plants, 10 to 30 percent higher for the majority of plants, and perhaps 50 percent higher for a few plants because of the general increase in population over a 50-year time interval beyond the FES analysis. Assuming such increases in population are representative of liquid dose increases, their effect on the results would be insignificant in relation to other uncertainties in the liquid pathway analysis.

However, it should be recognized that the uncertainty factor for liquid pathway uninterdicted population dose estimates in Tables 5.17 through 5.28 may be 10 or more. Codell (1985) does not recommend that these values be accepted at face-value; rather, they should be used for comparative purposes only (NUREG-1054). As stated previously, several parameters that are needed to perform a liquid pathway analysis (i.e., porosity, hydraulic conductivity, and adsorption coefficient) are not known with sufficient precision to provide better than order-of-magnitude estimates of population doses.

The LPGS and FES liquid pathway analyses (described above) provide uninterdicted population dose estimates based on the assumptions that core meltdown and penetration of the basemat have taken place. Such analyses are deterministic (i.e., they assume that the worst-case accident has occurred). However, the probability of occurrence of such an event is low (estimated to be no more than 10^{-4}/RY). Contamination of groundwater is not likely to occur in the event of a core meltdown unless the basemat is penetrated. Therefore, the deterministic population doses given in Table 5.17 should be multiplied by a factor of about 10^{-4} to obtain the risk (probability estimates times consequences) of annual uninterdicted population doses for an 1150-MW reactor.

The population doses provided by these analyses are also based on the assumption that contaminated surface water and groundwater are not interdicted. Interdiction would lower the population doses significantly and could consist of preventing the contaminants from reaching the surface water, preventing use of the water, or making it difficult to obtain contaminated food. It is assumed, however, that interdicting the source of contamination once it enters the groundwater is not by itself sufficient because it may be impractical to completely isolate a contaminated aquifer from its surroundings. At best, containment measures such as grout curtains slow the

Table 5.30 Sites having uncertain groundwater pathway population doses with respect to the Liquid Pathway Generic Study and other final environmental statement analyses

Category site	Major concern	~Downstream population × 10^3
Small river		
Arkansas Nuclear	Weathered rock	2506
Arnold	Pleistocene-holocene aquifer	5780
Bellefonte	Fractured limestone	3243
Browns Ferry	Limestone	3078
Connecticut Yankee	Uncertain pathway	< 10
Dresden	Pleistocene aquifer	6037
La Salle	Uncertain characteristics of glacial deposits	6012
McGuire	Weathered rock	1683
Monticello	Large nearby population	8690
North Anna	Weathered rock	< 10
Oconee	Fractured rock	752
Peach Bottom	Weathered rock	< 10
Prairie Island	Large nearby population	6302
Robinson	Low stream flow	231
Sequoyah	Weathered limestone	3681
Three Mile Island	Surrounded by Holocene alluvium	20
Vermont Yankee	Uncertain characteristics of glacial deposits	1724
Watts Bar	Limestone	3681
Yankee Row	Uncertain pathway	1724
Large river		
Trojan	Fractured rock	
WNP-2[a,b]	Fractured rock	

[a] WNP-2 = Washington Nuclear Project 2.

[b] This site has an existing severe accident liquid pathway analysis. Analytical results for this site may be non-conservative.

groundwater movement but do not prevent it. However, the increased travel time reduces the rate of groundwater discharge to surface water bodies and reduces the concentration of radionuclides through prolonged radioactive decay. In any event, limiting people's contact with contamination through such measures as preventing or confiscating catches of recreational and commercial fish and shellfish, prohibiting water-based recreation, and eliminating surface water as a drinking-water source may have to be employed.

Ocean and estuarine sites would be the hardest in which to effect interdiction because of the food pathway. Not only are the physical transport mechanisms of these systems complex, but many of the important recreational and commercial organisms are highly mobile. Thus, total confinement of the contamination would not be likely and controlling the taking of these organisms by man would need to be relied upon. However, it is reasonable to expect that dose reduction would occur as a result of interdiction of the pathways. It is estimated that the dose could be reduced by an order of magnitude (NUREG-0440, Table 7.3.2).

The risk to the population from releases to groundwater can be estimated by considering the information in Tables 5.17 through 5.29.

- For large river sites, risk to the population can be estimated from the LPGS analyses as approximately 12 person-rem/RY (assuming the annual probability is 1×10^{-4} for a core melt with penetration of the basemat). For the large river site that has a larger population dose estimate than the LPGS (WNP-2) it is estimated that WNP-2 exceeds the LPGS by 50 percent (Table 5.20) for a risk of approximately 18 person-rem/RY. Pathway interdiction can reduce this dose by an order of magnitude; thus, the predicted annual population dose for large river sites is only a small fraction of that from the atmospheric pathway.

- For small river sites, the risk to the population can be estimated from the LPGS analyses as approximately 1000 person-rem/RY with drinking-water risk contributing 890 person-rem/RY, ingestion contributing 70 person-rem/RY, and shoreline exposure contributing 40 person-rem/RY. Table 5.18 shows that the Byron Station FES-predicted population doses are higher than the LPGS small river site and would result in an annual population risk of approximately 3000 person-rem/RY at MYR. However, pathway interdiction could reduce this figure by a factor of 10, thus making the risk from groundwater releases only a small fraction of that from the atmospheric pathway for Byron Station. All other plants listed in Table 5.18 have much lower risk from groundwater releases than Byron Station.

From Table 5.19, there may be as many as 19 small river sites that could exceed the Byron Station dose estimate. However, conservatively assuming that all of the radionuclides would reach the river and considering the potentially greater population that could be exposed, it is estimated that in several cases the Byron Station population doses could be exceeded by up to a factor of 10; but in most cases the population doses would be similar to or less than those of Byron Station. Accordingly, the risk from groundwater releases at small river sites is, in most cases, a small fraction of that from atmospheric releases and in several cases may be similar to that from atmospheric releases.

- For Great Lakes sites, the risk to the population can be estimated from the LPGS analyses as approximately 350 person-rem/RY. However, the Fermi-2 FES analyses estimate a risk to the population of approximately 40 percent higher than the LPGS (Table 5.22), or approximately 500 person-rem/RY, uninterdicted. Pathway interdiction could reduce this by a factor of 10, thus making the annual population risk from groundwater releases only a small fraction of that from atmospheric releases. Since Section 5.3.3.4.4 concludes that the Fermi analysis provides the largest estimated groundwater pathway population dose of all Great Lake sites, the risk from groundwater releases at these sites is only a small fraction of that from atmospheric releases.

- For estuarine sites, the LPGS analyses predict a high population risk without interdiction (17,700 person-rem/RY). Pathway interdiction could reduce this by a factor of 10. Section 5.3.3.4.6 indicates that the LPGS analyses provide the largest estimated population risk for all estuarine sites. Therefore, the risk from groundwater releases at estuarine sites is lower than or comparable to that from atmospheric releases.

- For ocean sites, the risk to the population can be estimated from the LPGS analysis as approximately 55 person-rem/RY. From review of the Seabrook FES, it is estimated that the risk to the population may be as much as six times higher for Seabrook (Table 5.24), or approximately 330 person-rem/RY. Since pathway interdiction can reduce this by a factor of 10, it is a small fraction of the predicted risk from atmospheric releases from Seabrook. For other ocean sites, as discussed in Section 5.3.3.4.5, the Seabrook analysis provides a larger groundwater pathway population dose than all but Turkey Point. However, from the data in Table 5.25, assuming all the radionuclides from the reactor reach the groundwater, the population dose from Turkey Point at MYR would not be expected to exceed Seabrook (considering the differences in reactor size and surrounding population). Therefore, it can be concluded that the risk from groundwater releases at ocean sites would be a small fraction of that from atmospheric releases.

- For dry sites, all predicted releases are orders of magnitude lower than the LPGS. From the LPGS (NUREG-0440, Table 6.2.21), the uninterdicted population risk from drinking water could be as high as 10^4 person-rem, which would be one person-rem/RY on an annual risk basis. This is much less than the risk from atmospheric releases.

5.3.3.4.9 Conclusion

Based on the above discussion, it is concluded that groundwater generally contributes only a small fraction of that risk attributable to the atmospheric pathway but in a few cases may contribute a comparable risk.

5.3.3.5 Economic Impacts

The purpose of this section is to determine if the economic costs of the severe accidents that have been estimated in the 27 FESs that contain severe accident analyses can be used to predict the future costs of such accidents at all sites. Similar to Section 5.3.3.2, the EI is used as a predictor of cost because the cost should be dependent upon the economic impact in the same way and for the same reason as population dose estimates are dependent.

CRAC was used to calculate off-site severe accident costs for the area contaminated by the accident. The off-site costs that were considered relate to avoidance of adverse health effects and are categorized as follows:

- evacuation costs,
- value of crops contaminated and condemned,
- value of milk contaminated and condemned,
- costs of decontamination of property where practical, and
- indirect costs resulting from the loss of use of property and incomes derived therefrom (including interdiction to prevent human injury).

The severe accident analysis for the 27 FES plants uses these five cost category models to estimate an average (annual) expected cost due to a severe accident. These costs are a sum of the costs for a range of accidents multiplied by the probability that each of the accidents will occur. Costs in this section are stated in 1980 dollars to facilitate comparisons among plants. Key cost variables include projected population distributions, habitable land fraction, and statewide land-use statistics that identify land and crop values. The off-site consequence code then computes the off-site mitigation costs described above. For the FES plants that have severe accident analyses, estimated off-site accident costs could reach as high as $6 billion to $8 billion, but the probability of an accident with such high consequences would only be once in one million operating years. Higher costs are estimated for accidents with much lower probabilities. Projected costs of adverse health effects from deaths and illnesses would average about 10–20 percent of off-site mitigation costs. These costs are not considered in the economic cost calculations. One addition to these off-site costs was made in NRC risk analyses beginning in 1984. Recognizing that termination of economic activities in a contaminated area would create adverse economic impacts in wider regional markets and sources of supplies outside the contaminated area, NRC began estimating these additional economic costs in FESs. These costs are calculated only for a 1-year period after an accident and can reach into the billions of dollars.

Because some key variables affecting cost are strongly related to population density, it may be possible to predict mitigation costs for contaminated areas off-site using the EI developed in Section 5.3.3.2.1. To test this possibility, the expected cost of an accident calculated in 27 FESs having severe accident analyses was normalized for a plant size of 1000 MW(t) (Table 5.31) and then regressed against the EI value at 150 miles for that plant (Table 5.4).

Upper bound normalized expected costs of accidents during the MYR period for all plants were then predicted using this regression and the EI for populations for the MYR period. The estimates were then

Table 5.31 Average expected costs during the current license period and predicted expected costs during the middle year of license renewal (MYR) resulting from a severe accident

Plant	Average expected cost/RY[a] (dollars)	10-mile MYR population	MYR 95% projected cost/RY[b] (1994 dollars)
Arkansas	—	33,992	477,750
Beaver Valley	29,000	155,141	1,565,550
Bellefonte	—	35,846	2,278,500
Big Rock Point	—	11,037	73,500
Braidwood	14,000	32,652	6,357,750
Browns Ferry	—	36,400	1,984,500
Brunswick	—	15,348	992,250
Byron	8,400	23,900	4,226,250
Callaway	4,300	6,877	1,528,800
Calvert Cliffs	—	24,564	4,336,500
Catawba	7,100	130,735	1,764,000
Clinton	6,700	16,543	3,344,250
Comanche Peak	3,900	19,400	882,000
Cooper	—	6,768	2,116,800
Crystal River	—	20,368	1,249,500
D.C. Cook	—	63,680	2,094,750
Davis-Besse	—	19,714	3,013,500
Diablo Canyon	—	29,591	661,500
Dresden	—	48,248	2,609,250
Duane Arnold	—	94,461	463,050
Farley	—	16,421	624,750
Fermi 2	23,000	93,010	2,138,850
FitzPatrick	—	34,403	1,029,000
Fort Calhoun	—	17,978	220,500
Ginna	—	39,649	404,250
Grand Gulf	3,060	10,943	1,984,500
Haddam Neck	—	91,760	2,249,100
Hatch	—	6,607	1,881,600
Hope Creek	40,000	32,844	4,704,000
Indian Point	—	247,253	8,246,700
Kewanee	—	12,966	551,250
La Salle	—	20,204	3,785,250
Limerick	62,200	178,626	3,505,950
Maine Yankee	—	41,435	771,750
McGuire	—	72,117	1,697,850
Millstone 3	80,000	130,000	3,461,850
Monticello	—	28,091	992,250
Nine Mile Point	8,000	35,208	1,396,500
North Anna	—	11,668	2,352,000

See footnotes at end of table.

Table 5.31 (continued)

Plant	Average expected cost/RY[a] (dollars)	10-mile MYR population	MYR 95% projected cost/RY[b] (1994 dollars)
Oconee	—	77,790	1,234,800
Oyster Creek	—	96,364	1,675,800
Palisades	—	39,720	2,572,500
Palo Verde	2,260	1,378	1,176,000
Peach Bottom	—	34,894	3,858,750
Perry	7,300	89,247	2,028,600
Pilgrim	—	45,921	1,176,000
Point Beach	—	26,447	588,000
Prairie Island	—	28,450	441,000
Quad Cities	—	42,521	2,131,500
Rancho Seco	—	12,489	2,646,000
River Bend	50,000	33,120	1,580,250
Robinson	—	37,681	1,543,500
Salem	—	32,868	8,636,250
San Onofre	19,000	91,940	2,734,200
Seabrook	5,800	130,574	882,000
Sequoyah	—	66,110	1,433,250
Shearon Harris	3,770	26,423	1,690,500
Shoreham	—	113,644	2,138,850
South Texas	2,600	4,149	2,998,800
St. Lucie	4,250	166,860	1,058,400
Summer	4,800	14,997	2,205,000
Surry	—	103,830	1,146,600
Susquehanna	9,000	54,887	3,153,150
Three Mile Island	—	170,142	3,748,500
Trojan	—	21,958	3,050,250
Turkey Point	—	11,136	551,250
Vermont Yankee	—	2,354	2,763,600
Vogtle	16,000	2,648	2,763,600
Waterford	4,500	1,930	3,998,400
Watts Bar	—	95,237	573,300
WNP-2[c]	2,600	22,878	918,750
Wolf Creek	3,600	7,239	1,411,200
Yankee Row	—	27,263	1,249,500
Zion	—	293,491	2,138,850

[a] RY = reactor year; estimates presented in the final environmental statements for operation license.

[b] Distribution free values (nonparametric—see Appendix G). Includes MELCOR Accident Consequence Code System-implied correction factors as well as an inflation multiplier derived from the Implicit Gross Domestic Price Inflator Index = 125.9/85.7 = 1.47 (from 1980 to 2nd quarter 1994).

[c] WNP-2 = Washington Nuclear Project 2.

Note: 10 miles ≒ 16 km.

nonnormalized to convert to expected costs (MYR).

Economic consequences were also benchmarked to the MACCS computer code to ensure the calculated values were based on the most current models and data. The benchmark computations indicated that the CRAC calculations used to estimate the economic impacts for the FES plants did not have a continuous linear relationship with population. The MACCS code predicted higher costs than did the CRAC code; low population sites were underpredicted by substantial margins. The differences were primarily due to the difference in the handling of decontamination costs in the two codes. Results from Tingle (1993) indicate that in order to be comparable to results calculated from MACCS, the regression values should be adjusted though the use of population-dependent correction factors. Table 5.31 reflects average expected cost values that were derived from the regression and then corrected with the following factors:

- Sites with MYR 10-mile (16-km) populations ≤ 10,000 multiply cost data by 40.
- Sites with MYR 10-mile populations > 10,000 and ≤ 50,000 multiply cost data by 25.
- Sites with MYR 10-mile populations > 50,000 multiply cost data by 15.

Also, the FES values were in 1980 dollars. To correct for this the average expected cost values were adjusted to 1994 dollars.

In addition to assessing the economic impact of severe accidents, six of the 27 FESs that analyze severe accidents also assess the amount of off-site land that could be contaminated and subject to long-term interdiction as a result of a severe accident.

These plants and their predicted conditional mean values of land contamination are listed below:

• Hope Creek	7000 m^2/year (8400 yd^2/year)
• Limerick 1 and 2	1500 m^2/year (1800 yd^2/year)
• Millstone 3	4000 m^2/year (4800 yd^2/year)
• Nine Mile Point 2	20,000 m^2/year (24,000 yd^2/year)
• River Bend	40,000 m^2/year (48,000 yd^2/year)
• South Texas 1 and 2	600 m^2/year (720 yd^2/year)

These predicted values would not be expected to change for the license renewal period since they are not affected by increases in population.

As can be seen by the values listed above, the predicted conditional land contamination is small (10 acres/year at most). This is also consistent with WASH-1400 (NUREG-75/014) and a 1982 study on siting criteria (NUREG/CR-2239) which predicts small conditional land contamination values. The land contamination values for these six plants can be considered representative of all plants since they cover the major vendor and containment types and include sites at the upper end of annual rainfall. However, even considering that land contamination values can vary at other sites, it is not expected that predicted land contamination from plants at other sites would vary more than 1 or 2 orders of magnitude from the values listed above and would, therefore, still be a small impact.

5.3.4 Uncertainties

FESs referred to in this section have been based mostly upon the methodology presented in RSS, which was published in 1975 (NUREG-75/014).

Although substantial improvements have been made in various facets of the RSS methodology since its publication, large uncertainties in the results of these analyses remain, including uncertainties associated with the likelihood of the accident sequences and containment failure modes leading to the release categories, the source terms for the release categories, and the estimates of environmental consequences. A comprehensive discussion of the uncertainties associated with risk assessments is provided in NUREG-1150. The relatively more important contributors to uncertainties in the results presented in this environmental statement are as follows.

5.3.4.1 Probability of Occurrence of Accident

If the probability of a release category were to change by some percentage, the probabilities of various types of consequences from that release category would also change by the same percentage. Thus, an order of magnitude uncertainty in the probability of a release category would result in a corresponding order of magnitude uncertainty in both societal and individual risks stemming from the release category. In RSS, there are substantial uncertainties in the probabilities of the release categories. This uncertainty is due, in part, to difficulties associated with the quantification of human error and to limitations in the database on failure rates of individual plant components and in the database on external events and their effects on plant systems, structures, and components that are used to calculate the probabilities. However, since the publication of RSS, substantial NRC programs to improve nuclear plant safety have been implemented such as resolution of generic safety issues (NUREG-0933), Station Blackout and Anticipated Transient Without Scram Rulemakings, and improvements resulting from reviews of the TMI accident (NUREG-0737). These programs, as well as others, all served to reduce the average risk of the overall nuclear industry such that in this GEIS, the use of RSS risk values and their associated frequencies of an accident (because they are embodied within the risk calculation) are reasonable upper estimates of risk for the industry. This is true for even those plants that have not had the benefit of a PRA analysis.

5.3.4.2 Quantity and Chemical Form of Radioactivity Released

There are also significant uncertainties associated with the timing, quantity, and chemical form of each radionuclide species that would be released from a reactor unit during a particular accident sequence. Radioactive material originates in the fuel and would be released from any damaged fuel during an accident. Some would be attenuated by physical and chemical processes en route to being released to the environment. Depending on the accident sequence, such factors as attenuation in the reactor vessel, the rest of the cooling system, the containment, and adjacent buildings would influence both the magnitude and chemical form of radioactive releases. Additional radionuclide releases may originate from on-site dry cask storage facilities for those sites which develop the capability, although the radionuclide inventory is much less than that in the reactor core. Information available in NUREG-0956, in NUREG-1150, and from the latest research activities sponsored by NRC and the industry indicates that the uncertainty in radionuclide source terms is large and represents a significant contribution to the uncertainty in the absolute value of risk. In comparison with the RSS source terms (which are used in the FES analyses), source terms in recent studies were in some instances higher and in other instances lower. However, for the early containment failure sequences, which have the greatest impact on risk, the RSS source terms appear to be larger than the mean values estimated from the recent work and are typically at the upper bound of the uncertainty range of estimates for NUREG-1150.

5.3.4.3 Atmospheric Dispersion Modeling for the Radioactive Plume Transport

Uncertainties are involved in modeling the atmospheric transport of radioactivity in gaseous and particulate states and the actual transport, diffusion, and deposition or fallout that would occur during an accident (including the effects of condensation and precipitation). The phenomenon of plume rise from heat associated with the atmospheric release, effects of precipitation on the plume, and fallout of particulate matter from the plume all have considerable impact on the magnitudes of early health consequences along with the distances from the reactors where these consequences would occur. These factors can result in overestimates or underestimates of both early and later effects (health and economic).

Other areas that have effects on uncertainty are as follows:

- **Duration, energy release, and in-plant radionuclide decay time.** These areas relate to the differences between assumed release duration, energy of release, and the in-plant radioactivity decay times compared with those that would actually occur during a real accident.

  For an atmospheric release of relatively long duration (greater than a half-hour), the actual cross-wind spread (i.e., the width) of the radioactive plume would likely be larger than the width calculated by the dispersion model in the staff code (CRAC). However, the effective width of the plume is calculated in the code using a plume expansion factor that is determined by the release duration. For a given quantity of radionuclides in a release, the plume and, therefore, the area that would come under its cover would become wider if the release duration were longer. In effect, this would result in lower air and ground concentrations of radioactivity but a greater area of contamination.

  The thermal energy associated with the release affects the plume rise phenomenon; a plume that rises quickly or to a high altitude (as in the Chernobyl accident) results in relatively lower air and ground concentrations in the closer-in regions and relatively higher concentrations in the farther-out regions (because of fallout) than would be predicted for plumes that do not rise. Therefore, if large thermal energy were associated with a release containing a large fraction of core-inventory radionuclides, it could increase the distance from the reactor over which early health effects may occur. If, on the other hand, the release behavior were dominated by the presence of large amounts of condensing steam, very much the reverse could occur because of close-in deposition of radionuclides induced by the falling water condensed from the steam.

The time from reactor shutdown until the beginning of the release to the environment (atmosphere), known as the time of release, is used to calculate the depletion of radionuclides by radioactive decay within the plant before release. The depletion factor for each radionuclide (determined by the radioactive decay constant and the time of release) multiplied by the release fraction of the radionuclide and its core inventory determines the actual quantity of the radionuclide released to the environment. Later releases would result in the release of fewer curies to the environment for given values of release fractions.

These parameters can all have significant impacts on accident consequences, particularly early consequences.

- **Meteorological sampling scheme used.** There is a possibility that the meteorological sequences used with the selected start times (sampling) in CRAC may not adequately represent all meteorological variations during the year, or that the year of meteorological data may not represent all possible conditions. This factor is judged to produce greater uncertainties for early effects and less for latent effects.

- **Emergency response effectiveness and warning time.** This relates to the differences between modeling assumptions regarding the emergency response of the people residing near nuclear facilities compared with what would happen during an actual severe reactor accident. Included in these considerations are such subjects as evacuation effectiveness under different circumstances, possible sheltering and its effectiveness, the effectiveness of population relocation, and the fraction of people assumed not to relocate. The warning time is the interval between the time the plant operating staff recognize plant conditions which would indicate that protective actions should be taken for the general population and the time of the release of radioactive material from the plant. In calculations with CRAC, it is assumed that the protective action taken would always be evacuation. Therefore, in the calculation, the evacuating public could be caught by a radioactive plume and exposed or could evacuate into a passing plume. In reality, there are other protective actions that might be called for by public officials—for instance, sheltering to avoid such a situation. This can affect the simplified assumptions about protective actions in the calculated results and would most likely be in the direction of larger calculated early effects. Longer warning times are always more favorable in reality because they would allow time for consideration of several protective action options. The uncertainties associated with emergency response effectiveness and warning time could cause large uncertainties in early health consequences. The uncertainties in latent health consequences and costs are considered smaller than those for early health consequences.

- **Dose-conversion factors and dose-response relationships for early health consequences.** There are uncertainties associated with the conversion of contamination levels to doses, relationships of doses to health effects, and considerations of the availability of what was described in RSS as supportive medical treatment (a specialized medical treatment program, of limited availability in the local area but with additional availability outside the area, that would minimize the early health effect consequences of high levels of radiation exposure following a severe reactor accident). Although all health impacts have not been enumerated in this evaluation, the primary ones have been, and references to other documents such as RSS provide additional insights into the subject.

- **Dose-conversion factors and dose-response relationships for latent health consequences.** Estimates of dose and latent (delayed and long-term) health effects on individuals and on their succeeding generations involve uncertainties associated with conversion of contamination levels to doses and of doses to health effects. The staff judges that this category has a large uncertainty. The uncertainty could result in relatively small underestimates of consequences, but also in substantial overestimates of consequences. Previous FES analyses have been based on results that utilized dose-response relationships provided in BEIR-III (or earlier reports). Consequently the results presented in this GEIS have been corrected to account for the more recent dose-response relationships provided in BEIR-V and to reflect models and relationships found in the most current consequence assessment codes.

- **Chronic exposure pathways.** Uncertainty arises from the possibility that different protective action guide levels may be used for interdiction or decontamination of the exposure pathways (both the atmospheric pathway and the groundwater pathway) than those assumed in the staff analysis. Furthermore, uncertainty arises because there is a lack of precise knowledge about the fate of the radionuclides in the environment as influenced by natural processes such as runoff and weathering. The staff's qualitative judgment is that the uncertainty from these considerations is substantial.

- **Economic data and modeling.** This relates to uncertainties in the economic parameters and economic modeling such as costs of evacuation, relocation, medical treatment, and decontamination of properties and other costs of property damage. Uncertainty in this area could be substantial.

NUREG-1150 contains a state-of-the-art quantification of the uncertainties in core-melt frequency, containment behavior, and source term evaluation. Also included are discussions of the major factors affecting the uncertainty. For further detail on the topics discussed in Sections 5.3.4.1 through 5.3.4.3, refer to the appropriate topics in NUREG-1150.

5.3.4.4 Assumption of Normality for Random Error Components

The predictions of risk values (early and latent fatalities and total dose) were developed statistically by regressing consequence values calculated in recent nuclear plant FESs. A "standard" assumption in the calculation of confidence bounds for these predictions is that the regression errors have a normal distribution. However, without specific evidence of normality, normal-theory confidence bounds for the risk may be too high or low, possibly by a significant margin. Therefore, alternative confidence bounds were considered, which do not rely on the errors having a specified distribution such as the normal, but depend instead on a large-sample approximation. When the normal-theory and alternative bounds differed, the ones leading to higher calculated values were used. (This subject is discussed in Appendix G.)

5.3.4.5 Exposure Index

The concept of using a parameter such as EI to predict future risks is also subject to uncertainty. Such issues are discussed below.

- **Selection of EI parameters.** EI is a calculated parameter based on plant-specific information: population surrounding the plant and wind direction frequency data for the plant. The data on population projections used in the calculation of EI values are based on the 1980 census. EI estimates were made for years 1990, 2000, 2010, 2030, and 2050 and for populations at 10 and 150 miles from the plant. Population estimates for these years were obtained from data provided by the Bureau of Economic Analysis. It is estimated that the uncertainty in these population projections is relatively small, certainly less than a factor of two, and, consequently, would not significantly impact the conclusions of this evaluation.

  The wind data were obtained from plant license documentation such as environmental reports or final safety analysis reports; site-specific data are used in this analysis.

  However, other parameters such as exclusion area distance, rainfall, evacuation speed, and terrain can also affect the consequence calculations. The NUREG-1150 study found that for the five plants studied, the fatality magnitudes (early and latent) were driven primarily by the core-damage frequency, the source term releases, site meteorology, population distribution, and the effectiveness of emergency response measures. All these factors were considered in the CRAC analyses done for the FES plants, using site-specific information for meteorology, population, and emergency response actions. The FES plant analyses enveloped a broad range of such site-specific values. Consequently, it is likely that the use of the UCB limit to estimate future environmental impacts would envelop the effects of these parameters for all plants. The FES analyses were usually performed assuming populations representative of the middle year of the normal 40-year license period. Populations would continue to increase as operation continued into a renewal period. Thus, renewal period risks were predicted using population representative of the middle year of the renewal period. Wind direction frequency is very plant-specific and was not considered to be adequately enveloped for the non-FES plants by the FES plant's wind direction frequencies, especially when these frequencies are weighted by the plant-specific population. However, by selection of population and wind direction frequency for the EI and using UCB values to envelop the effects of other parameters, the uncertainty introduced by the selection of EI parameters should be minimized.

- **Selection of distances.** Although the selection of 10 miles and 150 miles for computing EI values produces rather strong correlations between the EI values and the reported effects in FESs (Appendix G), other distances could exist whose selection would result in stronger correlations. Indeed, as shown in Table 5.5, the FES plants showed a range of 7 to 50 miles for occurrence of total acute fatalities whereas the GEIS analysis used only one distance, 10 miles. However, the effect of stronger correlations would serve primarily to reduce the uncertainty of the regression, thus resulting in a general reduction in the UCB values. Consequently, because the correlations that are used in the study are relatively strong and GEIS uses the UCB values to estimate risk, the possibility of under prediction should be small.

- **Regressing early fatalities for only large plants.** As described in Section 5.3.3.2.1, the regressions for early fatality estimates were performed using data for FES plants having thermal power levels greater than about 3025 MW(t). Although there is some relationship between plant size and predicted early fatalities (all other factors being held constant), the relationship is not linear because of the threshold effects for early fatalities. Therefore, normalization for plant size for the early fatality regression process was not considered appropriate; rather, early fatalities were predicted based only on the data for large plants. This approach should generally provide overpredictions for plants less than 3025 MW(t) resulting in most of the uncertainty being in the direction of smaller predicted effects. For plants equal to or greater than 3025 MW(t), small uncertainty in the calculated values may be present. However, the use of UCBs for predicting risk values should minimize the possibility of underprediction.

- **Normalization of plants for latent fatalities, costs, and dose.** As described in Section 5.3.3.2.1, the regression for latent fatality and dose curves were performed using FES data that had been normalized to 1000 MW(t) in order to reduce the influence of plant size on the fitted parameters. Actual plant size was used for making the predictions and, therefore, the final results reflect nonnormalized values. The regression of latent fatalities, dose, and costs using normalized FES values assumes a linear relationship between power level and source term released. The use of UCBs to predict risk values should minimize the possibility of underprediction.

5.3.4.6 Summary

The state of the art for the quantitative evaluation of the uncertainties for PRA analyses is presented in the NUREG-1150 studies. The NUREG-1150 results indicate that reduction of uncertainty considerations or previously unanalyzed phenomena and sequences and consideration of plant changes have resulted in individual risk components that are both higher and lower than originally provided in RSS. However, NUREG-1150 shows that the cumulative effect is a reduction in risk for those plants studied, and it is also likely to be the case for the industry as a whole. The GEIS results, when reviewed against current data and methodology, have large uncertainties associated with them. The bounds on this uncertainty could be between a factor of 10 and 1000 and could result in the values used being higher or lower.

5.4 SEVERE ACCIDENT MITIGATION DESIGN ALTERNATIVES (SAMDAs)

In 1980 NRC issued an interim policy statement on the consideration of severe accidents in environmental impact statements (EISs) (45 *FR* 40101) applicable to Construction Permit and Operating License applications submitted on or after July 1, 1980. That policy statement states that it is "the intent of the Commission that the staff take steps to identify additional cases that might warrant early consideration of either additional features or other actions which would prevent or mitigate the consequences of serious accidents." Recently, these features have become commonly referred to as SAMDAs. The policy statement goes on to say, "cases for such consideration are those for which a Final Environmental Statement has already been issued at the Construction Permit stage but for which the Operating License review stage has not yet been reached." This statement was made in recognition of the fact that changes in plant design features may be more easily incorporated in plants when construction has not yet progressed very far.

In August 1985, NRC issued its policy statement on severe reactor accidents. That policy statement presented NRC's conclusion that existing plants pose no undue risk to public health and safety and that there was no present basis for immediate action on generic rulemaking or other regulatory changes for those plants because of severe accident risk. Nevertheless, it called for each licensee to perform an analysis designed to discover instances of particular vulnerability to core melt or unusually poor containment performance given a core-melt accident. NRC believed that this policy statement was a sufficient basis for not requiring a consideration of SAMDAs at the operating license review stage for previously constructed plants. However, a 1989 court decision ruled that such a policy statement was not sufficient to preclude a consideration of SAMDAs and that such a consideration is required for plant operation, *Limerick Ecology Action v. NRC*, 869 F.d 719 (3rd Cir. 1989). In order to assess whether SAMDAs can be adequately addressed generically for all plants in this GEIS, it is necessary to consider the level of experience the commission has regarding SAMDAs and the extent to which this experience can reasonably address the SAMDA issue for all plants.

5.4.1 Commission Experience Regarding Severe Accident Mitigation

NRC has gained considerable experience regarding severe accident mitigation during the past several years through implementation of its severe accident policy statement. Specific major actions that have been initiated and, in some cases, completed are (1) evaluation of containment performance and various alternatives for improvement, (2) initiation of individual plant examination, and (3) initiation of an accident management program. Additionally, NRC has performed three site-specific evaluations of SAMDAs pursuant to the 1989 court decision. These

SAMDA analyses were included in the final environmental impact statements for Limerick 1 and 2 and Comanche Peak 1 and 2 operating license reviews, and the Watts Bar supplemental final environmental statement for operation. These actions are addressed below.

5.4.1.1 Containment Performance

NRC has examined each of five U.S. reactor containment types (BWR Mark I, II and III; PWR Ice Condenser; and PWR Dry) with the purpose of examining the potential failure modes, potential fixes, and the cost benefit of such fixes. This examination has been called the containment performance improvement (CPI) program and has been documented in a series of reports (NUREG/CR-5225; NUREG/CR-5278; NUREG/CR-5528; NUREG/ CR-5529; NUREG/CR-5565; NUREG/CR-5567; NUREG/CR-5575; NUREG/CR-5586; NUREG/CR-5589; NUREG/CR-5602; NUREG/CR-5623; NUREG/ CR-5630). Tables 5.32 through 5.34 summarize the results of this program. As can be seen from these tables, many potential changes were evaluated but only a few containment improvements were identified for site-specific review. The items evaluated in the CPI program were also included in the list of plant-specific SAMDAs examined in the Limerick, Comanche Peak, and Watts Bar FES supplements, discussed later.

5.4.1.2 Individual Plant Examinations

In accordance with NRC's policy statement on severe accidents, each licensee has been requested to perform an individual plant examination (IPE) to look for vulnerabilities to both internal and external initiating events (Generic Letter 88-20, Supplements 1–4). This examination will consider potential improvements on a plant-specific basis. In effect, IPE could be considered equivalent to a monitoring program that looks at the severe accident performance of each licensed plant. Detailed guidance has been issued to each licensee regarding the scope and conduct of IPE and the reporting requirements. NRC staff intends to review each submittal and, if plant modifications not proposed by the licensee appear warranted, to pursue the incorporation of such modifications via NRC's backfit rule (10 CFR Part 50.109). To date, 22 IPEs have been reviewed by NRC. These IPEs have resulted in plant procedural and programmatic improvements (i.e., accident management) and, in only a few cases, minor plant modifications, to further reduce the risk and consequences of severe accidents.

5.4.1.3 Accident Management

Accident management involves the development of procedures that promote the most effective use of available plant equipment and staff in the event of an accident. NRC has indicated its intent (Generic Letter 88-20, Supplement 2) to request that licensees develop an accident management framework that will include implementation of accident management procedures, training, and technical guidance. It is expected that insights gained as a result of IPE will be factored into the accident management program. As discussed earlier, the majority of improvements identified from the completed IPEs to date have been in the area of accident management or other procedural and programmatic improvements.

5.4.1.4 SAMDA Analyses

Site specific SAMDA analyses were performed for Limerick, Comanche Peak, and Watts Bar. A listing of the specific

Table 5.32 Potential boiling-water reactor containment improvements considered in the containment performance improvement program

Number	Potential improvement	Resolution	Comments
1	Enhanced ADS, low pressure water supply, and backup power	Include in IPE	*a*
2	Hardened vent	Implemented for Mark-Is, included in IPE for Mark-II and IIIs	*b*
3	ATWS sized-hardened vent	Drop	*c*
4	External filter	Drop	*c*
5	Dedicated suppression pool cooling	Drop	*c*
6	Alternate decay heat removal	Drop	*c*
7	Core debris control	Drop	*c*
8	Enhanced drywell spray	Drop	*c*
9	Drywell head flood	Drop	*c*
10	Enhanced reactor building DF	Drop	
11	Backup power for hydrogen ignitors (Mark IIIs)	Included in IPE	*d*

Acronyms: ADS = automatic depressurization system, IPE = individual plant examination, ATWS = anticipated transit without scram, DF = decontamination factor.

[a] Analysis showed that potential improvement may be cost beneficial.

[b] Cost beneficial for Mark-Is.

[c] Not cost effective—potential improvement will be too expensive with too little benefit.

[d] May be cost beneficial.

Table 5.33 Potential pressurized-water reactor ice condenser improvements considered in the containment performance improvement program

Potential improvement	Resolution	Comments
Reactor cavity flooding	Drop	Not cost beneficial. Might cause ex-vessel steam explosion.
Backup water to the containment spray system	Drop	Not cost beneficial
Backup power to the air return fan system	Drop	Not cost beneficial. May increase containment pressurization
Reactor depressurization	Include in accident management	Currently being pursued as a viable accident management strategy
Improved hydrogen ignitor system (backup power)	Include in individual plant examination (IPE)	Most cost beneficial of all alternatives considered (although it still does not meet the backfit test). To be looked at within the IPE program
Containment inerting	Drop	Not cost beneficial, may reduce accessibility for maintenance
Filtered vent	Drop	Not cost beneficial
Ex-vessel core debris curb	Drop	Large uncertainty as to effectiveness
Steam generator tube rupture improvements—increased testing	Further research needed	Being examined in separate Nuclear Regulatory Commission program by the Materials Engineering Branch, RES
Containment bypass improvements	Included in generic issues program	Being examined as part of a separate interfacing system loss of coolant accident generic issue (GSI 105)

Table 5.34 Potential pressurized-water reactor (PWR) large, dry containment improvements considered in the containment performance improvement program

Potential improvement	Resolution	Comments
Operator depressurization using power-operated relief valve	Drop	No conclusive findings on its benefit to risk reduction
Addition of a cavity flooding system	Drop	Not cost beneficial. The effect of a flooded cavity on the direct containment heating threats may be beneficial or detrimental, depending on each plant
Addition of hydrogen control system	Assess in individual plant examination (IPE)	Recommend all dry PWR containments assess the likelihood of local hydrogen detonation in the IPE

SAMDAs reviewed for applicability to Limerick is provided in Table 5.35. The staff examined each SAMDA (individually and, in some cases, in combination) to determine its individual risk reduction potential. This risk reduction was then compared with the cost of implementing the SAMDA to provide cost-benefit evidence of its value. Considering that the estimates of risk at Limerick used by the staff in these evaluations were considered to be high and that the uncertainties associated with the costs, effectiveness, and/or operational disadvantages of some SAMDAs were large, the staff concluded that there was no clear evidence that modifications to Limerick were justified for the purpose of further mitigating severe accident risks.

The staff made a similar assessment of SAMDAs for the Comanche Peak Steam Electric Station. A list of the SAMDAs reviewed in this evaluation is provided in Table 5.36. As with the Limerick evaluation, the staff had no basis for concluding that modifications to Comanche Peak were justified for the purpose of further mitigating environmental concerns as they relate to severe accidents. Recently, the staff evaluated SAMDAs for the Watts Bar Nuclear Plant. As in the Limerick and Comanche Peak analyses, no plant modifications were justified for the purpose of further mitigating severe accident risk and consequences.

Several important items from these analyses should be noted.

- First, the SAMDAs considered at Limerick, Comanche Peak, and Watts Bar covered a broad range of accident prevention and mitigation features. These features included the items that were evaluated for all containment types as part of the CPI Program.
- Second, the Limerick analyses were for a plant at a high population site. Since risk to the public is generally proportional to the population surrounding the plant, one would

Table 5.35 Severe accident mitigation design alternatives (SAMDAs) considered for the Limerick Generating Station

1. Installation of alternative means to maintain suppression pool subcooling to improve plant's capability to remove decay heat and prevent containment overpressure challenge

2. Provision of an alternative means of decay heat removal

3a. Installation of containment vent of sufficient size to prevent containment overpressure due to an anticipated transient without scram event

3b. Installation of containment vent and filter of sufficient size to prevent containment overpressure due to an inability to remove decay heat

3c. Installation of containment vent (no filter) of sufficient size to prevent containment overpressure due to an inability to remove decay heat[a]

4. Installation of core debris control devices to prevent core/concrete interaction and remove decay heat from the core debris

5a. Provide enhanced drywell spray capability to increase the reliability for removal of heat from the drywell atmosphere and the core debris, thereby minimizing the threat of containment failure due to overpressure

5b. Provide modification for flooding of the drywell head to help mitigate accidents that result in leakage through the drywell head seal

6. Provide the capability for diesel-driven, low-pressure makeup to the reactor to help in mitigation of core damage resulting from accident sequences in which the reactor vessel is depressurized and all other means of injecting water to the vessel have been lost

7. Improve the reliability of the automatic depressurization system to reduce the probability of vessel failure at high pressure during a severe accident

8. Establish an improved decontamination factor for secondary containment through enhancement to the fire protection system and/or the standby gas treatment system hardware and procedures to improve fission product removal

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[a] This SAMDA has been implemented for plants having Mark I containments.

Table 5.36 Listing of severe accident mitigation design alternatives considered for the Comanche Peak Steam Electric Station

1. Additional Instrumentation for Bypass Sequences: Install pressure-monitoring or leak-monitoring instruments (permanent pressure sensors) between the first two pressure isolation valves on low-pressure injection lines, residual heat removal (RHR) suction lines, and high-pressure injection lines. The additional instrumentation would improve the ability to detect valve leakage or open valves, and would decrease the frequency of interfacing system loss-of-coolant accidents (LOCAs).

2. Deliberate Ignition System: Provide a system to promote ignition of combustible gases (hydrogen and carbon monoxide) at low concentrations. The ignition system would prevent large-scale deflagrations or detonations in events involving gradual releases of combustibles (such as from cladding oxidation or core-concrete interactions) but may be ineffective for rapid releases of hydrogen that could occur coincident with reactor vessel failure at high pressure.

3. Reactor Coolant System Depressurization: Provide a capability to rapidly depressurize the reactor coolant system. Reactor depressurization would allow injection using low-pressure systems and would reduce the threat of direct containment heating and induced failures of steam generator tubes and primary coolant piping in the event low-pressure injection systems are not available. Depressurization could be achieved by a system specially designed to manually depressurize the reactor vessel or by actuation of existing pressurizer power-operated relief valves, reactor vessel heat vent valves, and secondary system valves.

4. Independent Containment Spray System: Provide an independent containment spray system, using the existing spray headers if appropriate. The spray system would cool the containment and the core debris, thereby reducing the challenge to containment from overtemperature and long-term overpressure by steam. However, unless the sprays terminate core-concrete interactions, the noncondensable gases released from the concrete are expected to cause the containment to eventually fail by overpressure.

5. Reactor Cavity Flooding System: Provide a capability to flood the reactor cavity before and after reactor vessel breach. Cavity flooding would promote debris coolability, reduce core-concrete interactions and noncondensable gas production, and provide fission product scrubbing.

6. Filtered Containment Venting: Provide a capability to vent the containment through a vent path routed to an external filter. The filtered vent would mitigate challenges to containment from long-term overpressure and hydrogen burn (by reducing the baseline containment pressure) but may not be effective for mitigating energetic events such as hydrogen burns coincident with reactor vessel failure.

Table 5.36 (continued)

7. Additional Diesel Generator: Provide an additional diesel generator with cross-ties to both Class 1E buses. This modification would increase the availability of the AC power system and reduce the frequency of station blackout sequences.

8. Additional DC Battery Capability: Provide additional DC battery capability to ensure eight hours of instrumentation and control power, as opposed to four in the event of a station blackout. This would extend the time available for recovery and reduce the frequency of long-term station blackout sequences.

9. Alternative Means of Core Injection: Provide a capability for makeup water to the reactor using a low-pressure, diesel-driven pump of sufficient capacity and associated piping hardware and procedures. The diesel-driven pump would serve as a backup to the front-line, low-pressure injection systems and could also be used to maintain core cooling in the event of a LOCA.

10. Improved Availability of Recirculation Mode: Provide a system to automatically switch the suction of the safety injection and centrifugal charging pumps to the RHR pump discharge when the refueling water storage tank is depleted. Automatic switchover would reduce the potential for operator error and improve the availability of core cooling in the recirculation mode.

11. Additional Service Water Pump: Add a third 100 percent service water pump to improve the availability of the station service water system. This would reduce the frequency of sequences involving failure of vital plant equipment due to loss of cooling.

generally expect SAMDAs for plants at high population sites to have the most favorable cost-benefit ratio. Since SAMDAs were found not to be justified at Limerick, it is unlikely that they would be justified for plants at other sites.

- Third, plant procedural and programmatic improvements (rather than plant modifications) were the only cost-beneficial improvements identified from these analyses.

5.4.1.5 Conclusion

Although NRC has gained considerable experience regarding severe accident mitigation improvements, the ongoing regulatory programs related to severe accident mitigation (i.e., individual plant examination/individual plant examination of external events and Accident Management) have not been completed for all plants. Since these programs have identified plant programmatic and procedural improvements (and in a few cases, minor plant modification) as cost effective in reducing severe accident consequence and risk, it would be premature to generically conclude that a consideration of severe accident mitigation is not required for license renewal.

However, based on the experiences discussed above, the NRC expects that a site-specific consideration of severe accident mitigation for license renewal will only identify procedural and programmatic improvements (and perhaps minor hardware changes) as being cost-beneficial in reducing severe accident risk or consequence. Therefore, a site-specific consideration of alternatives to mitigate severe accidents shall be performed for license renewal unless such a consideration has already been included in a previous EIS or related supplement. Staff evaluations of alternatives to mitigate severe accidents have already been completed and included in an EIS or supplement for Limerick, Comanche Peak, and Watts Bar; therefore, severe accident mitigation need not be reassessed for these plants for license renewal.

5.5 SUMMARY AND CONCLUSIONS

The foregoing discussions have dealt with the environmental impacts of accidents during operation after license renewal. The primary assumption for this evaluation is that the frequency (or likelihood of occurrence) of an accident at a given plant would not increase during the plant lifetime (inclusive of the license renewal period) because regulatory controls ensure the plant's licensing basis is maintained and improved, where warranted. However, it was recognized that the changing environment around the plant is not subject to regulatory controls and introduces the potential for changing risk. Estimation of future severe accident consequences and risk was based upon existing risk and consequence analyses found in FES for recently licensed plants because these include severe accident analyses and constitute a representative set of plants and sites for the United States.

5.5.1 Impacts from Design-Basis Accidents

The environmental impacts of postulated accidents were evaluated for the license renewal period in GEIS Chapter 5. All plants have had a previous evaluation of the environmental impacts of design-basis accidents. In addition, the licensee will be required to maintain acceptable design and performance criteria throughout the renewal period. Therefore, the calculated releases from design-basis accidents would not be expected to change. Since the consequences of these events are evaluated for the hypothetical maximally exposed individual at the time of licensing, changes in the plant environment will not affect these evaluations. Therefore, the staff concludes that the environmental impacts of design-basis accidents are of small significance for all plants. Because the environmental impacts of design basis accidents are of small significance and because additional measures to reduce such impacts would be costly, the staff concludes that no mitigation measures beyond those implemented during the current term license would be warranted. This is a Category 1 issue.

5.5.2 Impacts from Severe Accidents

5.5.2.1 Atmospheric Releases

The evaluation of health and dose effects caused by atmospheric releases used a prediction process to identify those plant sites that are bounded by existing analyses. Existing analyses represent only a subset of operating plants. A particular portion of this subset, specifically those plants having severe accident analyses in their respective FESs, was used in this evaluation. EI (which is a function of population and wind direction), in conjunction with the FES severe accident analyses, was then used to develop a means to predict consequences for all plants. Average values and 95 percent UCB values were estimated. Table 5.6 provides the results of this prediction process.

Results indicate that the predicted effects of a severe accident during MYR at the 74 sites of nuclear power plants in the United States are not expected to exceed a small fraction of that risk to which the population is already exposed. In addition, the dose to individuals was also predicted. Results indicate that the highest average individual dose would be 3×10^{-4} rem/RY. This dose compares to an average of 3×10^{-1} rem/person/year for all other causes, including radon. Therefore, the probability-weighted consequences from atmospheric releases associated with severe accidents is judged to be of small significance for all plants.

5.5.2.2 Fallout onto Open Bodies of Water

The results of comparative analyses for the drinking-water pathway concluded that Great Lakes sites have the same order-of-magnitude risk that was calculated in the Fermi 2 FES, which is only a small fraction of the risk from atmospheric pathway releases. River sites with potentially greater risk than in the Fermi FES are amenable to interdiction, which can significantly reduce risk. In the case of the aquatic food pathway, interdicted population exposures are less than or essentially the same as atmospheric pathway releases. For both the drinking water and aquatic food pathways, the probability-weighted consequences from fallout due to severe accidents is of small significance.

5.5.2.3 Releases from Groundwater

The comparative analyses for this pathway were done by first segregating all sites into six general categories as called out in the NRC LPGS (NUREG-0440) and then estimating if the risk consequences calculated in existing analyses (including the LPGS) bounds the risks for all other plants within each category.

Of the six categories, three are judged to be bound by existing analyses. These categories are Great Lake sites, estuaries, and dry sites.

For the other categories, estimates were made of the degree to which groundwater releases could exceed existing analyses. For all six categories, the staff concluded that the risk to the population was either a small fraction of that for atmospheric releases or, in a few cases, comparable to that from atmospheric releases. Therefore, the probability-weighted consequences from groundwater releases due to severe accidents is judged to be of small significance for all plants.

5.5.2.4 Societal and Economic Risks

The expected costs resulting from a severe accident at nuclear power plants during their renewal periods have been predicted from evaluations presented in 27 FESs. Estimates of the extent of land contamination have also been presented. In both cases, the conditional impacts are judged to be of small significance for all plants.

5.5.2.5 SAMDAs

The staff concluded that the generic analysis summarized above applies to all plants and that the probability-weighted consequences of atmospheric releases, fallout onto open bodies of water, releases to ground water, and societal and economic impacts of severe accidents are of small significance for all plants. However, not all plants have performed a site-specific analysis of measures that could mitigate severe accidents. Consequently, severe accidents are a Category 2 issue for plants that have not performed a site-specific consideration of severe accident mitigation and submitted that analysis for Commission review.

5.6 ENDNOTES

1. While a dose as low as 10 rem may cause such observable physiological changes as chromosomal aberrations, these changes are not classified as clinical injury.
2. Also referred to as the Rogovin report.
3. Grand Gulf, Sequoyah, Surry, Peach Bottom, and Zion.
4. The FitzPatrick and Nine Mile Point units are located closely enough to assume that they are located on the same site. A similar observation can be made for the Hope Creek and Salem units.
5. Because the hypothetical sites were to be modeled as either PWRs or BWRs, those using population data of actual PWR sites utilized updated WASH-1400 source terms taken from the Byron FES (NUREG-0848), while those using population data for BWRs utilized updated WASH-1400 source terms taken from the Clinton FES (NUREG-0854).

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6. THE URANIUM FUEL CYCLE AND SOLID WASTE MANAGEMENT

This chapter addresses the environmental impacts associated with the uranium fuel cycle as they apply to license renewal and the environmental impacts specifically associated with the management of radiological and nonradiological wastes resulting from license renewal.

6.1 INTRODUCTION

A generic assessment of the radiological and nonradiological environmental impacts of the uranium fuel cycle and transportation of nuclear fuel and wastes is provided in 10 CFR Part 51, Tables S-3 and S-4, respectively, and reproduced herein. This generic information, with the exception of ^{222}Rn and ^{99}Tc, provides the basis for the environmental information provided by applicants and must be used at individual licensing proceedings for the construction of light-water reactors (LWRs). In this chapter the U.S. Nuclear Regulatory Commission (NRC) supplements the data on environmental impacts of the uranium fuel cycle presented in Table S-3 and of transportation of radioactive wastes presented in Table S-4 to extend the coverage of impacts to ^{222}Rn, ^{99}Tc, higher fuel enrichment, higher fuel burnup, and license renewal of up to 20 additional years of operation. The data in Table S-3 were developed to represent the worst case on bounding estimates of the potential releases from the uranium fuel cycle while still being in compliance with NRC regulatory limits. This chapter provides a review of regulatory requirements of the various stages of the fuel cycle, including detailed discussions of the on-site and off-site requirements. The storage and disposal of spent fuel, reactor low-level waste, and mixed waste storage are also discussed. Both the radiological and nonradiological impacts to the environment are addressed.

In response to comments on the draft generic environmental impact statement (GEIS) and the proposed rule, the standard defining *small radiological impact* has changed from a comparison with background radiation to compliance with the dose and regulatory release limits applicable to the various stations of the fuel cycle. This change is appropriate and strengthens the criterion used to define *small environmental impact* for the reasons that follow: The Atomic Energy Act requires NRC to promulgate, inspect, and enforce standards that provide an adequate level of protection of the public health and safety and the environment. These responsibilities, singly and in the aggregate, provide a margin of safety. A review of the regulatory requirements and the performance of facilities provides the bases to project continuation of performance within regulatory standards. For the purposes of assessing radiological impacts, the Commission has concluded that impacts are of small significance if doses and releases do not exceed permissible levels in the Commission's regulations. Accidental releases or noncompliance with the standards could conceivably result in releases that would cause moderate or large radiological impacts. Such conditions are beyond the scope of regulations controlling normal operations and providing an adequate level of protection.

Table S.3 Uranium fuel-cycle environmental data[a] [Normalized to model light-water reactor (LWR) annual fuel requirement (WASH-1248) or reference reactor year (NUREG-0116)]

Environmental considerations	Total	Maximum effect per annual fuel requirement or reference reactor year of model 1000-MW(e) LWR
	Natural resource use	
Land		
Temporarily committed, acres[b]	100	
Undisturbed area	79	
Disturbed area	22	Equivalent to a 110-MW(e) coal-fired power plant.
Permanently committed, acres	13	
Overburden moved, millions of MT	2.8	Equivalent to a 95-MW(e) coal-fired power plant.
	Water (millions of gallons)	
Discharged to air	160	= 2% of model 1000-MW(e) LWR with cooling tower.
Discharged to water bodies	11,090	
Discharged to ground	127	
Total	11,377	< 4% of model 1000 MW(e) LWR with once-through cooling.
	Fossil fuel	
Electrical energy, thousands of MWh	323	< 5% of model 1000-MW(e) LWR output.
Equivalent coal, thousands of MT	118	Equivalent to the consumption of a 45-MW(e) coal-fired power plant.
Natural gas, millions of scf	135	< 0.4% of model 1000 MW(e) energy output.
	Effluents—chemical (MT)	
Gases (including entrainment)[c]		
SO_x	4,400	
NO_x[d]	1,190	Equivalent to emissions from 45-MW(e) coal-fired plant for a year.
Hydrocarbons	14	
CO	29.6	
Particulates	1,154	

See footnotes at end of table.

Table S.3 Continued

Environmental considerations	Total	Maximum effect per annual fuel requirement or reference reactor year of model 1000-MW(e) LWR
Other gases		
F	0.67	Principally from UF_6 production, enrichment, and reprocessing. Concentration within range of state standards—below level that has effects on human health.
HCl	0.014	
Liquids		
SO	9.9	From enrichment, fuel fabrication, and reprocessing steps. Components that constitute a potential for adverse environmental effect are present in dilute concentrations and receive additional dilution by receiving bodies of water to levels below permissible standards. The constituents that require dilution and the flow of dilution water are NH_2—600 ft^3/sec, NO_x—20 ft^3/sec, Fluoride—70 ft^3/sec.
NO	25.8	
Fluoride	12.9	
Ca	5.4	
C1	8.5	
Na	12.1	
NH	10.0	
Fe	0.4	
Tailings solutions	240,000	From mills only—no significant effluents to environment.
Solids	91,000	Principally from mills—no significant effluents to environment.
Effluents—Radiological (curies)		
Gases (including entrainment)		
Rn-222		Currently under reconsideration by the Commission.
Ra-226	0.02	
Th-230	0.02	
Uranium	0.034	
Tritium	18,100	
C-14	24	
Kr-85	400,000	
Ru-106	0.14	
I-129	1.3	Principally from fuel reprocessing plants.

See footnotes at end of table.

Table S.3 Continued

Environmental considerations	Total	Maximum effect per annual fuel requirement or reference reactor year of model 1000-MW(e) LWR
I-131	0.83	
Tc-99		Currently under consideration by the Commission.
Fission products and transuranics	0.203	
Liquids		
Uranium and daughters	2.1	Principally from milling—included tailings liquor and returned to ground—no effluents; therefore, no effect on environment.
Ra-226	0.0034	From UF_6 production.
Th-230	0.0015	
Th-234	0.01	From fuel fabrication plants—concentration 10% of 10 CFR 20 for total processing 26 annual fuel requirements for model LWR.
Fission and activation products	5.9×10^{-a}	
Solids (buried on site)		
Other than high level (shallow)	11,300	9100 Ci comes from low-level reactor wastes and 1500 Ci comes from reactor decontamination and decommissioning—buried at land burial facilities. 600 Ci comes from mills—included in tailings returned to ground. Approximately 60 Ci comes from conversion and spent-fuel storage. No significant effluent to the environment.
TRU and HLW (deep)	1.1×10^6	Buried at federal repository.
Effluents—thermal, billions of British thermal units	4,063	< 5% of model 1000-MW(e) LWR.

See footnotes at end of table.

Table S.3 Continued

Environmental considerations	Total	Maximum effect per annual fuel requirement or reference reactor year of model 1000-MW(e) LWR
Transportation, man-rem		
Exposure of workers and general public	2.5	
Occupational exposure	22.6	From reprocessing and waste management.

[a] In some cases where no entry appears, it is clear from the background documents that the matter was addressed and that, in effect, the table should be read as if a specific zero entry had been made. However, other areas are not addressed at all in the table. Table 10.5-3 does not include health effects from the effluents described in the table, estimates of releases of radon-222 from the uranium fuel cycle, or estimates of technetium-99 released from waste management or reprocessing activities. These issues may be the subject of litigation in the individual licensing proceedings.

Data supporting this table are given in WASH-1248; NUREG-0116; NUREG-0216; and in the record of the Docket RM-50-3. The contributions from reprocessing, waste management, and transportation of wastes are maximized for either of the two fuel cycles (uranium only and no recycle). The contribution from transportation excludes transportation of cold fuel to a reactor and of irradiated fuel and radioactive wastes from a reactor, which are considered in Table S-4 of § 5.20(g). The contributions from the other steps of the fuel cycle are given in columns A through E of Table S-3A of WASH-1248.

[b] The contributions to temporarily committed land from reprocessing are not prorated over 30 years, because the complete temporary impact accrues regardless of whether the plant services 1 reactor for 1 year or 57 reactors for 30 years.

[c] Estimated effluents based upon combustion of equivalent coal for power generation.

[d] 1.2% from natural gas use and process.

Source: 10 CFR 51.51.

Table S.4 Environmental impact of transportation of fuel and waste to and from one light-water-cooled nuclear power reactor,[a] normal conditions of transport

	Environmental impact
Heat (per irradiated fuel cask in transit)	250,000 Btu/hr
Weight (governed by Federal or State restrictions)	73,000 lb per truck; 100 tons per cask per rail car
Traffic density	
Truck	Less than 1 per day
Rail	Less than 3 per month

Exposed population	Estimated number of persons exposed	Range of doses to exposed individuals[b] (per reactor year)	Cumulative dose to exposed population (per reactor year)[c]
Transportation workers	200	0.01 to 300 mrem	4 man-rem
General public			
Onlookers	1,100	0.003 to 1.3 mrem	3 man-rem
Along route	600,000	0.0001 to 0.06 mrem	

Accidents in transport

	Environmental risk
Radiological effects	Small[d]
Common (nonradiological) causes	1 fatal injury in 100 reactor years, 1 nonfatal injury in 10 reactor years, $475 property damage per reactor year

[a] Data supporting this table are given in the Commission's *Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants*, WASH-1238, December 1972, and Supp. 1 NUREG-75/038, April 1975. Both documents are available for inspection and copying at the Commission's Public Document Room, 2120 L Street N.W., Washington, D.C., and may be obtained from National Technical Information Service, Springfield, VA 22161. WASH-1238 is available from NTIS at a cost of $5.45 (microfiche, $2.25) and NUREG-75/038 is available at a cost of $3.25 (microfiche, $2.25).

[b] The Federal Radiation Council has recommended that the radiation doses from all sources of radiation other than natural background and medical exposures should be limited to 5000 mrem per year for individuals as a result of occupational exposure and should be limited to 500 mrem per year for individuals in the general population. The dose to individuals due to average natural background radiation is about 130 mrem per year.

[c] Man-rem is an expression for the summation of whole body doses to individuals in a group. Thus, if each member of a population group of 1000 people were to receive a dose of 0.0001 rem (1 mrem), or if 2 people were to receive a dose of 0.5 rem (500 mrem) each, the total man-rem dose in each case would be 1 man-rem.

[d] Although the environmental risk of radiological effects stemming from transportation accidents is currently incapable of being numerically quantified, the risk remains small regardless of whether it is being applied to a single reactor or a multireactor site.

Source: 10 CFR 51.52.

Given current regulatory activities and past regulatory experience, the Commission has no reason to expect that such noncompliance will occur at any significant frequency. To the contrary, the Commission expects that future radiological impacts from the fuel cycle will represent releases and impacts within applicable regulatory limits. Collective doses and associated health effects are calculated and discussed at various places in this chapter. These estimates are provided for perspective only.

Estimates of the magnitude of the human health risks associated with the expected occupational and public dose levels based on the linear effects model should be evaluated relative to the following positions taken by the International Commission on Radiological Protection (ICRP), the National Academy of Sciences/National Research Council (NAS/NRC), and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR): (1) the estimation of health effects at low doses (comparable to external natural background) are based on extrapolation from effects seen at high doses and dose rates, with no threshold (the linear model); however, health effects at these low doses have not been demonstrated by human epidemiological studies; (2) the possibility that there may be no risk from exposures comparable to natural background radiation levels cannot be ruled out by any epidemiological studies; and (3) at low doses and dose rates, it must be acknowledged that the lower limit on the range of uncertainty in the risk estimate extends to zero. Section I.B. of the preamble to final 10 CFR Part 20 (56 FR 23360; May 21, 1991) states: "In the absence of convincing evidence that there is a dose threshold or that low levels of radiation are beneficial, the Commission believes that the assumptions regarding a linear nonthreshold dose-effect model for cancers and genetic effects and the existence of thresholds only for certain nonstochastic effects remain appropriate for formulating radiation protection standards and planning radiation protection programs." Therefore, because the health effects are uncertain at low levels of radiation dose, for regulatory purposes it is prudent to use the linear nonthreshold dose-effect model; accordingly, this model was used to estimate health effects.

Table S-3 states the environmental impacts of the uranium fuel cycle from the mining of uranium ore to the ultimate disposal of spent fuel and other radioactive waste that is generated by the use and management of fuel. Table S-4 states the environmental impacts specific to the transportation of fuel and radioactive waste to and from a reactor.

10 CFR Part 51.51(a) states in part, "Every environmental report prepared for the construction permit stage of a light-water-cooled nuclear power reactor, and submitted on or after September 4, 1979, shall take Table S-3, Table of Uranium Fuel Cycle Environmental Data, as the basis for evaluating the contribution of the environmental effects of uranium mining and milling, the production of uranium hexafluoride, isotopic enrichment, fuel fabrication, reprocessing of irradiated fuel, transportation of radioactive materials and management of low-level wastes and high-level wastes related to uranium fuel-cycle activities to the environmental costs of licensing the nuclear power reactor."

The impacts of the uranium fuel cycle are discussed in Section 6.2. The following sections of the chapter are organized by waste type: low level, mixed, and spent fuel. For each waste type, the issues are divided into "baseline," those that are present with or without license renewal, and "effects of license renewal," those that are attributable solely to waste management activities associated with license renewal. In addition, transportation is addressed in a separate section because it applies to all waste types.

6.2 IMPACTS OF THE URANIUM FUEL CYCLE

The following discussion of the environmental impacts of the fuel cycle as related to the operation of an individual nuclear power plant during the license renewal period is based on the values given in Table S-3 and the staff's analysis of the radiological impact from radon and technetium releases. For the sake of consistency, the data presented in Table S-3 have been cast in terms of a model 1000-MW(e) LWR operating at an annual capacity factor of 80%.

Specific categories of natural resource use included in Table S-3 relate to land use, water consumption and thermal effluents, radioactive releases, burial of transuranic and high- and low-level wastes, and radiation doses from transportation and occupational exposures. The contributions in the table for reprocessing, waste management, and transportation of wastes are maximized for either of the two fuel cycles (uranium only and no recycle); that is, the cycle that results in the greater impact is used.

6.2.1 Background of Tables S-3 and S-4

Tables S-3 and S-4 provided a summary of the environmental data, and Table S-4 provided a summary of the environmental impacts related to the LWR fuel-cycle facilities and processing operations. The environmental impact values are expressed in terms normalized to show the potential impacts attributable to processing the fuel required for the operation of a 1000-MW(e) nuclear power plant for one year at an 80 percent availability factor to produce about 800 megawatt-years (0.8 gigawatt-year) of electricity. This is referred to as one reference reactor year (RRY). The RRY fuel replacement requires, as raw material, about 182 metric tons (tonnes) of uranium. Based on U.S. uranium industry averages, which are expected to hold well into the next century, the ore assay is assumed to be 0.1 percent uranium, and the recovery of uranium from the ore to be about 90 percent. Thus the mining of about 202,000 tonnes of ore per RRY would be required. The values in Table S-3 are based on the mining and milling of this quantity of ore and the subsequent processing of related quantities of uranium compounds through all steps of the uranium fuel cycle, including radioactive waste disposal.

6.2.2 Uranium Fuel Cycle Environmental Impact

6.2.2.1 Radioactive Effluents

Radioactive effluents estimated to be released to the environment from reprocessing and waste-management activities and certain other phases of the fuel-cycle process are listed in Table S-3. Using these data, the staff has calculated for 1 year of operation of the model 1000-MW(e) LWR, the 100-year involuntary environmental dose commitment to the U.S. population from the LWR-supporting fuel cycle. The

100-year environmental dose commitment is the integrated population dose for 100 years (i.e., it represents the sum of the annual population doses for a total of 100 years).

It is estimated from these calculations that the overall involuntary total-body gaseous dose commitment to the U.S. population from the fuel cycle (excluding reactor releases and the dose commitment due to ^{222}Rn) would be about 400 man-rem for each year of operation of the model 1000-MW(e) LWR (RRY). Based on Table S-3 values, the additional involuntary total-body dose commitments to the U.S. population from radioactive liquid effluents resulting from all fuel-cycle operations other than reactor operation would be about 200 man-rem per year of operation. Thus, the estimated involuntary 100-year environmental dose commitment to the U.S. population from radioactive gaseous and liquid releases due to these portions of the fuel cycle is about 600 man-rem (whole body) per RRY. Using risk estimators of 500 cancer deaths per million man-rem for total-body (NUREG/CR-4214, Rev. 1, Part II, Addendum 1, p. 54), the estimated cancer risk would be 0.3 per RRY ($600 \times 500 \times 10^{-6}$).

Currently, the radiological impacts associated with ^{222}Rn and ^{99}Tc releases are not addressed in Table S-3. Principal radon releases occur during mining and milling operations and as emissions from mill tailings, whereas principal ^{99}Tc releases occur from gaseous diffusion enrichment facilities. Estimates of ^{222}Rn release per RRY from these operations are given in Table 6.1. The underlying assumptions are given later. The staff has calculated population-dose commitments for these sources of ^{222}Rn using the RABGAD computer code described in Volume 3 of NUREG-0002, Appendix A, Chapter IV, Section J. The results of these calculations for mining and milling activities prior to tailings stabilization are given in Table 6.2.

For radon releases from stabilized tailings piles, the staff has assumed that the tailings would emit 1 Ci per RRY, with covering fully intact. Based on this radon release rate, the 100-year dose commitments from stabilized tailing piles are estimated to be 2.6 man-rem for total-body, 68 man-rem for bone, and 56 man-rem for lung (bronchial-epithelium). These dose commitments will continue for many years because ^{222}Rn emission source strength will be constant for about 10,000 years and ultimately decline by a factor of 2 every 80,000 years.

The long-term integrity of the coverings must be maintained because the standards in 40 CFR 192 and 10 CFR 40, Appendix A, require certification of stability and the control of average radon flux levels to 20 pCi/m^2/s. Under Section 83 of the Atomic Energy Act, a government agency will maintain licensed custody and provide for long-term care of mill tailings sites after closure. Actions the government agency is authorized to conduct include monitoring, maintenance, and emergency measures necessary to protect the public health and safety and other measures necessary to ensure compliance with the standards in 10 Part 40. The NRC has adopted general licenses (10 CFR 40.27 and 40.28) to implement this provision for inactive and active sites, respectively. The general licensee will be the Department of Energy or successor agency, another agency designated by the President, or a state where the disposal site is located. The design and implementation of the radon cover and erosion protection features are the primary reliance for maintaining radon

Table 6.1 Radon releases from mining and milling operations and mill tailings for each year of operation of the model 1000-MW(e) light-water reactor

Radon source	Quantity released
Mining, Ci	4060
Milling and tailings (during active milling), Ci	780
Inactive tailings (prior to stabilization), Ci	350
Stabilized tailings, Ci/year	1

Table 6.2 Estimated 100-year environmental dose commitment from mining and milling for each year of operation of the model 1000-MW(e) light-water reactor

		Dosage (man-rem)		
Radon source	^{222}Rn release (Ci)	Total body	Bone	Lung (bronchial epithelium)
Mining	4100	110	2800	2300
Milling and tailings (other than stabilized)	1100	29	750	620
Total		140	3600	2900

emissions within the Part 40 limits; significant failure of the covers is considered highly unlikely. However, the indefinite licensed long-term custody and care provide additional assurances. Thus, the NRC staff concludes that any needed repairs will be done and that the most likely future for the closed stabilized tailings piles is conformance with the emission standards in 10 CFR 40. On the other hand, there are inherent uncertainties associated with any reliance on institutional controls. In its recent report (NAS 1995), NAS concluded that there is no technical basis for relying on institutional controls for high-level waste facilities. From a policy/resource perspective, future generations may choose not to fulfill the obligations now specified in law for mill tailings. If such a decision is made, the radon emissions might increase by a factor of two orders of magnitude as centuries. Such a policy decision is not irrevocable and may be reversed so that the covers could be repaired at a later date. In spite of these uncertainties, staff believes that the combination of engineering and institutional controls will most likely result in compliance with the flux emission standards now in place for the foreseeable future.

These doses and predicted health effects have been compared with those that can be expected from natural emissions of ^{222}Rn. Using data from the National Council on Radiation Protection and Measurements (NCRP 1987), the average indoor ^{222}Rn air concentration in air in the contiguous United States is about 1 pCi/L, and the short-half-lived daughter concentration is 0.004 WL (working level). The NCRP estimates that an annual lung dose from radon of 20 mrem will result in an annual dose to the bronchial epithelium of 2400 mrem as a result of the daughter products. For a stabilized future U.S. population of 300 million, this represents a total lung-dose commitment of 720 million man-rem per year. Using the same risk estimator of 78 lung-cancer fatalities per million lung man-rems used to predict cancer fatalities for the model 1000-MW(e) LWR, estimated lung-cancer fatalities alone from natural ^{222}Rn in the indoor air can be calculated to be up to 56,000 per year.

The staff has assumed that after completion of active mining, underground mines will be sealed, returning releases of ^{222}Rn to background levels. For purposes of providing an upper-bound impact assessment, the staff has assumed that open-pit mines will be unreclaimed and has calculated that if all ore were produced from open-pit mines, releases from them would be 110 Ci per RRY. However, because the distribution of uranium ore reserves available by conventional mining methods is 66 percent underground and 34 percent open-pit [GJO-100(78)], the staff has further assumed that uranium to fuel LWRs will be produced by conventional mining methods in these proportions. This means that long-term releases from unreclaimed open-pit mines will be 37 Ci/year (0.34 × 110) per RRY. In 1994, 100 percent of the domestic uranium came from in situ mining and other sources. None came from underground or open pit (conventional) mining (DOE/EIA-0478, 1995).

Based on these assumptions, the radon released from unreclaimed open-pit mines over 100- and 1000-year periods would be about 3,700 and 37,000 Ci per RRY, respectively. The total dose commitments for a 100- to 1,000-year period would be as shown in Table 6.3. These commitments represent a worst-case situation in that no mitigating circumstances are assumed. However, state and federal laws currently require reclamation of strip and open-pit coal mines, and it is very probable that similar reclamation will be required for open-pit uranium mines. If so, long-term releases from such mines should approach background levels.

For long-term radon releases from stabilized tailings piles, the staff has assumed that the tailings would emit, per RRY, 1 Ci/year for 100 years (covering fully intact), 10 Ci/year for the next 400 years (covering partially failed), and 100 Ci/year for periods beyond 500 years (covering failed). With these assumptions, the cumulative radon-222 release from stabilized tailings piles per RRY would be 100 Ci in 100 years, 4090 Ci in 500 years, and 53,800 Ci in 1000 years (NRC Docket No. 50-488). The total-body, bone, and bronchial-epithelium dose commitments for these periods are as shown in Table 6.4.

It should be noted that there would be global radiological impacts from ^{222}Rn. The number of potential health effects within the U.S. is estimated to be about 90 percent of the total continental health effects. Mexico and Canada would account for the remaining 10 percent of the

Table 6.3 Population-dose commitments from unreclaimed open-pit mines for each year of operation of the model 1000-MW(e) light-water reactor

Time period (years)	^{222}Rn release (Ci)	Population-dose commitments (man-rem)		
		Total body	Bone	Lung (bronchial epithelium)
100	3,700	96	2,500	2,000
500	19,000	480	13,000	11,000
1,000	37,000	960	25,000	20,000

Table 6.4 Population-dose commitments from stabilized tailings piles for each year of operation of the model 1000-MW(e) light-water reactor

Time period (years)	^{222}Rn release (Ci)	Population-dose commitments (man-rem)		
		Total body	Bone	Lung (bronchial epithelium)
100	100	2.6	68	56
500	4,090	110	2,800	2,300
1,000	53,800	1,400	37,000	30,000

continental health effects. Exposure in Europe and Asia would add about 25 percent more potential health effects to the number of effects predicted for North America (NUREG-0706, p. 6-68).

The staff also considered the potential health effects associated with the release of ^{99}Tc. The release per RRY of ^{99}Tc is 0.007 Ci from chemical reprocessing of recycled UF_6 before it enters the isotope enrichment cascade and 0.005 Ci into the groundwater from a federal repository. The major risks from ^{99}Tc are from exposure of the gastrointestinal tract and kidney, although there is a small risk from total-body exposure. Using organ-specific risk estimators, these individual organ risks can be converted to a total-body 100-year dose commitment of 100 man-rem per RRY. These calculations are based on the gaseous and the hydrological pathway model systems described in Volume 3 of NUREG-0002, *Final Generic Environmental Statement on the Use of Mixed Oxide Fuel in Light Water Cooled Reactors-Health, Safety, and Environment*, Chapter IV, Section J, Appendix A.

The consideration of risks to large populations over long periods of time from exposures to very low concentrations of radionuclides involves many uncertainties. The issue of estimating risks from radon and daughters at very low levels continues to be studied. For example, in a June 7, 1995, article in the Journal of the National Cancer Institute (Lubin et al. 1995), the authors reexamined data on miner exposures and described the uncertainties in projecting risks to indoor radon levels. The indoor concentrations are generally about an order of magnitude lower than the miner exposures, but there is some overlap when comparing lifetime exposures to the exposures of the worker cohorts. The authors concluded that much uncertainty still exists in projecting risks at indoor levels from miner data, including the exposures of miners to agents such as arsenic and diesel exhaust, but that reduction of radon levels in homes above the U.S. Environmental Protection Agency's (EPA's) recommended action level of 4 pCi/L "*may* [emphasis added] reduce lung cancer deaths about 2%–4%." Average U.S. indoor levels are about an order of magnitude higher than ambient outdoor levels. Radon releases from tailings for hundreds and thousands of years are undetectable from background levels at a few km, or less than one km in some cases (NRC Docket 50-488 1986). Thus, in the staff's view, projecting risks from levels another order of magnitude or more lower involves even greater uncertainties. However, the linear nonthreshold assumption continues to be used to calculate potential health effects in documents such as this GEIS where the agency is airing the impacts and potential impacts of activities under consideration.

When added to the 500 man-rem total-body dose commitment for the balance of the fuel cycle, the overall estimated total-body involuntary 100-year environmental dose commitment to the U.S. population from the fuel cycle for the model 1000-MW(e) LWR is about 740 man-rem (500 + 140 + 2.6 + 100). Over this period, this dose is equivalent to 0.0008 percent of the natural total-body dose of about 90 million man-rem to the U.S. population. This estimate is based on an annual average natural individual dose commitment of 300 mrem (includes radon) and a stabilized (assumed constant) U.S. population of 300 million.

Using risk estimators of 500, 0.6, and 78 (NUREG/CR-4214, Rev. 1, Part II, Addendum 1, p. 54; Addendum 2, pp. 38 and 49) cancer deaths per million man-rem for total-body, bone, and lung exposures, respectively, the estimated risk of cancer mortality resulting from fuel cycle from emissions of radioactive material is about 0.6 cancer fatality per RRY $[(740 \times 500 + 3668 \times 0.6 + 2956 \times 78) \times 10^{-6}]$.

Using the estimates above, the 100-year environmental dose commitment to the U.S. population from the fuel cycle, high-level-waste and spent-fuel disposal excepted, is calculated to be about 14,800 man-rem, or 12 cancer fatalities, for each additional 20-year power reactor operating term. Much of this, especially the contribution of radon releases from mines and tailing piles, consists of tiny doses summed over large populations. This same dose calculation can theoretically be extended to include many tiny doses over additional thousands of years as well as doses outside the United States. The result of such a calculation would be thousands of cancer fatalities from the fuel cycle, but this result assumes that even tiny doses have some statistical adverse health effects that will not ever be mitigated (for example, no cancer cure in the next thousand years), and that these dose projections over thousands of years are meaningful. However, these assumptions are questionable. In particular, science cannot rule out the possibility that there will be no cancer fatalities from these tiny doses. For perspective, the doses are very small fractions of regulatory limits, and even smaller fractions of natural background exposure to the same population.

Although collective doses and associated potential health effects are calculated and discussed at various places in this chapter, no conclusion is drawn as to the significance of the collective doses or potential health effects. These collective doses are provided for information purposes.

Uranium fuel cycle facilities must comply with NRC, EPA, other federal and state regulations regarding, among other things, the dose limits to the members of the public. Table 6.5 lists types of facilities, the governing regulatory requirements, and the applicable dose limits for individual members of the public. All licensees must provide reasonable assurance that these dose limits are being met for all unrestricted areas. Since each licensee must ensure that the dose is within the limit and be as low as reasonably achievable (ALARA), the dose to individual members of the public is considered by the staff to be small. More detailed discussions on regulatory limits and compliance are presented below.

In the 1989 National Emission Standards for Hazardous Air Pollutants (NESHAP) rulemaking for radionuclides, discussed elsewhere, EPA examined the uranium fuel-cycle (UFC) licensees (see 54 FR 51668; December 15, 1989) as a separate category. Nonradon emissions from uranium mill tailings, uranium hexafluoride conversion plants, fuel fabrication plants, and power plants (all types of facilities in operation subject to 40 CFR 190 and licensed by NRC at the time) were evaluated and combined. The results of EPA's risk assessment was that:

> the most exposed individual receives a dose associated with an increased risk of fatal cancer of 1.5×10^{-4}. There is a predicted incidence of 0.1 fatal cancer per year in the population, with almost all the population risk received by people with a lifetime risk of less than 1×10^{-6}. Virtually the entire U.S. population lives within 80 km of at least one UFC facility.

EPA found that current emissions were at levels that provided an ample margin of safety but decided to regulate this category to ensure that "the current levels of emissions are not increased." The UFC licensees were included in the licensees subject to Subpart I of 40 CFR 61 and its 10 mrem/year annual dose standard. The UFC licensees other than power reactors have been required to comply with Subpart I since November 1992. Reports to EPA are required if emissions exceed 10% or more of the standard. Based on discussions with EPA staff, NRC understands that no fuel cycle licensees exceeded the standard in 1993 and that the same result is likely for 1994. Note that EPA rescind Subpart I for power reactors on September 5, 1995 (60 FR 46206). EPA evaluated enrichment facilities as part of the Department of Energy category and made similar findings and made them subject to the same 10 mrem/year limit.

The NRC dose limits for individual members of the public are found in 10 CFR 20.1301. The general limit is 100 mrem/year [20.1301(a)(1)]. The risk of fatal cancer to an individual receiving this limit is 5×10^{-5} per year of exposure.

Table 6.5 Dose limits for most exposed members of the public from uranium fuel cycle facilities

Facility	NRC 10 CFR 20 100 mrem/year and ALARA	EPA (UFC) 40 CFR 190 25/75/25 mrem/year[a]	EPA (CAA) 40 CFR 61 10 mrem/year[a]	Other selected standards
Mines				States, other federal agencies
Surface	No	No	No	
Underground	No	No	Yes	
Milling	Yes	Yes	Yes	10 CFR 40[b]
Mill tailings	Yes[c]	Yes[c]	Yes[c]	10 CFR 40 40 CFR 61, Subpart W[b] 40 CFR 192[b]
UF_6 production	Yes	Yes	Yes	10 CFR 40
Enrichment	Yes	Yes	Yes	10 CFR 76
Fuel fabrication	Yes	Yes	Yes	10 CFR 70
Reactor	Yes	Yes	No	10 CFR 50, Appendix I
Spent-fuel storage	Yes	Yes	Yes	10 CFR 72
Reprocessing	Yes	Yes	Yes	10 CFR 50
High-level waste and spent-fuel disposal	Yes[d]	No	No	10 CFR 60 40 CFR 191
Low-level waste disposal	Yes[d]	No	Yes	10 CFR 61
Transportation	No	No	No	10 CFR 71 DOT-49 CFR

[a] Does not include radon and decay products.
[b] Limiting radon flux to <20 pCi · m^{-2} · s^{-1}, no limit on dose.
[c] Until under general license or closed.
[d] Until closure.

Other limits are 2 mrem/hour in unrestricted areas [20.1301(a)(2)], case-by-case approvals of up to 500 mrem/year [20.1301(c)], and compliance with EPA's 40 CFR 190, if applicable [20.1301(d)]. Licensees are also required to maintain doses to members of the public ALARA by 10 CFR 20.1101(b). The NRC limits apply to all sources under the control of the licensee and to all pathways combined. The individual dose standards in 40 CFR 190 (25 mrem whole body, 75 mrem thyroid, and 25 mrem to other organs) apply to all pathways of exposure from most fuel-cycle facilities, although doses from radon are excluded. NRC generally implements 40 CFR 190 by means of license conditions and has incorporated it by reference in 10 CFR Part 20. Licensees are required to submit reports every six months on radionuclide emissions under 10 CFR 40.65, 70.59, and 76.35 and explicitly required to report exceeding 40 CFR 190 or violations of implementing license conditions by 10 CFR 20.2203(a)(4).

Procedures are in place for inspecting and ensuring licensee compliance with the regulations and license conditions related to public exposures and environmental protection. For example, Inspection Procedures 83822 ("Radiation Protection"), 88035 ("Radioactive Waste Management"), and 88045 ("Environmental Protection") address inspection and verification of matters such as ALARA for emissions, compliance with procedures and limits in license conditions related to releases and public doses, review of environmental monitoring data, and reporting incidents as required by 10 CFR 20.2203. Fuel cycle facilities are inspected at 6- to 12-month intervals, and compliance with public dose limits and license conditions are normally included in the scope of review. (Note that NRC is still in an observation mode only at the enrichment facilities. NRC certification of compliance with standards is still in process as of September 15, 1995.) NRC inspects uranium recovery facilities, including both mills and in situ operations, annually, and all were inspected in 1995. Inspections include review of effluent and environmental monitoring data and compliance with Part 20 and 40 CFR 190. Inspections have found no evidence that limits are being exceeded. The agreement states of Colorado, Texas, and Washington also license and inspect uranium recovery facilities. They have historically inspected for compliance with 40 CFR 190, and no significant problems have been identified. Most mill tailings are in reclamation. Fuel-cycle licensees are generally found to be in compliance, and many of the fuel-fabrication facilities are operating at small fractions of the limits. Violations found and reported involving the exceeding of public dose limits are serious matters. As a matter of policy, exceeding the public dose limits or license conditions related to the limits is at least a severity level III violation and is subject to escalated enforcement actions. The absence of major enforcement actions related to exceeding public dose limits by fuel-cycle facilities readily discernable from the enforcement data base since 1985 suggests that these facilities are operating within the limits. One mill licensee case involved exceeding 10 CFR 20.106 unrestricted area concentration limits for radon, but no actual overexposure of members of the public occurred. There were no other cases for mill licensees since 1985 readily discernable from the data base that might gave involved overexposure of members of the public.

As noted in the preamble to the final rule revising 10 CFR Part 20 in its entirety (56 FR 23374; May 21, 1991), 40 CFR 190 limits "apply to the total dose from all sources within the uranium fuel cycle. However, in its practical implementation, the sources would have to be located within a few miles of each other for the combined dose contributions to be significantly different from the dose from either facility alone." Thus, in the unlikely event that facilities should be near each other, each licensee would have to determine that the combined doses do not exceed the limits.

NRC regulatory authority does not include underground or surface/open pit mining. The states and other federal agencies regulate these activities. They are not subject to 40 CFR 190. EPA considered radon emissions from both types of uranium mining in the 1989 Clean Air Act rulemaking. For surface uranium mines, EPA found that the current situation protected the public with an ample margin of safety. Further, EPA noted that

> In addition, this source category is already regulated by a host of state and federal mine reclamation laws. Due to the depressed state of the uranium mining industry, there is no reason to believe that new surface mines will be constructed. The presence of these laws, the very low maximum individual risk and incidence level associated with this category, and the depressed nature of the industry lead EPA to the decision that it is unnecessary for EPA to set a NESHAP for this source category.

For underground mines, EPA found that a NESHAP of 10 mrem/year was necessary and provided an ample margin of safety. As noted elsewhere, no production from either type of uranium mining occurred in 1993 and 1994.

Consideration of EPA's target risk goal for regulatory actions provides perspective and further illuminates the significance of the public doses being estimated and received. The EPA target risk goal is 10^{-4} to 10^{-6} individual lifetime risk. This policy developed over a number of years and is used in many EPA programs, including corrective actions for hazardous waste sites, site cleanups under Superfund, drinking water maximum concentration limits (MCLs) for tap water, and for air emissions under the Clean Air Act. For example, in a 1991 proposed rule to modify the radionuclide MCLs (56 FR 33058; July 18, 1991), EPA stated that "Longstanding and carefully considered EPA policy for regulating carcinogens in drinking water is that the lifetime individual risk target is one in 10,000 (10^{-4}) to one in 1,000,000 (10^{-6}) risk."

The 1989 Clean Air Act (CAA) regulations establishing NESHAPs for radionuclides are based on the target risks. NESHAPs were established for NRC licensees (40 CFR 61, Subpart I) and for radon emissions from operating tailings piles (40 CFR 61, Subpart W) and the disposal of tailings (40 CFR 61, Subpart T). Risks to individuals from high-level waste repository emissions were found to be sufficiently low (less than 1 in 1 million) that no NESHAP was needed. In the final rule (54 FR 51654; December 15; 1989), EPA stated the EPA NESHAPs Policy concerning the risk goals as follows:

> This section provides a description of the EPA's approach for the protection of public health under section 112. In protecting public health with an ample margin of safety under section 112, EPA strives to provide maximum feasible protection against risks to health from hazardous air pollutants by

> (1) protecting the greatest number of persons possible to an individual lifetime risk level no higher than approximately 1 in 1 million and (2) limiting to no higher than approximately 1 in 10 thousand the maximum estimated risk that a person living near a plant would have if he or she were exposed to the emitted pollutant for 70 years. Implementation of these goals is by means of a two-step standard-setting approach, with an analytical first step to determine an "acceptable risk" that considers all health information, including risk estimation uncertainty, and includes a presumptive limit on maximum individual lifetime risk (MIR) of approximately 1 in 10 thousand. A second step follows in which the actual standard is set at a level that provides "an ample margin of safety" in consideration of all health information, including the number of persons at risk levels higher than approximately 1 in 1 million as well as other relevant factors including costs and economic impacts, technological feasibility, and other factors relevant to each particular decision. Applying this approach to the radionuclide source categories in today's notice results in controls that protect over 90 percent of the persons within 80 kilometers (km) of these sources at risk levels no higher than approximately 1 in 1 million.

The 1990 CAA amendments preserved these radionuclide NESHAPS and included a general 10^{-6} lifetime risk threshold for when EPA should consider developing standards or additional requirements on air emissions from sources or removing sources from the list [sections 112(f) and (c)(9), respectively]. The legislative history for the 1990 amendments also included the risk approach as expressed by the quote above as the acceptable basis for EPA not to regulate NRC licensees.

The limits in 40 CFR 190 equate to a maximum individual risk of about 5×10^{-4} per EPA's 1993 rulemaking related to 40 CFR 191 [derived from a lifetime (70-year) individual dose of 15 mrem/year and using risk factor of 500×10^{-6} per rem]. Because ALARA must be applied by licensees, few, if any, individuals would be exposed at this limit. Thus, individual doses expected should fall within EPA's target risk range.

6.2.2.2 Radioactive Wastes

The quantities of buried radioactive waste material (low-level, high-level, and transuranic wastes) associated with the uranium fuel cycle are specified in Table S-3. For low-level waste disposal at land-burial facilities, the Commission notes in Table S-3 that there will be no significant radioactive releases to the environment. The Commission notes that high-level and transuranic wastes are to be buried at a federal repository and that no release to the environment is associated with such disposal, although it has been assumed that all of the gaseous and volatile radionuclides contained in the spent fuel are released to the atmosphere prior to the disposal of the waste. NUREG-0116, which provides background and context for the high-level and transuranic Table S-3 values established by the Commission, indicates that these high-level and transuranic wastes will be buried and will not be released to the biosphere. The generation, storage, and ultimate disposal of low-level waste, mixed waste, and spent fuel from power reactors is addressed in greater detail later in this chapter.

Waste disposal facilities are not covered by 40 CFR 190, but 10 CFR 60 applies to disposal of high-level waste, and 10 CFR 61 applies or is applied to low-level-waste disposal facilities. The NRC regulations for geologic disposal of high-level radioactive waste in 10 CFR 60 limits the releases of radioactive material to the accessible environment. In addition to satisfying an overall performance objective to be established by EPA, the basic requirements are that containment of high-level waste within the waste packages will be substantially complete for a period between 300 and 1,000 years (to be determined by the Commission) and that the annual releases from the engineered barrier system thereafter should not exceed one part in 100,000 of the total inventory of each radionuclide calculated to be present 1,000 years following permanent closure of the repository. For high-level waste, 10 CFR 60.111 requires compliance with 10 CFR 20 and with EPA general environmental standards in 40 CFR 191.

For the high-level-waste and spent-fuel disposal component of the fuel cycle, there are no current regulatory limits for off-site releases of radionuclides for the candidate repository at Yucca Mountain. If we assume that limits are developed along the lines of the 1995 National Academy of Sciences (NAS) report, *Technical Bases for Yucca Mountain Standards*, and that in accordance with the Commission's Waste Confidence Decision, 10 CFR 51.23, a repository can and likely will be developed at some site that will comply with such limits, peak doses to virtually all individuals will be 100 mrem/year or less. While the NRC has reasonable confidence that these assumptions will prove correct, there is considerable uncertainty because the limits are yet to be developed, no repository application has been completed or reviewed, and uncertainty is inherent in the models used to evaluate possible pathways to the human environment. The National Academy report indicated that 100 mrem/year should be considered as a starting point for limits for individual doses, but notes that some measure of consensus exists among national and international bodies that the limits should be a fraction of the 100 mrem/year. The lifetime individual risk from 100 mrem/year dose limit is about 3×10^{-3}.

Estimating cumulative doses to populations over thousands of years is more problematic. The likelihood and consequences of events that could seriously compromise the integrity of a deep geologic repository were evaluated by the Department of Energy in the *Final Environmental Impact Statement: Management of Commercially Generated Radioactive Waste*, October 1980. The evaluation estimated the 70-year whole-body dose commitment to the maximum individual and to the regional population resulting from several modes of breaching a reference repository in the year of closure, after 1,000 years, after 100,000 years, and after 100,000,000 years. The release scenarios covered a wide range of consequences from the limited consequences of humans accidentally drilling into a waste package in the repository to the catastrophic release of the repository inventory by a direct meteor strike. Subsequently, the NRC and other federal agencies have expended considerable effort to develop models for the design and for the licensing of a high-level-waste repository, especially for the candidate repository at Yucca Mountain. More meaningful estimates of doses to population may be possible in the future as more is understood about the performance of the proposed Yucca Mountain repository. Such estimates would involve very great uncertainty, especially with respect to cumulative population doses over thousands of years. The standard proposed by the NAS is a limit on maximum individual dose. The relationship of potential new regulatory requirements, based on the NAS report, and cumulative population impacts has not been determined, although the report articulates the view that protection of individuals will adequately protect the population for a repository at Yucca Mountain. However, EPA's generic repository standards in 40 CFR 191 generally provide an indication of the order of magnitude of cumulative risk to population that could result from the licensing of a Yucca Mountain repository, assuming the ultimate standards will be within the range of standards now under consideration. The standards in 40 CFR 191 protect the population by imposing "containment requirements" that limit the cumulative amount of radioactive material released over 10,000 years. The cumulative release limits are based on EPA's population impact goal of 1,000 premature cancer deaths worldwide for a 100,000-metric tonne (MTHM) repository.

6.2.2.3 Occupational Dose

The annual occupational dose attributable to all phases of the fuel cycle for the model 1000-MW(e) LWR is about 600 man-rem.

6.2.2.4 Transportation

The transportation dose to workers and the public totals about 25 man-rem/RRY.

6.2.2.5 Fuel Cycle

The NRC staff analysis of the uranium fuel cycle did not depend on the selected fuel cycle (no recycle or uranium-only recycle) because the data provided in Table S-3 include maximum recycle-option impact for each element of the fuel cycle, and therefore the environmental impacts of the fuel cycle are not affected by the specific fuel cycle selected.

6.2.2.6 Land Use Impacts

The total annual land requirement for the fuel cycle supporting a model 1000-MW(e) LWR is about 46 ha (113 acres). About 5.3 ha (13 acres) are permanently committed, and 41 ha (100 acres) are temporarily committed. (A "temporary" land commitment is a commitment for the life of the specific fuel-cycle plant; e.g., mill, enrichment plant, or succeeding plants. On abandonment or decommissioning, such land can be used for any purpose. "Permanent" commitments represent land that may not be released for use after permanent storage, plant shutdown, and/or decommissioning.) Of the 41 ha per year of temporarily committed land, 32 ha (79 acres) are undisturbed and 9 ha (22 acres) are disturbed. Considering common classes of land use in the United States, fuel-cycle land-use requirements to support the model 1000-MW(e) LWR do not represent a significant impact. As a comparison, a coal-fired power plant of 1000-MW(e) capacity using strip-mined coal requires the disturbance of about 81 ha (200 acres) per year for fuel alone.

6.2.2.7 Water Use Impacts

The principal water-use requirement for the fuel cycle supporting a model 1000-

MW(e) LWR is that required to remove waste heat from the power stations supplying electrical energy to the enrichment step of this cycle. Of the total annual requirement of 43 × 10^6 m^3 (11.4 × 10^9 gal), about 42 × 10^6 m^3 (11.1 × 10^9 gal) are required for this purpose, assuming that these plants use once-through cooling. Other water uses involve the discharge to air (e.g., evaporation losses in process cooling) of about 0.6 × 10^6 m^3 (160 × 10^6 gal) per year and water discharged to ground (e.g., mine drainage) of about 0.5 × 10^6 m^3 (130 × 10^6 gal) per year.

On a thermal-effluent basis, annual discharges from the nuclear fuel cycle are about 4 percent of those from the model 1000-MW(e) LWR using once-through cooling. The consumptive water use of 0.6 × 10^6 m^3/year is about 2 percent of that from the model 1000-MW(e) LWR using cooling towers. The maximum consumptive water use (assuming that all plants supplying electrical energy to the nuclear fuel cycle used cooling towers) would be about 6 percent of that of the model 1000-MW(e) LWR using cooling towers. Under this condition, thermal effluents would be negligible. The staff finds that these combinations of thermal loadings and water consumption are acceptable relative to the water use and thermal discharges.

6.2.2.8 Fossil Fuel Impacts

Electrical energy and process heat are required during various phases of the fuel-cycle process. The electrical energy is usually produced by the combustion of fossil fuel at conventional power plants. Electrical energy associated with the fuel cycle represents about 5 percent of the annual electrical power production of the model 1000-MW(e) LWR. Process heat is generated primarily by the combustion of natural gas. This gas consumption, if used to generate electricity, would be less than 0.4 percent of the electrical output from the model plant. The staff finds that the direct and indirect consumptions of electrical energy for fuel-cycle operations are small and acceptable.

6.2.2.9 Chemical Effluents

The quantities of chemical, gaseous, and particulate effluents associated with fuel-cycle processes are given in Table S-3. The principal species are sulfur oxides, nitrogen oxides, and particulates. Judging from data in a Council on Environmental Quality report (seventh annual report), these emissions constitute an extremely small additional atmospheric loading in comparison with these emissions from the stationary fuel-combustion and transportation sectors in the United States (i.e., about 0.02 percent of the annual national releases for each of these species). These emissions can also be compared with those from coal-fired generation of electricity. As an example, one paper reported that in comparison with a coal-fired power plant of the same size with abatement system, a 1300-MW(e) nuclear power plant eliminates annually emission to the air of about 2,000 tons of particulates, 8.5 million tons of CO_2, 12,000 tons of SO_x, and 6,000 tons of NO_x. (Souza and Bennett 1989). The staff believes that such small increases in releases from the nuclear fuel cycle of these pollutants are acceptable.

Impacts from the chemical and physical properties of the materials handled by fuel-cycle licensees can also occur. For example, on January 4, 1986, an overfilled cylinder containing UF_6 ruptured while it was being heated in a steam chest at the Sequoyah

Fuels Conversion Facility near Gore, Oklahoma (NUREG-1179). One worker died because he inhaled hydrogen fluoride fumes, a reaction product of UF_6 and airborne moisture. Several other workers were injured, but none seriously, and there was on-site and off-site contamination with hydrogen fluoride and uranyl fluoride, a second reaction product.

Liquid chemical effluents produced in fuel-cycle processes are related to fuel enrichment, fabrication, and reprocessing operations and may be released to receiving waters. These effluents are usually present in dilute concentrations such that only small amounts of dilution water are required to reach levels of concentration that are within established standards. The flow of dilution water required for specific constituents is specified in Table S-3. Additionally, all liquid discharges into the navigable waters of the United States from plants associated with the fuel-cycle operations will be subject to requirements and limitations set forth in the NPDES permit. Tailings solutions and solids are generated during the milling process. Based on Table S-3, these solutions and solids are not released in quantities sufficient to have a significant impact on the environment.

6.2.3 Sensitivity to Recent Changes in the Fuel Cycle

The values given in Tables S-3 (10 CFR 51.51) and S-4 (10 CFR 51.52) were calculated from industry averages for the performance of each type of facility or operation within the fuel cycle. Recognizing that this approach meant that there would be a range of reasonable values for each estimate, the staff followed the policy of choosing the assumptions or picking the factors to be applied so that the calculated values would not be underestimated. This approach was intended to ensure that the actual environmental impacts would be less than the quantities shown in Tables S-3 and S-4 for all nuclear power plants within the widest range of operating conditions.

This discussion on the sensitivity of the estimates to changes in assumptions or factors used by the staff in making the environmental impact analyses is provided below in examples to show the degree of conservatism used in developing estimates and thus to give an indication of the uncertainty of the estimates when they are applied to a particular nuclear power plant or to the plant's operations within the applicable regulations. The methodology was deliberately constructed to estimate impacts closer to the upper bound than to the mathematical average or median. Considering this approach, one can judge that the level of precision in the estimates is about 10% at best, probably no more than single-significant-digit accuracy in most cases. For this reason, and to simplify the presentation, many subtle fuel-cycle parameters and interactions were recognized by the staff as being less than the precision of the estimates and were ignored or mentioned briefly to show that they were considered but had no effect on the Table S-3 and S-4 calculations. The following example shows the conservatism of Tables S-3 and S-4 with respect to impacts on the environment.

To determine the quantity of fuel required for a year's operation of a nuclear power plant, the staff defined the model reactor as a 1000-MW(e) light-water-cooled reactor operating at 80 percent capacity with a 12-month fuel reloading cycle and an average fuel burnup of 33,000 MWd/MTU. This is a reactor reference year (RRY). The sum of the initial fuel loading plus all of the reloads for the lifetime of the reactor can be divided by the now assumed 60-year (40-year initial license term and 20-year renewal license term) lifetime to obtain an average annual fuel requirement. This was done for both boiling-water reactors (BWRs) and pressurized-water reactors (PWRs), and the higher annual requirement, 35 metric tonnes (MT) of uranium made into fuel for a BWR, was chosen as the basis for the RRY. Since the original estimates in 1979 were made for Table S-3, a number of fuel management improvements have been adopted by nuclear power plants to achieve higher performance and to reduce fuel and separative work (enrichment) requirements. These improvements reduce the annual fuel requirement by 10 to 15 percent. Further, the average plant capacity factor achieved by reactors operating in the United States has been below the assumed 80 percent capacity factor in every reporting period to date, meaning that the consumption of fuel has been below estimated amounts. Some more recent studies have assumed average capacity factors of 70 to 75 percent, indicating a reduction of 6 to 12 percent in annual fuel consumption.

Today's once-through fuel cycle could be expected to require 15 to 20% more uranium from mining and milling to compensate for no recovery and recycle of uranium from spent fuel. However, this increase in requirements is assumed to be offset by the decreases from improved fuel management and the lower average operating capacity factor; and the average fuel requirement for 1 RRY is still estimated to be 182 MT of U_3O_8 (35 MTU), as it was in WASH-1248. However, there has been another change of even greater significance in the elimination of U.S. restrictions on importation of foreign uranium. The economic conditions of the uranium market now and in the foreseeable future favor full utilization of foreign uranium at the expense of the domestic uranium industry. These market conditions have forced the closing of most U.S. uranium mines and mills, substantially reducing the environmental impacts in the U.S. from these activities. However, the Table S-3 estimates have not been reduced accordingly to ensure that these impacts, which have been experienced in the past and may be fully experienced again in the future, are considered. This fact suggests that the environmental impacts of mining and milling could drop to levels far below those given in Table S-3.

In a somewhat similar situation, the Table S-3 estimates for enrichment are based on the gaseous diffusion process, which has been used in the United States since the earliest days of the nuclear power program. In this process, there can be significant changes in uranium feed requirements as a result of changes in the quantity of ^{235}U left in the process tails. The range of tails assay is generally from 0.16 to 0.30 wt-percent ^{235}U, and the value assumed in making Table S-3 estimates is 0.25 percent. If the value of 0.16 percent had been chosen, 16 percent less uranium feed would be required, and environmental impacts (except those associated with enrichment) would be correspondingly lower. At 0.30 percent tails, uranium requirements would increase by 11 percent and environmental impacts would be higher. Far greater potential changes would come from the use of enrichment services from overseas or from the use of centrifuge technology for enrichment in the United States. The largest impacts of the gaseous diffusion process are attributable to the large requirement for electric energy to run the plant (especially to the assumption that the electricity will come from coal-fired power plants) and to the large amount of cooling water used in the gaseous diffusion process equipment. The centrifuge process uses 90 percent less electrical energy and therefore would have far lower impacts attributable to coal-fired power plants and the use of cooling water. Clearly, when overseas enrichment services are utilized, domestic impacts from U.S. enrichment plants would drop nearly to zero. These potential reductions are not reflected in Table S-3 estimates. Because there are currently no centrifuge enrichment plants in the United States, this potential reduction is not reflected. However, there is an application pending with the NRC to construct such a plant in the U.S. The assumption of continued use of United States diffusion enrichment services ensures that environmental impacts are not underestimated.

It may be noted that the recycling of uranium in spent fuel would have only minor effects on enrichment because the recycled uranium has about the same ^{235}U assay as fresh natural uranium and would thus require about the same amount of enrichment. There is an increase in the concentration of the ^{236}U isotope in recycled uranium. This acts as a "poison" in the nuclear fuel, requiring more ^{235}U to overcome it. Each kilogram of ^{236}U that is present in the recycled fuel requires an additional 0.3 kg of ^{235}U to compensate for it. In total, the few kilograms of ^{236}U in the fuel cause increases of about 2 to 4 percent in the enrichment impacts.

There is only one U.S. plant currently converting uranium oxide product from the mills to UF_6 feed for the enrichment plant. The UF_6 conversion plant uses a "dry" process using gaseous reagents. Formerly, a "wet" process that starts with dissolving the yellow cake in nitric acid and purifying it by solvent extraction was also used. In the "dry" process, final purification is accomplished by fractional distillation of the UF_6; impurities are eliminated as volatile compounds or as solid wastes. In the "wet" process, many impurities are eliminated in the aqueous phase from solvent extraction. In both cases, environmental releases are so small that changing from 100 percent use of one process to 100 percent use of the other would make no significant difference in the totals given in Table S-3 or S-4. The assumption that half is processed by each method does not contribute significantly to the error band of the totals.

In the fuel fabrication plants, it has been assumed that the UF_6 from enrichment will be converted to UO_2 by the ammonium diuranate "wet" process. An alternative "dry" process for direct conversion of UF_6 to UO_2 powder is being introduced as obsolete facilities are replaced or as new capacity is added. This change reduces environmental impacts, but the impacts from fuel fabrication are so small that the changes are not significant.

Factors related to reactor operation can have a significant effect on the fuel cycle. The original Tables S-3 and S-4 were based on a 12-month fuel reloading cycle. Current practice favors an 18-month cycle although in certain circumstances, the original 12-month cycle or a longer 24-month cycle might be favored. Parametric studies show that producing the higher enrichment fuel needed for higher burnup requires an increase of about 5 percent in the natural uranium feed stream for each 6-month extension of the reload interval. Similarly, enrichment impacts increase by about 5 percent with each 6-month extension of the reload cycle. However, the higher burnup of fuel achieved in the longer reload cycles reduces the average annual output of spent fuel by as much as 45 percent.

The values shown in Tables S-3 and S-4 of 10 CFR Part 51 are conservative estimates originally developed on the basis of an average fuel irradiation (burnup) of 33,000 MWd/MTU. Discussions and analyses in NUREG/CR-5009 (PNL-6258), *Assessment of the Use of Extended Burnup Fuel in Light Water Power Reactors*, February 1988, show that the burnup level of fuel up to 60,000 MWd/MTU will not result in environmental impacts that are greater than the values currently in Tables S-3 and S-4, and, in many instances, are less (for example, see Table S.1 on p. viii of NUREG/CR-5009). Thus no revision to these tables would be required as a result of extended fuel burnup up to 60,000 MWd/MTU. Experience in handling fuel with burnups over 55,000 MWd/MTU and up to 5.5 percent ^{235}U enrichment has not revealed any unresolved safety concerns (NUREG/CR-5009 p. 1-7).

The reduction in the annual output of spent fuel at high burnup would correspondingly reduce the environmental impacts associated with transportation of spent fuel, with reprocessing, and with waste disposal on or off site. There would also be a decrease in occupational exposure to radiation because of the reduction in processing and handling requirements. Population radiation doses would be lower because of the reduced number of shipments per year.

There are other significant changes that would apply to reprocessing if fuel recycle were to be undertaken in the United States in the future. Estimates for reprocessing impacts were based on the Barnwell and Exxon reprocessing plant designs of the 1970s. The radioisotope release fractions used in the 1976 report (NUREG-0116) are now considered to be conservative by at least two orders of magnitude in comparison to current design values. Also, the original Table S-3 assumption that 100 percent of the volatile radioisotopes and compounds would be released is no longer valid. EPA regulations in 40 CFR Part 190 require that, after 1983, releases of ^{85}Kr and ^{129}I be limited to 50,000 Ci/GW-year and 5 mCi/GW-year, respectively. Because the model reactor that is the basis for Tables S-3 and S-4 values produces 0.8 GW-years of electricity, the EPA limits translate to 40,000 Ci/RRY and 4 mCi/RRY, respectively. Because plants will not be permitted to operate in violation of the EPA requirements, the current Table S-3 values are even more conservative, taking into account compliance with the new EPA requirements. A further EPA requirement is that releases of alpha-emitting transuranic elements with half-lives longer than 1 year must be limited to 0.5 mCi/GW-year, or 0.4 mCi/RRY. This limit for transuranic elements required no change in the Table S-3 estimate, which was already well below the new standard.

Another conservatism in the NUREG-0116 estimates for Table S-3 is an assumption of a cooling time of 160 d between the discharge of spent fuel from the reactor and the reprocessing of the fuel. This 160-d cooling period was based on the optimum for recycling plutonium as well as uranium. With the recycling of uranium only or with the present once-through mode of operation, there is no incentive to keep the cooling time short, and, indeed, virtually all spent fuel in storage today has been cooling for years. In comparison to 160-d-old spent fuel, fuel that has been cooled 1 year or more would have its radioactivity reduced by at least 50 percent and its radioactive decay heat emission similarly reduced. The effect of cooling for 5 years or more on site, the age range of most spent fuel today, is to reduce the radioactivity and the decay heat by more than 90 percent; therefore certain radioisotope inventory may be as low as 10 percent of the amount shown in Table S-3, in which case dose commitments and potential health effects calculated for Table S-3 releases would be overestimated.

One effect of going to higher fuel burnup is to increase the formation of transuranic elements, with the result that spontaneous neutron emission from transuranic elements becomes an important shielding consideration along with shielding for the gamma radiation. This fact has potential effects on the transportation of spent fuel. At the time of discharge from the reactor, the radioactivity and decay heat of high-burnup fuel may be up to 25 percent higher at 60,000 MWd/MTU, but this increase diminishes as the cooling time is lengthened. The emission of neutrons also decreases with longer cooling. Gamma radiation is shielded with lead or other dense materials, while neutrons are best shielded by water and neutron-absorbing materials such as boron or cadmium. It has been shown that present spent fuel transportation casks can be made safe for high-burnup fuel by adding boron to the cooling water in the casks. Longer cooling times would increase the margin of safety. With the large inventory of spent fuel that has accumulated, the age of any spent fuel that is reprocessed or transported to a repository is likely to be many years. At the conclusion of the hearings on reprocessing and waste management (Dockets 50-277, 50-278, 50-320, 50-354, and 50-355, Consolidated Hearing on Radon Before the Appeal Board), the Hearing Board concluded that 5 years would be a reasonable value to use in making estimates. The scenario that is visualized today for emplacement of spent fuel and high-level waste in a geologic repository calls for this final disposal to occur after the spent fuel or waste is at least 10 or more years old. Longer cooling times on site reduce the impact on the environment and increase the margin of safety once the fuel is being transported.

The NRC regulations for geologic disposal of high-level radioactive waste (10 CFR Part 60) limit the releases of radioactive material to the accessible environment. In addition to satisfying an overall performance objective to be established by the EPA, the basic requirements are that there should be no leakage from the waste packages in the first 300 to 1,000 years and that the annual releases from the engineered barrier system thereafter should not exceed one part in 100,000 of the total inventory of each radionuclide calculated to be present 1,000 years following permanent closure of the repository. These values are conservative because no credit is taken for chemical or physical retardation and for additional decay of radionuclides during transport through groundwater within the controlled zone prior to release to the accessible environment. In summary, the discussion above shows that the Table S-3 estimates of environmental impacts are higher than the actual impacts would be under any foreseeable combination of reactor and fuel cycle operating conditions, including higher fuel burnup, and any future license renewal activities. One of the greatest changes would come from the use of foreign uranium and foreign enrichment services, which could easily reduce U.S. environmental impacts from the front end of the fuel cycle by factors of 10 to 100. Significant uncertainties are also associated with the estimates of environmental releases from high-level waste handling, storage, and disposal. Lacking knowledge of the actual operation of the facilities that will be licensed or relicensed in the future, the staff has estimated that releases will be at the maximum levels permitted by NRC and EPA regulations for releases from the engineered barriers to repository groundwater, whereas some engineering tests indicate that it may be possible to keep releases to much lower levels. The Table S-3 estimates could easily be high under any regulated change in operating, handling or storage conditions of high-level waste; they are not likely to be low.

6.2.4 Conclusions

The radiological and nonradiological environmental impacts of the uranium fuel cycle have been reviewed. The review included a discussion of the values presented in Table S-3, an assessment of the release and impact of ^{222}Rn and of ^{99}Tc, and a review of the regulatory standards and experience of fuel cycle facilities. Although the radiological release values presented in Table S-3 and in the discussion of ^{222}Rn and ^{99}Tc were intended to be within regulatory limits (except for ^{85}Kr and ^{129}I), not attempt was made to use realistic assumptions that would reflect the success of ALARA programs and the history of releases and doses generally being well under regulatory requirements. For assessing the radiological impacts of license renewal, the Commission has indicated that impacts are of small significance if doses and releases do not exceed permissible levels in the Commission's regulations.

The radiological impacts of the uranium fuel cycle on individuals off site have been considered within the framework of Table S-3 and supplemental analyses of ^{222}Rn and ^{99}Tc. Given the available information applicable regulatory requirements, the Commission has concluded that, other than for the disposal of spent fuel and high-level waste, these impacts on individuals from radioactive gaseous and liquid releases will remain at or below the Commission's regulatory limits. Accordingly, the Commission concludes that off-site radiological impacts of the fuel cycle (individual effects from other than the disposal of spent fuel and high-level waste) are small. ALARA efforts will continue to apply to fuel-cycle activities. This is a Category 1 issue.

The radiological impacts of the uranium fuel cycle on human populations over time (collective effects) have been considered within the framework of Table S-3. The 100-year environmental dose commitment to the U.S. population from the fuel cycle, except for high-level waste and spent-fuel disposal, is calculated to be about 14,800 person-rem, or 12 cancer fatalities, for each additional 20-year power reactor operating term. Much of this, especially the contribution of radon releases from mines and tailing piles, consists of tiny doses summed over large populations. This same dose calculation can theoretically be extended to include many tiny doses over additional thousands of years as well as doses outside the U.S. The result of such a calculation would be thousands of cancer fatalities from the fuel cycle, but this result assumes that even tiny doses have some statistical adverse health effect that will not ever be mitigated (for example no cancer cure in the next thousand years) and that these dose projection over thousands of years are meaningful. However, these assumptions are questionable. In particular, science cannot rule out the possibility that there will be no cancer fatalities from these tiny doses. For perspective, the doses are very small fractions of regulatory limits, and even smaller fractions of natural background exposure to the same populations. No standards exist that can be used to reach a conclusion as to the significance of the magnitude of the collective radiological effects. Nevertheless, some judgment as to the regulatory NEPA implication of this issue should be made, and it makes no sense to repeat the same judgment in every case. The Commission concludes that these impacts are acceptable in that these impacts would not be sufficiently large to require the NEPA conclusion, for any plant, that the option of extended operation under 10 CFR 54 should be eliminated. Accordingly, while the Commission has not assigned a single level of significance for the collective effects of the fuel cycle, this issue is considered Category 1.

The impacts associated with the high-level-waste and spent-fuel disposal component of the fuel cycle also involve a level of uncertainty. There are no current regulatory limits for off-site releases of radionuclides for the current candidate repository site. However, if we assume that limits are developed along the lines of the 1995 National Academy of Sciences report and that, in accordance with the Commission's Waste Confidence Decision, a repository can and likely will be developed at some site that will comply with such limits, peak doses to virtually all individuals will be 100 mrem/year or less. However, while the Commission has reasonable confidence that these assumptions will prove correct, there is considerable uncertainty because the limits are yet to be developed and no repository application has been completed or reviewed. In addition, uncertainty is inherent in the models used to evaluate possible pathways to the human environment. The National Academy report indicated that 100 mrem/year should be considered as a starting point for limits for individual doses, but notes that some measure of consensus exists among national and international bodies that the limits should be a fraction of the 100 mrem/year. The lifetime individual risk from 100 mrem/year dose limit is about 3×10^{-3}. Doses to populations from disposal cannot now (or possibly ever) be estimated without very great uncertainty.

Estimating cumulative doses for high-level-waste and spent-fuel disposal to populations over thousands of years is more problematic. The likelihood and consequences of events that could seriously compromise the integrity of a deep geologic repository were evaluated by the Department of Energy in the *Final Environmental Impact Statement: Management of Commercially Generated Radioactive Waste*, October 1980. The evaluation estimated the 70-year whole-body dose commitment to the maximum individual and to the regional population resulting from several modes of breaching a reference repository in the year of closure, after 1,000 years, after 100,000 years, and after 100,000,000 years. The release scenarios covered a wide range of consequences from the limited consequence of humans accidentally drilling into a waste package in the repository to the catastrophic release of the repository inventory by a direct meteor strike. Subsequently, the NRC and other federal agencies have expended considerable effort to develop models for the design and for the licensing of a high-level-waste repository, especially for the candidate repository at Yucca Mountain. More meaningful estimates of doses to population may be possible in the future as more is understood about the performance of the proposed Yucca Mountain repository. Such estimates would involve very great uncertainty, especially with respect to cumulative population doses over thousand of years. The standard proposed by the NAS is a limit on maximum individual dose. The relationship of potential new regulatory requirements, based on the NAS report, and cumulative population impacts has not been determined, although the report articulates the view that protection of individuals will adequately protect the population for a repository at Yucca Mountain. However, EPA's generic repository standards in 40 CFR 191 generally provide an indication of the order of magnitude of cumulative risk to population that could result from the licensing of a Yucca Mountain repository, assuming the ultimate standards will be within the range of standards now under consideration. The standards in 40 CFR 191 provide for the protection of the population by imposing "containment requirements" that limit the cumulative amount of radioactive material released over 10,000 years. The cumulative release limits are based on EPA's population impact goal of 1,000 premature cancer deaths worldwide for a 100,000-metric tonne (MTHM) repository.

Despite all the uncertainty surrounding the effects of the disposal of spent fuel and high-level waste, some judgment as to the regulatory NEPA implications of these matters should be made, and it makes no sense to repeat the same judgment in every case. Even taking the uncertainties into account, the Commission concludes that these impacts are acceptable in that these impacts would not be sufficiently large to require the NEPA conclusion, for any plant, that the option of extended operation under 10 CFR 54 should be eliminated. Accordingly, while the Commission has not assigned a single level of significance for the impacts of spent-fuel and high-level-waste disposal, this issue is considered Category 1.

Data on the nonradiological impacts of the fuel cycle are provided in Table S-3. These data have not been adjusted for the permanent disposal of high-level waste and spent fuel at the candidate site at Yucca Mountain. However, any changes in the data specific to Yucca Mountain would be minor. The nonradiological environmental impacts from any resource use or effluent datum specified in Table S-3 are assumed to be proportional to the magnitude of the datum. The standard of significance of the environmental impacts associated with Table S-3 is based on one of several relative comparisons.

Land requirements are compared to those for a coal-fired power plant that may be assumed to replace the nuclear capacity if the operating license is not renewed. The LWR fuel cycle requires only 10 percent of the temporarily committed land and 9.5 percent of the permanently committed land that would be required by replacement with coal-fired capacity. A conclusion on the relative land use impact between nuclear and coal should take into consideration differences in the quality and the opportunity cost of the land involved in each fuel cycle. If the quality and opportunity cost of the land were equivalent, then it would be reasonable to say that land requirements for the uranium fuel cycle (at 20 to 30 percent of those for the coal fuel cycle) are relatively small. If much of the land involved in the uranium fuel cycle is of lower quality and has a lower opportunity cost than does the land used in the coal fuel cycle, then the land has relatively lower value, and land requirements could be considered small for relative requirements beyond 30 percent. If these postulates are accepted, then the land requirements of about 10 percent given in Table S-3 are clearly small.

Water requirements for the uranium fuel cycle are compared to the annual requirements for an LWR. The amount of water withdrawn from surface and ground water and discharged to air by activities within the fuel cycle represents only 2 percent of the annual discharges to air of an LWR with cooling towers. The fuel cycle discharges are spread among facilities involved in the various stages of the fuel cycle; thus the water discharge to air from any one of these facilities will be less than the 2 percent. The environmental impacts of water withdrawal, use, and discharge from LWRs with cooling towers is reviewed in Chapter 3, and these discharges are found to have only small, or in special but unusual circumstances moderate, environmental impacts. Given that the water discharged to the air from other fuel cycle facilities for a RRY is only a small fraction of the discharge from an LWR, the environmental consequences will be even smaller. The amount of water withdrawn from surface and ground water and discharged to water bodies and to the ground represents only 4 percent of the annual discharges to water bodies and the ground of an LWR with once-through cooling. The fuel cycle discharges are spread among facilities involved in the various stages of the fuel cycle; thus the water discharges from any one of these facilities will be less than the 2 percent. The environmental impacts of water withdrawal and discharge from LWRs with once-through cooling is reviewed in Chapter 3, and these discharges are found to have small environmental impacts. Given that the water discharged to water bodies and to the ground from other fuel cycle facilities for an RRY is only a small fraction of the discharge from an LWR, the environmental consequences will be even smaller.

The fossil fuel (coal and natural gas) consumed to produce electrical energy and process heat during the various phases of the uranium fuel cycle results in a considerable net saving in the use of resources and chemical effluents over the use that would occur if the electrical output from the LWR were supplied by a coal-fired plant. The use of coal and natural gas in the uranium fuel cycle allows the production of electricity with nuclear fuel, which results in a substantial reduction in the requirements for coal and natural gas as fuels to produce electricity. Not only are the fossil fuel requirements small per RRY; there is a net saving in the use of fossil fuel compared to replacing the nuclear-generating capacity with coal-fired capacity.

The gaseous effluents SO_x, NO_x, hydrocarbons, CO, and particulates listed in Table S-3 are the consequence of the coal-fired electrical energy used in the uranium fuel cycle. The volume of effluent is equivalent to that of a quite small [45-MW(e)] coal-fired plant; thus the contribution to the degradation of air quality is small. The generation of electricity with nuclear rather than coal-fired power will result in a net improvement in air quality. For these reasons the impact of these effluents is considered small. Gaseous releases of fluorine and hydrogen chloride are at concentrations below state standards and below levels that impact human health. The impact of these effluents is small.

The liquid effluents listed in Table S-3 are present in dilute concentrations and are readily dilutable to meet effluent standards such that environmental impacts are negligible. The impacts from these liquid effluents are considered small.

Tailings solutions and solids generated during the milling process are not released in quantities sufficient to have a significant impact on the environment. Their impact on the environment is considered small.

The aggregate nonradiological impact of the uranium fuel cycle resulting from the renewal of an operating license for any plant is found to be small. License renewal of an individual plant is so indirectly connected to the operation of fuel-cycle facilities that it is meaningless to address the mitigation of the impacts identified above. This is a Category 1 issue.

6.3 TRANSPORTATION

6.3.1 Introduction

This section addresses both the radiological and nonradiological environmental impacts resulting from shipments of low-level radioactive waste (LLW) and mixed waste to off-site disposal facilities and of spent fuel to a monitored retrievable storage (MRS) or permanent repository. The nonradiological impacts are traffic density, weight of the loaded truck or railcar, heat from the fuel cask, and transportation accidents. The radiological impacts include possible exposures of transport workers and the general public along transportation routes. Radiation exposure to these groups also may occur through accidents along transportation corridors. Generic values for the environmental effects of transporting fuel and waste to and from reactors are provided in Table S-4.

Table S-4 "Environmental impact of transportation of fuel and waste to and from one light-water-cooled nuclear power reactor," is a summary impact statement concerning transportation of fuel and radioactive wastes to and from a reactor. The table is divided into two categories of environmental considerations: (1) normal conditions of transport and (2) accidents in transport. The normal conditions of transport consideration are further divided into environmental impact, exposed population, and range of doses to exposed individuals per reactor reference year. The "accidents in transport" consideration is concerned with environmental risk. Under "normal conditions of transport," the environmental impacts of the heat of the fuel cask in transit, weight, and traffic density are described. Also the number and range of radioactive doses of the transportation workers and of the general public are described. Under "accidents in transport," the environmental risk of radiological effect and common nonradiological causes such as fatal and nonfatal injuries and property damage are described. To indicate that Table S-4 adequately describes the environmental effects of the transportation of fuel and waste to and from the reactor, the reactor licensee must state that the reactor and this transportation either meet all of the conditions in paragraph (a) of 10 CFR 51.52 or all of the conditions in paragraph (b) of 10 CFR 51.52. Subparagraphs 10 CFR 51.52(a)(1) through (5) delineate specific conditions the reactor must meet to use Table S-4 as part of its environmental report. Subparagraph 10 CFR 51.52(a)(6) states, "The environmental impacts of transportation of fuel and waste to and from the reactor, with respect to normal conditions of transport and possible accidents in transport, are as set forth in Summary Table S-4 in paragraph (c) of this section; and the values in the table represent the contribution of the transportation to the environmental costs of licensing the reactor." Paragraph 10 CFR 51.52(b) states that reactors not meeting the conditions of 10 CFR 51.52(a) shall make a full description and detailed analysis for their reactor equivalent to Table S-4. Because the reactor must continuously meet the conditions of 10 CFR 51.52(a) to use Table S-4 in its environmental statement or make a full description and detailed analysis for their reactor equivalent to Table S-4, the conditions requiring the use of Table S-4 or its equivalent as an environmental transportation statement are continuously reviewed and therefore will be the same in the relicensing period as in the initial licensing period. Rail and truck transport corridors should safely accommodate increased shipments of radioactive waste associated with license renewal. The radiological and nonradiological environmental impacts of transportation of fuel and waste from an LWR are shown to be small.

To address the impacts from transportation of LLW associated with license renewal, the additional volumes of LLW from refurbishments related to license renewal, as well as from an additional 20 years of normal operations, have been compared with baseline information on current volumes of LLW that are shipped from nuclear power plants to licensed disposal facilities. In the case of mixed waste that is currently stored on site, the amount of waste that is likely to require off-site disposal when an off-site disposal facility becomes available is considered. Finally, in the case of spent fuel from nuclear power plants, estimates have been made of the additional amount of spent fuel that will be generated, assuming that all currently operating reactors continue to operate and store-spent fuel on site until a spent-fuel repository (or MRS) is made available, which probably will not occur before 2010 (DOE/RW-0006).

6.3.2 Table S-4—Environmental Impact of Transportation of Fuel and Waste to and from One Light-Water-Cooled Nuclear Power Reactor

6.3.2.1 Low-Level Waste

The volume of LLW disposed of annually (at licensed disposal facilities) from nuclear power plants varies by type of reactor. In 1987, the average PWR disposed of approximately 8,800 ft^3/year (250 m^3/year), while the average BWR disposed of about 19,700 ft^3/year (558 m^3/year). These volumes were disposed of through approximately 35 annual shipments from PWRs and 59 annual shipments from BWRs (EPRI NP-5983).

The majority of routine LLW transported from plants is made up of Class A wastes such as contaminated trash and other compacted material packaged in 55-gal drums. Normally, these drums contain less than 20 Ci of radioactivity. A small percentage contain more than 100 Ci and are shipped as Class B waste. Accident data have been compiled since 1971 involving commercial LLW. During this time, only four transportation accidents for all categories of shippers have involved the release of commercial LLW. None of these accidents involved serious injuries or fatalities attributable to the radioactive content of the shipments (Garcia 1992).

As a result of environmental impact studies on waste transportation that were undertaken in the 1970s, measures to minimize occupational and population exposure from all forms of radiological waste have been widely implemented by the nuclear industry, including operational restrictions on transport vehicles, ambient radiation monitoring, special packaging requirements, imposition of licensing standards by NRC (which ensure proper waste certification by testing and analyzing packages), changes in waste form to minimize the release of radioactivity in transit (such as cementing or solidifying liquid wastes), and training of emergency personnel to respond to mishaps (NUREG-0170; Levin 1981; ORNL/TM-9780/V3; DOE 1989). In accordance with licensing requirements and international standards, protection against worker and population exposure is provided principally by the waste packaging (NUREG-0170; O'Sullivan 1988).

In regard to footnote d of Table S-4, although the environmental risk of radiological effects stemming from a transportation accident has not been numerically quantified, the study *Shipping Container Response to Severe Highway and Railway Accidents* (NUREG/CR-4829) confirms that the radiological risk of transportation accidents is small. NUREG/CR-4829 is summarized in NUREG/BR-0111, in which the study results are compared with a 1977 study (NUREG-0170). The 1977 study evaluated the risk for all radioactive material shipments, including spent fuel. The evaluations indicated a radiological risk from transportation accidents of one latent cancer fatality every 59 years for all projected 1985 radioactive material shipments. Most of this risk was associated with shipments of medical radioisotopes. The contribution from spent fuel shipments was 2.5 percent of this estimate. The 1987 study included a more detailed approach to the calculation of radiological hazards and concluded that the hazard from spent fuel shipments is less than one-third of that estimated in the 1977 study.

6.3.2.2 Mixed Waste

Mixed waste from reactors accounts for only a small percentage of annual LLW generation. Only very limited off-site disposal facilities for mixed waste have been available since 1985 (NUREG/CR-5938). Utilities are finding ways to treat some of their mixed waste so that it is no longer hazardous, thus making it possible to dispose of the radioactive component along with other LLW (NUREG/CR-5938). The remainder of mixed waste, however, is currently stored on site.

6.3.2.3 Spent Fuel

The only spent-fuel shipments from nuclear power plants have been from one plant to another or to Department of Energy (DOE) facilities or fuel reprocessing plants. Table S.4 Rule (54 FR 187; 10 CFR 51.52) reflects the state and federal restrictions that trucks used to ship spent fuel are limited to 73,000 lb of capacity, while rail cars are limited to 100 tons/cask/car. Also, under Table S-4, each reactor is expected to make less than one shipment per day by truck and fewer than three per month by rail.

A concern in spent-fuel shipment is the risk of theft or sabotage leading to a release that could pose a major risk of occupational and population exposure and to the environment. Spent-fuel shipments, however, have proven to be unattractive targets for theft or sabotage. Shipping casks are designed to withstand severe transportation accidents and are resistant to small-arms fire and high-explosive detonation (NUREG-0170; DOE/RW-0065).

States and communities along transportation corridors may impose additional restrictions on the transport of nuclear waste. These restrictions, which are designed to protect health, safety, and the environment, are permitted if they afford an equal or greater level of protection, do not cause undue burdens on commerce, and do not discriminate against particular transporters (Pub. L. 93-633; OTA-SET-304). There has been dramatic growth in local ordinances pertaining to special permitting, prenotification, centralized dispatching and communications, and vehicle manifesting (Anderson 1981; Smith 1982; ORNL/TM-9563).

6.3.3 Effects of License Renewal

During the license renewal period, LLW annual shipments from BWRs and PWRs are expected to show a temporary increase (Section 6.3) in the generally decreasing trend. During the 10-year refurbishment period for the conservative license-renewal scenario, the average annual LLW shipments could increase by 96 percent (for a total of 69 shipments) per PWR and 31 percent (for a total of 77 shipments) per BWR. The increase in waste shipments would be considerably less during the subsequent 20 years of operation. In either case, however, rail and truck transport corridors should easily accommodate the increase in waste shipments.

Within the study sample, Cook, Washington Nuclear Project 2 (WNP-2), San Onofre, Vermont Yankee, and Comanche Peak are under the jurisdiction of compacts and agreement states that do not anticipate additional regulations governing the shipment of LLW from reactors to licensed disposal sites. In the case of WNP-2, there is a relatively short distance between the plant and the Hanford site, the licensed LLW facility for the Northwest Compact. The same applies to San Onofre, which expects to ship LLW to a facility in Ward Valley (25 miles west of Needles), to be operated by U.S. Ecology (*Radioactive Exchange* 1989). Greater distances between plants and disposal facilities will complicate the establishment of a corridor-by-corridor management system because of the number of jurisdictions involved. Staff estimates that transportation distances for some plants to disposal facilities could be as much as 2000 miles. Mixed-waste shipments to a licensed disposal facility (when available) should continue to be a small percentage of total LLW volumes shipped for disposal.

The original analysis on which Table S-4 was based is the report NUREG-75/038, *Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants, Supplement 1*, published in April 1975. This report assumed transportation distances for spent fuel and high-level wastes to be less than 1000 miles for almost all reactors except those located in the far western states. Shipping distances for other packaged wastes were assumed to be even shorter. In accordance with the Nuclear Waste Policy Amendments Act of

1987 (Pub. L. 100-203, Title V, Subtitle A, 101 stat. 1330-227, December 22, 1987), a possible high-level waste repository is being characterized at Yucca Mountain in Nevada. Therefore, the reactors in the eastern half of the country will have shipping distances near 2000 miles for spent fuel and high level wastes. However, the environmental impacts of transportation are so small that even an increase by a factor of 10 would not significantly change the total environmental impacts of the whole fuel cycle. Therefore, the values in Table S-4 do not need to be updated, because the conservatism (see Section 6.2.3) built into these estimates ensures that the total fuel cycle environmental impacts per reactor are not underestimated. Table S-4 would bound the proposed renewal of licenses currently permitted under 10 CFR 2.109 and 50.51.

For spent fuel, DOE has decided that when a permanent repository or MRS becomes available, acceptance allocation priority will go to the oldest spent fuel, on an industry-wide basis (DOE/RW-0220). For purposes of estimation, DOE assumes that if a spent-fuel repository opened in 2003, total storage requirements from all utilities (based on the above-mentioned priority system) would range from 12,200 metric tons (from 83 reactors) to 20,000 metric tons (from 107 reactors) (DOE/RW-0220). Thus, total spent-fuel volume per reactor would range from 147 to 187 metric tons. Assuming that license renewal would, on average, increase spent-fuel generation per reactor by 50 percent, the incremental amount of spent fuel that would be added to this volume would range between 73 and 93 metric tons. This would further translate into an additional 2 to 3 days of shipments for each reactor's spent fuel under the conditions specified in Table S-4 (10 CFR 51.52). If disposal without license renewal would have required between 330 and 550 days for shipment of all spent fuel by truck to a repository, license renewal could require from 170 to 270 additional days for shipment for all relevant plants (DOE/RW-0220). Transportation distances could range up to 2000 miles.

The public radiation exposure and other potential transportation impacts resulting from radioactive waste transport have been addressed generically in Table S-4 (10 CFR 51). All dose projections in Table S-4 are presented on the basis of a reference reactor year, so estimates are dependent on neither the number of years of operation nor the particulars of operation. The doses are small, as are the potential health effects. If these impacts are increased by a factor of 2 (as would occur if waste shipments were doubled, as is approximately projected for PWR refurbishment waste), the impacts would remain small. If occupational doses for transportation workers were 8 man-rem for 200 workers, the average worker exposure of 0.04 rem/year would be only 1 percent of the occupational dose limit guidelines of 10 CFR Part 20. Individual members of the public are exposed to doses from transportation of waste far lower than the standards discussed previously in this document. The average dose received per reactor-year by members of the exposed population is estimated to be 0.0027 rem (3 rem/1100), which is far lower than the individual annual total dose standard of 0.1 rem in 10 CFR 20.1301. Assuming this exposed population received doses from transportation of waste for 20 years, the cumulative average dose would be 0.054 rem, still less than 0.1 rem. Using the risk factor of 5 cancer deaths per 10,000 rem, the risk of death from cancer by an average member of the exposed population would be 2.7 × 10^{-6}, which is also an acceptable risk under the EPA risk standard. The potential for adverse impacts from low-probability accidents is discussed in the previous section. Design refinements to LLW shipping containers and changes to transport systems will continue to occur during the license renewal period, which should result in even lower probability of accidents and lower releases. Changes to the latter will result from continued interaction with states, communities, and tribal nations in emergency preparedness, vehicle inspection, and manifesting on a corridor-by-corridor basis (Anderson 1981; ORNL/TM-9563; Smith 1982; EPRI NP-5933; Sprecher 1990).

6.3.4 Conclusion

The environmental impacts from the transportation of fuel and waste attributable to license renewal are found to be small when they are within the range of impact parameters identified in Table S-4. The estimated radiological effects are within regulatory standards. The nonradiological impacts are those from periodic shipments of fuel and waste by individual trucks or rail cars and thus would result in infrequent and localized minor contributions to traffic density. Programs designed to reduce risk further, which are already in place, provide for adequate mitigation. Table S-4 should continue to be the basis for case-by-case evaluations of transportation impacts of fuel and waste until such time as a detailed analysis of the environmental impacts of transportation to the proposed repository at Yucca Mountain becomes available. This issue is Category 2.

6.4 GENERATION AND STORAGE OF RADIOACTIVE WASTE DURING THE TERM OF THE RENEWED LICENSE

6.4.1 Introduction

The following discussion considers in greater detail the generation of radioactive waste at nuclear power plants during the term of a renewed operating license and the issues associated with the management of that waste. The discussion addresses LLW, including greater than Class C (GTCC) LLW; mixed waste; and spent fuel.

6.4.2 Low-level Waste

LLW is defined as radioactive waste not classified as high-level waste, transuranic waste, spent nuclear fuel, or byproduct material as defined in Section 11e.(2) of the Atomic Energy Act of 1954 as amended. LLW is classified as A, B, C or GTCC according to the half-lives and concentrations of key radionuclides. Detailed descriptions of these classes are given in 10 CFR 61. In general, requirements for waste form, stability, and disposal methods become more stringent when going from class A to GTCC.

In 1992 approximately 65 percent of the total volume of LLW in the United States was generated by non-utility sources, including academic, medical, industrial and government sectors; 35 percent was generated by nuclear power plants (de Planque 1994). However, percentages vary and have been closer to 50 percent. For example, in 1993, 51 percent was generated by utilities (NUREG-1350, Vol. 7); in 1990, 56 percent (NUREG-1350, Vol. 4); in 1989, 52 percent (NUREG-1350, Vol. 3). LLW from nuclear power plants ranges from trash suspected of being slightly contaminated to highly radioactive material such as activated structural components found within or in close proximity to the reactor. LLW includes reactor components, tools, spent demineralizer resins, evaporator concentrates, used filters, and miscellaneous contaminated wastes such as rags, mops, paper, and protective clothing.

Additional LLW will be generated by the license renewal of nuclear power plants requiring interim on-site storage. The following discussion focuses on how projected volumes of LLW generated could affect on-site storage requirements, particularly in light of state-to-state variations in the availability of LLW disposal facilities. In this regard, it is pertinent to note that when storage of LLW extends beyond the 5-year guideline established by the NRC, and perhaps in excess of SAR projected curie or volume limits, licensees may have to secure additional license authority under 10 CFR 30 and/or 10 CFR 50 (EPRI TR-100298). Although the demand for on-site interim storage for refurbishment waste and license renewal operations is an important issue, it is one that relates primarily to the uncertainties associated with additional license authority to store the increased activity of radioactive material. Of less concern is the potential for significant environmental impacts from the storage of radioactive material.

Off-site disposal issues relevant to license renewal are also discussed below; however, it is important to stress that these issues are framed in terms of how they could affect the need for on-site interim storage rather than in terms of potential environmental impacts associated with off-site disposal facilities. Operating licenses for disposal facilities ensure minimal impacts to disposal-site workers, adjacent workers, and the environment. Under 10 CFR 61, licensed LLW disposal facilities must protect the general population from release of radioactivity, protect workers, protect inadvertent intruders after institutional controls cease, and ensure disposal site stability.

6.4.3 LLW Baseline

The following section provides information on past and present volumes of LLW generated at nuclear power plants and current practices and trends in volume reduction (VR). Subsequent sections present information pertaining to on-site storage conditions and the status of off-site disposal facilities. This baseline information is used to frame potential issues associated with LLW generated from operations and refurbishments under current licenses as well as from operations and refurbishments for an additional 20 years.

6.4.3.1 LLW Waste Generation and Volume Reduction

The first step in assessing potential issues associated with LLW generation during both the initial license period and from extended operations is to determine primary trends in the production of LLW. These trends suggest both future on-site storage and off-site disposal requirements. In general, the following analysis shows that the production of LLW is on the decline and indicates that VR activities will continue to reduce the amount of waste requiring storage and disposal during the period of the initial license and beyond.

Specifically, Table 6.6 shows historic and projected routine LLW volumes and radioactivity for BWRs and PWRs through

Table 6.6 Historic and projected volume and radioactivity of routine compacted low-level radioactive waste shipped for disposal from boiling-water reactors and pressurized-water reactors: 1980–2020

End of calendar year	Volume (10^3 m^3)[a]		Radioactivity[b] (10^3 Ci)	
	Annual	Accumulated[c]	Annual	Accumulated[d]
	Boiling-water reactors			
1980	26.1	141	41	128
1981	23.0	164	42	144
1982	25.5	190	38	155
1983	22.6	212	56	183
1984	24.4	237	29	178
1985	23.1	260	28	177
1986	17.3	277	32	182
1987	14.3	292	28	183
1988	11.7	303	29	185
1989	14.2	317	32	190
1990	10.3	328	34	196
1991	15.6	343	53	221
1992	9.6	353	34	220
1993	9.5	362	34	223
1994	9.5	372	34	225
1995	9.5	381	34	228
1996	9.5	391	34	231
1997	9.5	401	34	233
1998	9.5	410	34	235
1999	9.5	420	34	238
2000	9.5	429	34	240
2001	9.5	439	34	242
2002	9.5	448	34	244
2003	9.5	458	34	246
2004	9.5	467	34	248
2005	9.5	477	34	250
2006	9.5	486	34	252
2007	9.5	496	34	254
2008	9.5	505	34	256
2009	9.4	514	34	257
2010	9.1	523	33	258
2011	8.5	532	30	256
2012	8.4	540	30	255
2013	7.8	548	28	253
2014	6.6	555	24	247
2015	5.8	560	20	239
2016	5.4	566	20	233
2017	5.1	571	18	227
2018	4.9	576	18	222
2019	4.8	581	17	217
2020	4.8	585	17	213

Table 6.6 (continued)

End of calendar year	Volume (10^3 m^3)[a]		Radioactivity[b] (10^3 Ci)	
	Annual	Accumulated[c]	Annual	Accumulated[d]
		Pressurized-water reactors		
1980	22.4	124	24	81
1981	22.8	147	31	102
1982	20.8	168	34	122
1983	21.4	189	32	138
1984	21.0	210	41	163
1985	18.7	229	29	171
1986	11.6	241	22	175
1987	12.2	253	25	184
1988	10.9	264	36	203
1989	13.4	277	48	231
1990	7.8	285	27	234
1991	8.1	293	24	237
1992	7.8	301	29	247
1993	7.9	309	30	257
1994	8.0	317	30	267
1995	8.1	325	30	277
1996	8.2	333	31	287
1997	8.2	341	31	297
1998	8.2	349	31	307
1999	8.3	358	31	316
2000	8.3	366	31	326
2001	8.3	374	31	334
2002	8.3	383	31	343
2003	8.3	391	31	352
2004	8.3	399	31	360
2005	8.3	407	31	368
2006	8.3	416	31	378
2007	8.3	424	31	384
2008	8.3	432	31	392
2009	8.3	440	31	400
2010	8.2	449	31	407
2011	8.1	457	31	414
2012	8.0	465	30	420
2013	7.6	472	28	425
2014	6.9	479	26	427
2015	6.5	485	24	429
2016	6.3	492	24	430
2017	6.0	498	22	431
2018	5.8	504	22	431
2019	5.7	510	21	432
2020	5.7	515	21	433

[a] One cubic meter = approximately 35.3 ft^3.

[b] Decayed from year of addition using ORIGEN 2 code; 1 Ci (curie) = 37×10^9 becquerels.

[c] Volume accumulation means total waste volume shipped from all plants up to and including the current year.

[d] Radioactivity accumulation is the total curies from low-level waste disposal up to and including the current year.

Source: DOE/RW-0006, Rev. 7 (1980–1989 data) and Rev. 8 (1990–2020 data).

2020; Table 6.7 shows historic volume and radiological trends for the 10 plants in the study sample from 1985 to 1990. Estimates provided by both tables do not include the additional radiological waste generated for activities associated with license renewal. Table 6.8 depicts total generated solid LLW shipped for off-site disposal after compaction or other predisposal VR treatment. Declining disposal volumes in the plant sample generally reflect those of the industry as a whole, with a few exceptions. The exceptions are accounted for by waste-producing refurbishment activities such as steam generator replacements.

Data in Table 6.6 are provided by the Integrated Radioactive Waste Inventory database prepared for the U.S. Department of Energy (DOE) by Oak Ridge National Laboratory (DOE/RW-0006). Sources of data for this inventory include annual figures from the nuclear industry, trade organizations [e.g., Electric Power Research Institute (EPRI)], and a variety of scientific organizations. LLW volume figures provided by this integrated data, while exhibiting a consistent downward trend, are larger than those provided by the industry through the Institute for Nuclear Power Operations (INPO).

VR and waste minimization efforts have been undertaken by utilities in response to increased disposal costs for LLW. These efforts include segregation, decontamination, minimizing exposure of materials and tools to the contaminated environment, sorting potential contaminated materials, and dewatering and evaporation (Strauss 1987; Coley 1987; EPRI NP-5526 Vols. 1 and 2). Some of the most effective VR strategies are compacting, consolidating, and monitoring waste streams to reduce the volume of LLW requiring storage, as well as reducing the exposure of routine equipment to the reactor environment (Strauss 1987; Taylor 1987; EPRI NP-6163; EPRI NP-5526 Vols. 1 and 2; Shaw 1988). As shown in Tables 6.6 and 6.7, which pertain to wet and dry wastes, significant average VRs have been achieved for LLW shipped for disposal from nuclear power plants. According to EPRI, during the 1980s, BWRs achieved an average disposal VR of 24 percent. Between 1981 and 1985, there was a 50 percent reduction in dry waste, a 42 percent reduction in wet waste, and a 48 percent reduction in total waste volume from PWRs. In 1987, the median total LLW volumes shipped for disposal from BWRs and PWRs was 19,700 ft^3 (558 m^3) and 8800 ft^3 (250 m^3), respectively (EPRI NP-5526, Vols. 1 and 2).

According to 1993 performance indicators published by the INPO, the level of LLW per power plant unit has continued to decrease since the 1980s. During 1993, for example, the median value of the low-level solid radioactive waste per BWR unit was about 5,620 ft^3 (159 m^3) as compared to the industry median of 10,800 ft^3 (306 m^3) in 1988. Similarly, the median values for 1993 are below industry 1995 goals of 8,650 ft^3 (245 m^3) for BWRs and 3,880 ft^3 (110 m^3) for PWRs. Technological advances, as well as major reductions in the extent of contaminated areas within power plants, have contributed to the decrease in waste quantities generated over the past several years. Although volumes have declined, radioactivity levels have remained the same (INPO 1994).

The 10 plants in the study sample illustrate current industry-wide VR practices, including ultra-high-pressure compaction of waste drums, incineration of waste oils and

Table 6.7 Solid low-level radioactive waste generated by 10 power plants: 1985–1990

Year	1985	1986	1987	1988	1989	1990
Pressurized-water reactor plant volume[a]						
Comanche Peak	NA[b]	NA	NA	NA	NA	0
D. C. Cook 1 and 2	8.28+02	5.28+02	4.63+02	2.46+02	3.88+02	1.95+02
H. B. Robinson	6.42+02	4.53+02	1.01+02	8.42+01	9.69+01	6.99+01
Indian Point 1 and 2	6.89+02	5.30+02	2.30+02	2.41+02	4.78+02	2.60+02
Indian Point 3	2.39+02	8.29+01	3.17+02	1.82+02	5.77+02	6.66+02
San Onofre 1	1.80+02	2.51+02	3.69+02	3.08+01	1.19+02	5.81+01
San Onofre 2 and 3	5.45+02	2.94+02	2.45+02	2.60+02	3.28+02	1.75+02
Surry 1 and 2	2.02+03	6.39+02	5.15+02	7.30+02	5.38+02	1.48+02
Pressurized-water reactor plant activity[c]						
Comanche Peak	NA	NA	NA	NA	NA	NA
D. C. Cook 1 and 2	2.00+03	1.59+03	2.30+03	5.58+02	1.17+03	1.44+02
H. B. Robinson	3.35+03	1.58+02	2.59+02	3.76+02	1.86+02	1.44+01
Indian Point 1 and 2	5.75+02	2.52+02	8.34+02	4.67+02	3.60+02	2.08+03
Indian Point 3	5.49+02	2.58+01	3.33+02	3.57+02	3.50+02	1.50+02
San Onofre 1	6.04+00	3.82+02	4.98+01	4.06+00	1.72+03	1.27+01
San Onofre 2 and 3	1.72+03	1.93+02	2.71+02	2.55+03	2.72+03	3.34+01
Surry 1 and 2	1.21+03	1.16+03	2.94+04	1.94+02	1.31+03	1.13+03
Boiling-water reactor plant volume[a]						
Hatch 1	2.04+03	1.35+03	7.78+02	8.36+02	8.53+02	1.38+03
Hatch 2	*d*	*d*	*d*	*d*	*d*	*d*
Vermont Yankee	5.43+02	3.10+02	2.23+02	1.73+02	4.84+00	0
Limerick	3.06+02	5.76+02	3.81+02	8.95+02	5.76+02	6.86+02
WNP-2[e]	4.02+02	3.02+02	3.75+02	4.70+02	3.64+02	3.34+02
Boiling-water reactor plant activity[c]						
Hatch 1	3.83+04	8.82+02	1.82+03	2.02+03	1.91+03	2.85+04
Hatch 2	*d*	*d*	*d*	*d*	*d*	*d*
Vermont Yankee	1.73+04	3.33+02	1.19+04	4.25+02	2.15+00	0
Limerick	2.06+01	7.53+02	2.15+03	9.70+02	3.40+04	1.24+03
WNP-2	2.96+02	5.07+02	1.09+03	1.01+03	1.10+03	1.29+03

[a] In exponential notation (m^3); 1 m^3 = approximately 35.3 ft^3.

[b] NA = not available; in most cases because the plant was not on line.

[c] In curies; 1 Ci = 37 × 10^9 becquerels.

[d] Included with Hatch 1 totals.

[e] WNP-2 = Washington Nuclear Project 2.

Source: NUREG/CR-2907.

Table 6.8 Percent of low-level radioactive waste treated by volume reduction methods in current use in the plant sample[a]

Plant	Waste compaction	Sorting before segregation	Decontamination	Shipment	Other
Comanche Peak		100			*b*
D. C. Cook	85	85	85	85	15[c]
Hatch	85–90			80–90	
Indian Point 2	30	55	50		15[d]
Indian Point 3	90		5	1	
Limerick	55		5	35	5[e]
Robinson		60–75	5	70	75[f]
San Onofre					
Surry	60	5	25	5	5[g]
Vermont	95	40	10	40	*h*
Yankee	55				45[j]
WNP-2[i]					
Sample average	50–51	31–36	17	29–30	15
Industry-wide average (*n*)[k]	46(49)	30(33)	15(41)	35(31)	42(44)

[a] In percent of waste volume treated. Because of multiple volume reduction methods, totals may not equal 100 percent.

[b] Comanche Peak color codes all hazardous and radioactive waste and does limited sorting prior to shipment. An off-site contractor performs incineration, compaction, and decontamination of tools.

[c] D. C. Cook dewaters 15 percent of its wet waste.

[d] Indian Point 2 employs sand blasting, steam cleaning, freon cleaning, and sectioning as well as direct burial of resins, filters, and sludges and is also examining plans for chemical decontamination of reactor coolant.

[e] Limerick incinerates contaminated oils and reagents.

[f] Robinson relies heavily on decontamination of material to the reactor environment and has seen steady improvements in use of this method.

[g] Surry employs an off-site vendor for incineration of waste oil and for supercompaction. The plant is completing an interim storage facility for storage of one year's LLW stream. This facility will employ asphalt solidification, high-pressure compaction, and decontamination of waste.

[h] Vermont Yankee employs a survey process for dry active waste that results in the sorting of high- and low-activity wastes and supercompaction of the former followed by off-site disposal. Irradiated reactor components are stored in the spent-fuel pool. High reliance on compaction has resulted from LLW being stored on site between 1989 and 1991 (Vermont has no available compact).

[i] WNP-2 = Washington Nuclear Project 2.

[j] WNP-2 dewaters spent resins.

[k] (*n*) = number of plants responding to survey. In updating data for the Final GEIS, the sample plants were resurveyed and published updates were used. However, no new industry-wide survey was undertaken because neither published updates nor sample plant data showed significant departures from previous trends.

resins, mobile thin-film evaporation, waste crystallization, and asphalt solidification of resins and sludges. These are aided by formal establishment of VR goals, assignment of responsibilities to each plant division, special training, and monitoring of procedures (EPRI NP-3763; Riales 1985; Taylor 1987; EPRI NP-5526 Vols. 1 and 2; EPRI NP-5983; Shaw 1988). Some VR activities are performed on site; others are undertaken by off-site contractors. As shown in Table 6.8, the most common VR techniques used for plants in the study sample are compaction, waste segregation through use of radiation control zones and control points, and sorting of wastes into radioactive and nonradioactive batches prior to off-site shipment. The proportions of waste volumes treated by these techniques in the plant sample reflect those of the industry as a whole.

The efforts of three BWRs (WNP-2, Limerick, and Hatch) and two PWRs (Surry and Robinson 2) are representative of emerging VR trends, especially the growing reliance on off-site waste management vendors. VR techniques utilized by these plants typify the state of the art for the industry as a whole. Utilization of these VR methods will support NRC policy encouraging LLW volume reduction to alleviate concern for adequate LLW disposal capacity (46 FR 51100). WNP-2 has hired a radioactive-waste-processing service for segregation, compaction, and waste packaging (Macbeth and Allen 1986). Limerick has hired a vendor to establish a plant database and surveillance program for radionuclide management (Trinoskey et al. 1987).

Following licensed operation, Surry adopted a filtration system in conjunction with demineralization and evaporation processes for liquid waste that are provided by an off-site vendor. Hatch employs a box compactor on site and uses an off-site vendor for supercompaction and incineration (EPRI TR-101160). Robinson relies principally upon segregation, sorting of waste before shipment, and source control to minimize plant areas devoted to LLW storage. In 1985, Robinson averaged 5200 ft^3 (150 m^3) of LLW storage area plant-wide. By 1986, this was reduced to 2300 ft^3 (65 m^3) through sorting, segregating, and retrieving usable nonradioactive wastes. Segregated refuse that emits less than 5 mrem/h is sent to a trash-monitoring facility. Trash that demonstrates an activity level less than 100 counts per minute above background is then sent to the plant landfill. The remainder is currently disposed of at Barnwell (EPRI NP-5934).

6.4.3.2 Interim LLW On-Site Storage

LLW is normally stored on site on an interim basis before being shipped off site for permanent disposal. On-site storage facilities are designed to minimize personnel exposures. High-dose-rate LLW is isolated in a shielded storage area and is easily retrievable. The lower-dose-rate LLW is stacked or stored to maximize packing efficiencies. NRC requirements and guidelines ensure that LLW is stored in facilities that are designed and operated properly and that public health and safety and the environment are adequately protected (EPRI NP-7386). NRC requirements and guidelines include the following:

- The amount of material allowed in a storage facility and the shielding used should be controlled by dose rate criteria for both the site boundary and any adjacent off-site areas. Direct radiation and effluent limits are restricted by 10 CFR Part 20 and 40 CFR Part 190. The exposure limits given in 10 CFR 20.1301 apply to unrestricted areas.

- Containers and their waste forms should be compatible to prevent significant corrosion within the container. After a period of storage, the subsequent transportation and disposal should not cause a container breach.
- Gases generated from organic materials in waste packages should be evaluated periodically with respect to container breech. After a period of storage, the subsequent transportation and disposal should not cause a container breach.
- Gases generated from organic materials in waste packages should be evaluated periodically with respect to container breech. High-activity resins should not be stored more than 1 year unless they are in containers with special vents.
- A program of at least quarterly visual inspection should be established.
- A liquid drainage collection and monitoring system should be in place. Routing of the drain should be to a radwaste processing system (EPRI NP-7386).

NRC has historically discouraged the use of on-site storage as a substitute for permanent disposal. NRC Generic Letter 81-38 (NRC 1981) states that no facility should be built to store waste for longer than 5 years under a licensee's 10 CFR 50.59 evaluation. Specific NRC approval should be obtained. This limitation was based in part on safety considerations but was aimed at encouraging the development of permanent LLW disposal facilities. However, recognizing that the 5-year limit has not influenced the development of new waste disposal facilities and that the states continue to make slow progress, NRC has eliminated in its guidance any language that the 5-year term is a limit beyond which storage would not be allowed.

Regarding nuclear power reactors, the 5-year limit is associated with the need to obtain a separate Part 30 license to store LLW. Generic Letter 81-38 states that under certain conditions, Part 50 licensees should obtain a Part 30 materials license to store LLW. These conditions are that (1) there exists an unreviewed safety question with the proposed storage facility, (2) the existing license conditions or technical specifications prohibit increased storage, or (3) the planned storage time exceeds 5 years. Other than for the conditions noted, NRC regulations and procedures do not call for a separate Part 30 license for power reactors for LLW storage, because power reactor licensees are already authorized under Part 30 to possess by-product materials produced by the operation of the facility within the limits of their operating license.

Generic Letter 81-38 states that the application for a Part 30 license is for the administrative convenience of the Commission and is not intended to be substantively different from an application for amendment of the facility operating license (i.e., the Part 50 license). Because Part 50 licensees are already authorized under Part 30 to possess their LLW, NRC staff revised the guidance to state that these licensees should amend their Part 50 licenses when the storage of LLW is not within the limits of their current operating license. On February 1, 1994, the Commission, in responding to SECY-93-323, which recommended withdrawal of the on-site storage rulemaking, directed the staff to eliminate the requirement for power reactor licensees to obtain a separate Part 30 license (SECY-94-198). Agreement states are currently reviewing proposed changes to existing guidance.

Several events have increased the trend towards longer on-site storage. These events include the closure of the Beatty, Nevada, site in 1992; the restriction of the Richland, Washington, facility to Northwest Compact and Rocky Mountain Compact states and the restriction of the Barnwell, South Carolina, site to waste generated by Southeast Compact states. As of July 1994, 33 states were without access to licensed full-service disposal facilities. The status of state efforts to form compacts and identify new disposal sites is discussed in Section 6.4.3.3. However, as of July 1, 1995, all states except North Carolina have access to the Barnwell site. The Envirocare site in Utah takes limited types of waste from certain generators.

Most utilities have adequate on-site space for at least the near term, and many facilities are already in place (de Planque 1994). For example, the Cook nuclear plant in Michigan has built an on-site disposal facility (completed in 1992) that will not reach capacity until about 2003. Moreover, the facility is designed so that it can be easily expanded to double its storage capacity after that date (McRae 1994). Vermont Yankee has stored LLW on site since 1989, when it was denied access to off-site disposal space. Vermont is not a member of a compact, nor does it have official "unaffiliated state" status. However, pending Congressional approval, Vermont will become a member of the Texas Compact. Vermont Yankee has one of the smallest plant sites in the study sample [125 acres (50.6 ha)]. Typically, for on-site storage of LLW or spent fuel, a few tenths of an acre are disturbed and occupied by the storage facilities themselves. In addition, a few acres are maintained as exclusion areas surrounding the facilities.

Indian Point is planning to store routine LLW on site if use of an out-of-state disposal facility is denied to New York State after 1994 and if New York fails to establish its own repository. Current (1994) plans are to store LLW for up to 5 years in a qualified interim facility. For two operating units and a 239-acre (96.7-ha) site, such a facility would probably utilize no more than 1 to 2 acres (0.4 to 0.8 ha), or 0.8 percent of the site. Surry is completing an interim facility that will be able to store packaged LLW for up to 1 year. It will employ asphalt solidification, high-pressure compaction, and decontamination to reduce the volume of LLW requiring storage until a new Southeast Compact disposal facility becomes available. Limerick can store LLW for 5 years after closure of the plant site (a contingency undertaken in contemplation of decommissioning). It is investigating the possibility of shipping LLW to two other plants owned by Philadelphia Electric Company. One of these facilities has a 5-year storage capacity, and the other can store 3 months' volume. No plant has had to acquire additional land for interim waste storage.

The environmental impacts of on-site LLW management activities, including interim storage, result principally from exposure to radioactivity. Workers receive external doses from exposure to radiation while handling and packaging the waste materials and from periodic inspections of the packaged materials and any other handling operations required during interim storage. Such doses, however, account for a small fraction of the total radiation dose commitment to workers and, as discussed in Section 4.6.3, the total dose commitment is well within regulatory limits. Radiation doses to off-site individuals and biota from interim LLW storage are insignificant. The principal exposure pathway is direct radiation from steam generator assemblies and other large assemblies stored in shielded buildings, but this pathway results in a very small dose commitment (Section 3.8.1.6).

6.4.3.3 LLW Disposal

In 1992 approximately 35 percent of LLW disposed of in the United States was generated by nuclear power plants (DOE/LLW-181) although, as noted earlier, percentages vary and have been closer to 50 percent. Compacted dry waste is the largest single form of LLW disposed of from nuclear power plants, accounting for approximately 46 and 36 percent of total average annual volumes from PWRs and BWRs, respectively (EPRI NP-5526, Vols. 1 and 2; Shaw 1988). Through 1994, the two remaining commercial disposal sites—Barnwell, South Carolina, and Hanford, Washington—acquired a total LLW volume of 39,576 ft^3 (1,121 m^3) (Radioactive Exchange 1994).

The NRC emphasizes an integrated-systems approach to LLW disposal, including consideration of site selection, site design and operation, waste form, and disposal facility closure (10 CFR 61). NRC specifies requirements that must be met by the waste generator, including requirements for waste form and content, waste classification, and waste manifests. The NRC's approach emphasizes passive rather than active systems to minimize and retard releases to the environment over the extremely long periods of time contemplated for the control of radioactive material. The performance objectives given in 10 CFR 61 assume no active controls at the disposal site after 100 years and, further, depending on the waste classification, site stability for up to 300–500 years. The site itself, including subsurface zones, is considered to be part of the containment mechanism, which by design (e.g., clay liners and covers or engineered surface barriers) slows the expected release of acceptably small quantities of radioactivity (NUREG-0945).

Waste disposal facilities sited and operated consistent with 10 CFR 61 and other appropriate regulations would result in minimal environmental impact. Licensing of these facilities requires environmental documentation, including assessment of potential environmental impacts. Procedures are established to ensure that performance objectives are met. Waste generators must meet the waste acceptance criteria established for the facility and adhere to packaging requirements.

With the passage of Pub. L. 96-573 in 1980, the Low-Level Radioactive Waste Policy Act, states were assigned responsibility for the disposal of certain LLW generated within their borders (except for LLW generated by the federal government). This act was amended by the Low-Level Radioactive Waste Policy Amendments Act of 1985 (Pub. L. 99-240), which mandated that from January 1, 1986 through December 1992, states were to divide their volume allocations among waste generators. Volume allocations for the 10 plants in the study sample are depicted in Table 6.9. Volumes due to unusual activities ("unusual volumes") denote a special disposition allocation reserved for refurbishment, decommissioning, and core-related accident waste. As of December 31, 1992, DOE had

Table 6.9 Profile of allocation of low-level radioactive waste for 10 power plant sites: current and projected allocations[a]

Plant	Compact or unaffiliated state	Unusual volumes[a] (ft^3/year)[b]	Total allocation volume (ft^3/year)	Volume received at disposal[c] used (ft^3/year)	Percentage of allocation used 1986–1992
Comanche Peak	Texas	0	12,330	7,746	63
D. C. Cook 1 and 2	Midwest	46,538	179,474	64,437	36
Hatch 1 and 2	Southeast	0	371,352	237,532	64
Indian Point 1 and 2	New York	0	132,936	71,313	54
Indian Point 3	New York	0	66,468	24,672	37
Limerick 1	Appalachian	0	82,920	137,265	81
Robinson 2	Southeast	0	165,840	32,885	40
Surry 1 and 2	Southeast	0	199,404	89,184	54
San Onofre 1, 2, and 3	Southeast	0	148,836	86,407	43
Vermont Yankee	Vermont	0	148,836	48,546	33
WNP-2[d]	Northwest	0	185,676	94,196	51

[a] Volumes due to unusual activities (e.g., steam generator replacement).
[b] 1 ft^3 = 0.028317 m^3.
[c] To Barnwell, South Carolina; Beatty, Nevada; and Hanford, Washington.
[d] WNP-2 = Washington Nuclear Project 2.
Source: DOE/EM-0143P.

granted six requests for unusual volume allocation, totaling 190,283 ft^3 (5,388 m^3); two of the six requests were returned to the requestor for additional information and no requests were denied. D. C. Cook, Unit 2, which requested an additional 46,538 ft^3 (1,318 m^3), was the largest of the six requests. A balance of 609,717 ft^3 (17,265 m^3) of the original 800,000 ft^3 (22,653 m^3) of unusual volume allocation remains undistributed. No petitions for unusual volume allocations were submitted to the DOE in 1992.

Between 1986 and 1992, all plants in the study sample stayed within allocated ceilings, averaging 51-percent utilization of disposal capacity. The plant that came closest to exceeding its allocated ceiling was Limerick, which used 81 percent of its volume allocation by 1992. Nuclear power plants have generally shipped far less LLW for disposal than had been anticipated under Pub. L. 99-240. Even those few reactors that received unusual volume allocations could have disposed of the waste generated by the unusual activities using only their regular allocations specified under the law. From 1986 through 1992, commercial power reactors used only 49.5 percent of the total regular allocations issued through 1992 (DOE/EM-0143P). While historical patterns of disposal provide no guarantees regarding future disposal, the fact that these ceilings remained intact suggests that compact planners will design new disposal facilities that can accommodate a wide range of disposal scenarios.

Pub. L. 99-240 also provides milestones, incentives, and penalties to promote the states' continuous progress toward new LLW disposal facility development. States must ensure their own disposal capacities by forming waste compacts or siting their own disposal facilities. Table 6.10 identifies current and future host states for LLW disposal facilities.

Figure 6.1 shows the geographic arrangement of current compacts and their respective state members. Also shown in Fig. 6.1, incremental progress is being made in forming enduring compacts and siting new LLW disposal facilities. Recent examples of progress include the formation of a new Texas Compact that includes Maine and Vermont, which is pending before the U.S. Congress for consent. Also, the Southeast Compact has selected a new site in North Carolina that is expected to be operational by mid-1998. Moreover, the process of site selection is progressing in the Appalachian, Central, and Midwest compacts. Facilities in the host states of Connecticut, Illinois, Massachusetts, Nebraska, New Jersey, Pennsylvania, and New York are scheduled for operation in the period 1999 to 2002. In addition, site activity in the host state of Ohio can begin when the Ohio General Assembly enacts enabling legislation. Michigan, New Hampshire, Rhode Island, District of Columbia, and Puerto Rico are unaffiliated states and have no plans to develop an LLW-disposal facility. They may be able to fulfill their responsibilities through the contracting and/or compact process. Envirocare, in Utah, takes limited types of LLW from certain generators. Despite evidence of incremental progress in siting new facilities, the lack of access of 33 states to LLW disposal sites until Barnwell became available to all states except North Carolina on July 1, 1995 shows the potential to affect all classes of waste generators, including nuclear power plants. Specifically, about 50 percent of the nation's LLW was expected to require on-site storage after 1994, much of it at the point of generation (DOE/EM-0143P).

6.4.4 Effects of License Renewal on LLW

Additional quantities of LLW will result from refurbishment and extended power plant operations under renewed licenses. These activities could, in turn, require the development of additional on-site storage facilities for LLW, including GTCC waste, especially if the power plant is located in a compact or unaffiliated state that has not developed adequate disposal facilities.

6.4.4.1 Generation

Table 6.11 shows that the annual incremental increase in LLW generation for BWRs would be approximately 6163 ft^3 (175 m^3) during the 10-year refurbishment period (assuming four current-term refurbishment outages and one major refurbishment outage; see Section 2.4 for refurbishment scenario). For PWRs, the average incremental increase in LLW generation would be approximately 8410 ft^3 (238 m^3).

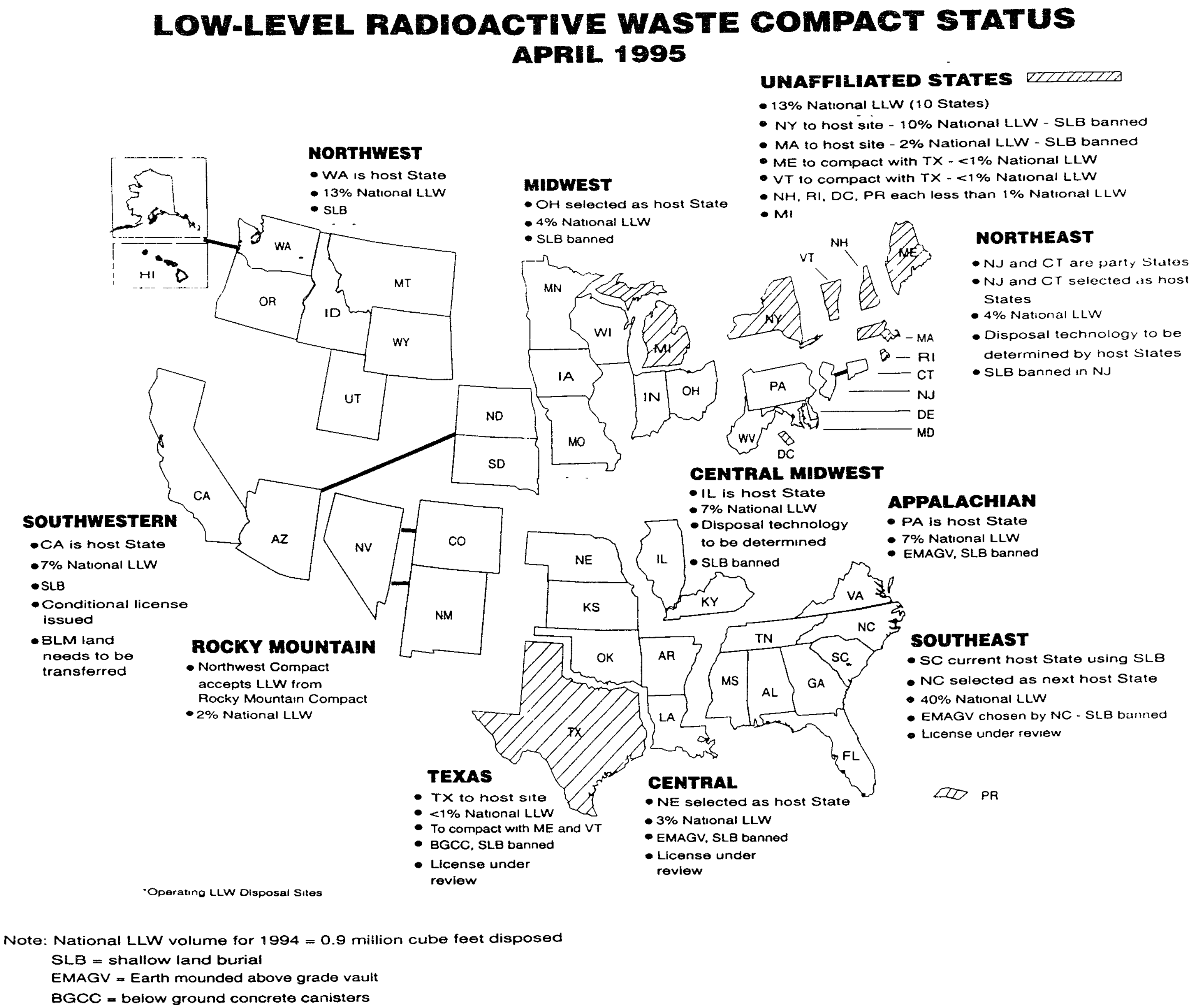
The considerably greater volume of refurbishment-associated LLW in the latter case is largely caused by the potential need for steam-generator replacements in PWRs. For the 20 years of operation after refurbishment, annual average LLW generation rates from the eight refueling outages and three in-service inspections would increase approximately 205 ft^3 (5.8 m^3) for BWRs and 145 ft^3 (4.1 m^3) for PWRs (Table 6.6). These conservative-case estimates include waste from refueling operations and represent about 4 percent of the median waste volume generated by BWRs during 1993 and about 9 percent of

Table 6.10 Actual and estimated dates for completing steps in facility development (estimated dates obtained from compacts/states), April 1995

Compact/host state	Select site	Submit license application	Operate facility
Appalachian/Pennsylvania	1995	Early 1997	Mid-1999
Central/Nebraska	Dec. 1989	July 1990	Fall 1999
Central Midwest/Illinois	Unscheduled	Nov. 1997	July 2000
Midwest/Ohio	Unscheduled	Unscheduled	Unscheduled
Northeast/Connecticut	Unscheduled	1999	2002
New Jersey	Unscheduled	Jan. 1998	July 2000
Southeast/North Carolina	Dec. 1993	Dec. 1993	Mid-1998
Southeast/California	Mar. 1988	Dec. 1989	Mid-1997
	Unaffiliated States		
Maine[a]			
Massachusetts	Unscheduled	Feb. 1998	2000/2001
Michigan	Unscheduled	Unscheduled	Unscheduled
New York	Unscheduled	June 1999	Nov. 2001
Texas	Aug. 1991	Mar. 1992	Mid-1997
Vermont[a]			
District of Columbia, New Hampshire, Rhode Island, Puerto Rico[b]			

[a] Formation of a compact pending with Texas as the host state.

[b] Currently not planning to develop a low-level radioactive waste disposal facility.



LOW-LEVEL RADIOACTIVE WASTE COMPACT STATUS
APRIL 1995

UNAFFILIATED STATES ▨
- 13% National LLW (10 States)
- NY to host site - 10% National LLW - SLB banned
- MA to host site - 2% National LLW - SLB banned
- ME to compact with TX - <1% National LLW
- VT to compact with TX - <1% National LLW
- NH, RI, DC, PR each less than 1% National LLW
- MI

NORTHWEST
- WA is host State
- 13% National LLW
- SLB

MIDWEST
- OH selected as host State
- 4% National LLW
- SLB banned

NORTHEAST
- NJ and CT are party States
- NJ and CT selected as host States
- 4% National LLW
- Disposal technology to be determined by host States
- SLB banned in NJ

CENTRAL MIDWEST
- IL is host State
- 7% National LLW
- Disposal technology to be determined
- SLB banned

APPALACHIAN
- PA is host State
- 7% National LLW
- EMAGV, SLB banned

SOUTHWESTERN
- CA is host State
- 7% National LLW
- SLB
- Conditional license issued
- BLM land needs to be transferred

ROCKY MOUNTAIN
- Northwest Compact accepts LLW from Rocky Mountain Compact
- 2% National LLW

SOUTHEAST
- SC current host State using SLB
- NC selected as next host State
- 40% National LLW
- EMAGV chosen by NC - SLB banned
- License under review

TEXAS
- TX to host site
- <1% National LLW
- To compact with ME and VT
- BGCC, SLB banned
- License under review

CENTRAL
- NE selected as host State
- 3% National LLW
- EMAGV, SLB banned
- License under review

*Operating LLW Disposal Sites

Note: National LLW volume for 1994 = 0.9 million cube feet disposed
SLB = shallow land burial
EMAGV = Earth mounded above grade vault
BGCC = below ground concrete canisters

Fig. 6.1. Low-level radioactive waste compact status.

Table 6.11 Total estimated incremental[a] low-level radioactive waste generation during 10-year renewal refurbishment activities and 20-year post-refurbishment operations (ft^3),[b] as shipped

Activity	Boiling-water reactor	Pressurized water reactor
LLW attributable to refurbishments prior to year 41		
Current-term refurbishment outages (4)[c]	8,2000 x 4 = 32,880	9,340 x 4 = 37,360
Major refurbishment outage (1)	28,750	46,740
LLW attributable to plant life extension period (41–60 years)		
Refueling outages (8)	160 x 8 = 1,280	116 x 8 = 928
5-year in-service inspections (2)	731 x 2 = 1,462	466 x 2 = 932
10-year in-service inspection (1)	1,348	1,035
Total LLW	66,000	87,000

[a] Incremental wastes are those in addition to baseline annual for routine operations for the 20 years.

[b] $1\ ft^3 = 0.028317\ m^3$.

[c] Number in parentheses is the number of times the activity is performed.

Source: SEA 93-461-10-A:3.

the median value of LLW produced by PWRs during 1993. The total projected increases in LLW generation [66,000 ft^3 (1,870 m^3) for BWRs and 87,000 ft^3 (2,460 m^3) for PWRs] amount to a volume of about 3 percent of the total nuclear power plant waste allocation volume used from 1983 through 1992. Although this scenario assumes distinct LLW streams related to license renewal refurbishments, in fact refurbishments will probably occur as a continuation of normal operations under the original license. Consequently, it will be difficult to distinguish LLW generated by continuing operations (including waste from steam generator replacement) from waste streams related to license renewal. Also, continued progress in VR should slow the accumulation of waste volumes either on site or at a permanent waste disposal facility. Although utilities would rely on the same VR techniques used under original licenses during license renewal (Table 6.12), plants in the study sample anticipate less reliance on waste compaction for VR, because the greatest VR gains from this method have already been achieved. Utilities expect to rely increasingly on incineration, resin drying (dewatering), and off-site contracting for the disposal of large contaminated components through a variety of methods (Efremenkov 1989; DOE/RW-0220).

Certain activities may also produce increased volumes of GTCC waste as a result of removing neutron-activated materials from the reactor vessel or removing materials that are located sufficiently close to the reactor core such that activation results (SEA 93-461-10-A:3). The current inventory of GTCC waste from nuclear utilities consists of a small volume of startup sources, stellate bearings, and other wastes that are being stored at utility sites until a disposal option is available. These wastes bring the total

Table 6.12 Percent of anticipated low-level waste volumes that will be treated by five types of volume-reduction methods during license renewal for the sample plants[a]

Plant	Waste compaction	Sorted before segregation	Decontamination	Shipment	Other
Comanche Peak		100			
D. C. Cook	85	85	85	85	85
Hatch	85–90			80–90	
Indian Point 2	30	55	50		15[b]
Indian Point 3	90				20[c]
Limerick	20		5	35	40[d]
Robinson		>75	1–5	<70	75[e]
San Onofre					
Surry	35	5	25	5	30[f]
Vermont Yankee	95	40	10	40	
WNP-2[g]	25		5	25	45[h]
Sample average	42–43	33	16–17	31–32	28
Industry-wide average (n)[i]	34(50)	32(35)	19(41)	42(30)	50(43)

[a] In percent of waste volume treated. Because of multiple volume-reduction methods, totals may not add up to 100 percent.

[b] Under license renewal, Indian Point 2 anticipates moving toward greater waste incineration because of increasing volume-reduction costs and uncertainties surrounding availability of a New York state disposal facility. It can keep low-level waste on site in a qualified interim facility.

[c] Indian Point 3 plans to employ a combination of resin drying, incineration of dry active waste, and metals smelting off site during license renewal.

[d] Limerick will move increasingly toward incineration. It will be able to store up to 5 years of low-level waste on site after closure of site.

[e] Robinson will place a greater emphasis on minimizing contamination during license renewal.

[f] Surry will move toward more incineration.

[g] WNP-2 = Washington Nuclear Project 2.

[h] WNP-2 will move toward increasing dewatering of resins. It also anticipates contracting for the disposal of large turbine components and moisture separator reheaters during refurbishment, as well as constructing interim refurbishment-waste warehouse space.

[i] n = number of plants responding to survey. In updating data for the Final GEIS, the sample plants were resurveyed and published updates were used. However, no new industry-wide survey was undertaken because neither published updates nor sample plant data showed significant departures from previous trends.

inventory of GTCC waste from nuclear utilities to 364 ft^3 (10.3 m^3). The activity of the current inventory is estimated to be 3,873,000 Ci (DOE/LLW-114).It is difficult to predict amounts of GTCC waste likely to be produced by refurbishment activities without knowing if reactor core components have to be removed and the extent of irradiation-induced activity. The current conservative estimate is that about 1540 ft^3 (44 m^3) of refurbishment-associated GTCC waste will be generated by BWRs and about 500 ft^3 (14 m^3) of GTCC waste will be generated by PWRs (SEA 93-461-10-A:3).

The Low-Level Radioactive Waste Policy Amendments Act of 1985 assigned the responsibility for disposal of GTCC LLW to DOE. Disposal by DOE must be in a facility licensed by NRC; however, states may allow disposal of GTCC waste at LLW sites. NRC's current LLW regulations (10 CFR 61.55) require disposal of GTCC waste by DOE in a geologic repository as defined in 10 CFR Part 60, unless a specific alternative is approved by the Commission. The combined impacts of all waste buried at the repository will be required to meet the applicable standards.

Both the activity and volume of GTCC waste is small when compared to spent fuel. DOE estimates of GTCC waste to be generated through the year 2055 are on the order of 2000 m^3 containing about 90 million curies (DOE/LLW-114). Utility wastes contribute about 66 percent of the volume and 90 percent of the activity of the GTCC waste; the predominant waste form is activated metal components. The volume estimates vary, depending on factors such as assumed packaging, averaging methods, and nonfuel components that may be determined to be covered by HLW contracts; a range of 1000–8700 m^3 is possible for total GTCC waste generation through 2055 (DOE/LLW-114). These volumes and activities can be compared to commercial spent-fuel inventories as of December 31, 1992 of about 10,000 m^3 (just the fuel rods and space between, no packaging) and 26,000 million curies and projections of about 34,000–41,000 m^3 and 25,000–52,000 million curies in the year 2030 (DOE/RW-0006). Spring of 1995 DOE estimates for the Yucca Mountain repository are 147,000 m^3 of waste, a peak activity of 43,000 million curies, and an excavated volume of 4–6 million/m^3. Based on the data in Section B.4.1.2 of Appendix B to this GEIS and assuming 72 PWRs and 37 BWRs, the total volumes of GTCC that would result from renewal activities and plant life extension from all 109 plants would be 2,044 m^3 for the typical case and 2,636 for the conservative case. These volumes appear to be consistent with the other estimates.

The staff also notes that in the 1989 rulemaking to require disposal of GTCC in a deep repository unless disposal elsewhere has been approved by the Commission (54 FR 22578; May 25, 1989), the Commission stated:

> The fact that the expected volume of GTCC waste is very low was an important factor in the Commission's decision to propose the Part 61 amendments. Current evidence shows that the expected volume of GTCC waste is very small relative to volumes of HLW and Class A, B, and C LLW. It is projected that 2000–4800 cubic meters of commercially-generated GTCC waste will need disposal through the year 2030 [U.S. Department of Energy estimates]. This amount of waste is smaller than the anticipated excavated volume of a single emplacement room of a repository, and would not present a significant burden on the capacity of the repository to receive HLW. It would not be a significant factor underlying the need for a second repository.

Based on the Waste Confidence finding reflected in 10 CFR 51.23 concerning the safety and availability of a HLW repository, the Commission has previously determined that there is reasonable assurance at least one geologic HLW repository will be available within the first quarter of the twenty-first century, and that sufficient repository capacity will be available within 30 years beyond the licensed life of operation of any reactor. Although the Waste Confidence finding did not expressly encompass GTCC waste, the staff concludes that the Waste Confidence reasoning and information on repository availability, together with relatively small incremental volume and hazard associated with GTCC waste, support a finding that there is reasonable assurance that sufficient GTCC LLW disposal capacity will be made available when needed for facilities to be decommissioned consistent with NRC decommissioning requirements. Off-site disposal capacity for these wastes can reasonably be expected to be available when the HLW repository begins operating.

6.4.4.2 Interim LLW Storage

If compact and unaffiliated states are able to site disposal facilities and accept waste in normal increments (i.e., in accordance with the assigned allocations for each plant in the compact or unaffiliated state), there should be no significant issues or environmental impacts associated with interim storage of LLW generated by nuclear power plants with renewed licenses. Interim storage facilities would be utilized until these wastes could be safely shipped to licensed disposal facilities (EPRI NP-6163). While on-site land will be needed to store the waste, measures taken by the industry appear to be adequate to encompass these additional volumes. For example, Indian Point 2, Limerick, Robinson, and WNP-2 are contemplating construction of additional interim storage facilities associated with license renewal. Indian Point expects to store resin and filter wastes after dewatering in a special Butler-style building. A separate facility may be required for storage of Indian Point 3's old steam generators. Limerick's additional 165,000-ft^2 (15,300-m^2) facility for spent fuel and LLW, to be completed by 1999, will be used for refurbishment-associated wastes. WNP-2 is planning to construct a special warehouse for storage of its low-pressure turbines. The incremental volumes of LLW requiring interim on-site storage would result in increased worker exposure and external radiation dose commitments from waste handling, packaging, and inspection activities. However, such incremental dose commitments would be small and pose a low risk (Section 4.6.3.2).

If off-site disposal facilities are unavailable to accept waste in normal increments, then on-site interim storage may have to take place longer than the 5-year time frame once envisioned by NRC, and additional on-site storage capacity may be needed. As discussed in more detail in Section 6.4.4.6, the radiological implications of storing larger quantities of LLW on site for relatively longer periods of time would be minimal. The external dose commitments to workers would increase slightly because of periodic inspections of the waste and perhaps some handling, but this incremental dose would not be significant. Emergency response capabilities already in place would be adequate for any additional LLW storage capacity that may be required.

6.4.4.3 LLW Disposal

During the 20-year period for which the renewed licenses are granted, most utilities may have uncertain access to currently operating disposal facilities. Beatty closed in 1992, and Barnwell was closed to noncompact facilities in June 1994 but made available again in July 1995. The Hanford disposal site is limited to the Pacific Northwest and Rocky Mountain compact states. The additional quantities of LLW resulting from refurbishment and extended power plant operations under renewed licenses will be stored on site or shipped to existing or future disposal facilities.

Three issues associated with off-site disposal may be faced by LLW compacts, compact host-site disposal states, and unaffiliated states during license renewal. First, although routine waste stream volumes continue to decline as VR measures are implemented, major refurbishments that occur during license renewal could produce additional short-term volumes that could tax available off-site disposal space in some compact and unaffiliated states. Although unlikely, refurbishments for some nuclear power plants could be concentrated in a 1-year period before license expiration, thereby exceeding the waste volume acceptance criteria established by the host state.

Most compacts, however, are expected to develop facility design specifications that can encompass multiple, simultaneous refurbishment activities. For example, the Southeast Compact assumes an initial licensing volume of 11 million ft^3 (311,500 m^3) that will be disposed of in its North Carolina site scheduled to be operational in mid-1998. Current Southeast Compact policy limits the annual volume of waste to be received at this facility to 1.6 million ft^3 (45,300 m^3) per year for all categories of waste generators.

Assuming that a major refurbishment (involving the replacement of a steam generator) would generate about 45,000 ft^3 (1,275 m^3) of LLW and that annual regional waste disposal volumes would average 350,000 ft^3 (9,900 m^3) for all categories of generators, it would take about 28 major refurbishments to reach the 1.6 million ft^3 (45,300 m^3) annual ceiling for the Southeast Compact. Because it is unlikely that this many refurbishments will take place in any one year, disposal capacity problems are not likely to surface (data for scenario provided by D. G. Ebenhack Clean-Nuclear Systems, Inc., in letter to J. MacMillan, North Carolina Low-Level Radioactive Waste Management Authority, July 21, 1993; SCCLLRWM 1994). In situations where there is the likelihood that the specified annual compact waste acceptance ceilings will be reached, refurbishment could be staggered over several years. The expected waste from refurbishment is significantly less than the waste generated by decommissioning, which ranges from 650,000 ft^3 (18,400 m^3) for a PWR to 672,000 ft^3 (19,000 m^3) for a BWR (SCCTAC 1994). If 12 nuclear units in the Southeast Compact are decommissioned between 2009 and 2017, approximately 7,800,000 to 8,064,000 ft^3 (220,900 to 228,300 m^3) of LLW would be generated. This amount of waste can still be accommodated within the maximum operating life of a facility with a capacity of 32 million ft^3 (906,000 m^3), depending on the future volumes of LLW produced by other categories of generators.

Second, some host states have advised waste generators that they will be responsible for their own interim storage until disposal facilities can be opened; and those facilities may not open until *some* current licenses[1] have expired. However, for most nuclear power plants, new LLW disposal facilities are scheduled to open well before the expiration date for current licenses. An analysis of the expiration dates of nuclear power plant licenses and the expected dates for new LLW waste facilities to be available^2 reveals that existing power plant licenses will expire, on average, about 19 years after planned LLW facilities are currently scheduled to begin operations. Nevertheless, any nuclear power plant can start the license renewal process after 20 years of operation; consequently, the flexibility afforded by the 19-year cushion may be more apparent than real.

Third, an agreement state under the Low-Level Radioactive Waste Policy Amendments Act of 1985 may use averaging criteria that are different from those of the NRC to determine if a particular container of LLW is class C or GTCC wastes. Waste exceeding class C limits may be unacceptable for disposal in a licensed facility (Hutchison and Magleby 1990; Newberry and Coleman 1990). If a particular host state classifies waste as GTCC, it may refuse to accept that waste for disposal. This would increase the volume of GTCC that must be stored on-site by nuclear power plant operators until DOE provides disposal capacity at an HLW repository or other licensed facility.

The environmental impacts associated with LLW disposal during the terms of a renewed license of nuclear power plants should not be different in kind or magnitude from that during the terms of the initial 40-year license. The disposal facilities would be licensed and in compliance with appropriate regulations (10 CFR 61). The waste generators would have to meet the packaging and waste acceptance criteria for the specific disposal facility. Thus, measures would be in place to ensure that the performance objectives for the facility are met and that public exposures will be within regulatory limits.

6.4.4.4 Regulations Applicable

10 CFR Parts 20, 60, 61, and 62. 10 CFR 50.59.

6.4.4.5 Impacts of Extended On-Site Storage of LLW

6.4.4.5.1 Introduction

Preceding sections have discussed LLW from refurbishment and continued operations and presented the more likely events and impacts. The earlier discussion indicated that LLW treatment and disposal capacity are expected to become available before or during the license renewal period, although delayed from the Congressional timetables in the LLW statutes. This additional section separately addresses the more unlikely scenario of on-site storage of both refurbishment and operational low-level radioactive wastes (LLW) for the renewal period of approximately 20 years. Summary data are provided and radiological and nonradiological impacts are addressed. Radiological impacts to members of the public and workers are considered.

First, the nature of the problem is reviewed. As discussed in Chapter 3 and Appendix B, the refurbishment of the plants will produce additional LLW. For the typical case, increased "as-shipped" volumes for a BWR are estimated to be 220 m^3/year, and for a PWR 170 m^3 (Table B.4 of Appendix B). For the conservative case, higher volumes are estimated because of more extensive refurbishment. Major refurbishment activities are replacement of recirculating piping at BWRs and steam generator replacement for a PWR. The conservative case estimate for refurbishment waste is 1900 m^3 for a BWR and 2500 m^3 for a PWR. The analysis of refurbishing impacts included preparing wastes for shipment during the outages (e.g., see B.3.2.3 of Appendix B) but did not include inspection and any additional treatment or repackaging activities that might occur with extended on-site storage; however, on-site storage of steam generators was assumed and analyzed. Annual operating LLW that would be generated during the license renewal term is estimated to be about the same as current levels: 560 m^3 for BWRs and 250 m^3 for PWRs for the typical case (see Section 2.6.3.2) and for the conservative case, 11 percent higher volumes for BWRs and 30 percent higher for PWRs (see Section 2.6.4.2). For the typical case, the maximum stored volumes for the license renewal period, assuming no off-site capacity becomes available, would be about 20 times the annual value, or 11,200 m^3 for BWRs and 5,000 m^3 for PWRs. As Table 6.6 shows, based on historical data and DOE projections, the accumulated activities should remain about constant when decay is taken into account.

Extended storage is covered by the existing regulatory framework. Long-term storage of LLW at reactor sites has become necessary because of the slow pace of development of new off-site disposal facilities. In addition, utilities have opted for on-site storage for economic or other reasons. Utilities also store LLW that has been shipped off site for treatment (e.g., compaction, incineration) at commercial treatment facilities and returned for extended storage. Before licensees can build new storage facilities or make changes to the design or operation of the facility as described in the Safety Analysis Report (SAR), they must perform written safety evaluations under 10 CFR 50.59. This requirement applies to activities related to LLW, including long-term storage of LLW and mixed LLW. Under 10 CFR 50.59, licensees are allowed to make changes to their facility without permission of the NRC if the evaluation indicates that a change in the technical specifications is not required or that an unreviewed safety question does not exist. Licensees would have to ensure that the new LLW activities would not represent an unreviewed safety concern for routine operations or because of potential accidents. Both on-site and off-site impacts would have to be considered. If the LLW or mixed-LLW activity fails either of these tests, a license amendment is required. Thus, extended storage would be evaluated by the licensee, subject to inspection by NRC, or approved by NRC. Both licensee and NRC evaluations would include evaluation of anticipated compliance with applicable standards and requirements.

6.4.4.5.2 LLW Off-Site Radiological Impacts to Members of the Public

The storage of LLW is subject to several regulatory requirements related to potential public exposures. An overview of the regulatory requirements is given in Sections 3.8.1.1 and 6.2.2.5 and in Appendix E, but is repeated here. The basic provisions of 10 CFR Part 20 apply to all activities at the site. Part 20 contains both occupational and public dose limits, requirements for radiation safety programs that keep occupational and public doses and releases ALARA, survey and monitoring requirements, and reporting and record-keeping requirements. Part 20 also incorporates 40 CFR 190 [10 CFR 20.1301(d)], the EPA's general environmental standards for the uranium fuel cycle. NRC implements and enforces the limits in 40 CFR 190, which cover storage of LLW at the reactor site. The standards in 40 CFR 190 apply to the combined impacts from all uranium fuel cycle facilities and are expressed as annual dose limits for individual members of the public and annual quantity limits on certain radionuclides.[3] Therefore, any LLW activities should not result in doses and releases that would result in the site's failing to meet Part 190. Licensees are further limited by technical specifications to ensure compliance with the design objectives in Appendix I to 10 CFR Part 50. Appendix I design objectives are fractions of the limits in 10 CFR Part 20 and 40 CFR Part 190 and the dose range for doses to the whole body and organs is from 3 to 20 mrem/year. The numerical objectives in Section II of Appendix I state that:

> A. The calculated annual total quantity of all radioactive material above background [Footnote text: Here and elsewhere in this appendix background means radioactive materials in the environment and in the effluents from light-water-cooled power reactors not generated in, or attributable to, the reactors of which specific account is required in determining design objectives]. to be released from each light-water-cooled nuclear power reactor to unrestricted areas will not result in an estimated annual dose or dose commitment from liquid effluents for any individual in an unrestricted area from all pathways of exposure in excess of 3 millirems to the total body or 10 millirems to any organ.
>
> B.1. The calculated annual total quantity of all radioactive material above background to be released from each light-water-cooled nuclear power reactor to the atmosphere will not result in an estimated annual air dose from gaseous effluents at any location near ground level which could be occupied by individuals in unrestricted areas in excess of 10 millirads for gamma radiation or 20 millirads for beta radiation.
> 2. Notwithstanding the guidance of paragraph B.1.
> (a) The Commission may specify, as guidance on design objectives, a lower quantity of radioactive material above background to be released to the atmosphere if it appears that the use of the design objectives in paragraph B.1 is likely to result in an estimated annual external dose from gaseous effluents to any individual in an unrestricted area in excess of 5 millirems to the total body; and
> (b) Design objectives based upon a higher quantity of radioactive material above background to be released to the atmosphere than the quantity specified in paragraph B.1. will be deemed to meet the requirements for keeping levels of radioactive material in gaseous effluents as low as in reasonably achievable if the applicant provides reasonable assurance that the proposed higher quantity will not result in an estimated annual external dose from gaseous effluents to any individual in unrestricted areas in excess of 5 millirems to the total body or 15 millirems to the skin.
>
> C. The calculated annual total quantity of all radioactive iodine and radioactive material in particulate form above background to be released from each light-water-cooled nuclear power reactor in effluents to the atmosphere will not result in an estimated annual dose or dose commitment from such

radioactive iodine and radioactive material in particulate form for any individual in an unrestricted area from all pathways of exposure in excess of 15 millirems to any organ.

D. In addition to the provisions of paragraphs A, B, and C above, the applicant shall include in the radwaste system all items of reasonably demonstrated technology that, when added to the system sequentially and in order of diminishing cost-benefit return, can for a favorable cost-benefit ratio effect reductions in dose to the population reasonably expected to be within 50 miles of the reactor. As an interim measure and until establishment and adoption of better values (or other appropriate criteria), the values $1000 per total body man-rem and $1000 per man-thyroid-rem (or such lesser values as may be demonstrated to be suitable in a particular case) shall be used in this cost-benefit analysis.

The requirements of this paragraph D need not be complied with by persons who have filed applications for construction permits which were docketed on or after January 2, 1971, and prior to June 4, 1976, if the radwaste systems and equipment described in the preliminary or final safety analysis report and amendments thereto satisfy the Objectives on Design Objectives for Light-Water-Cooled Nuclear Power Reactors proposed in the Concluding Statement of Position of the Regulatory Staff in Docket-RM-50-2 dated February 20, 1974, pp. 25–30, reproduced in the Annex to this Appendix.

Reactor licensees conduct and are required to conduct extensive monitoring and surveillance programs to demonstrate compliance with the limits in the regulations and in technical specifications. Releases and direct radiation from LLW activities, including storage, would be evaluated and included in demonstrating compliance with these standards, which apply to the exposures from all activities at the site combined. The effectiveness of licensee ALARA and compliance efforts in response to these regulatory requirements are demonstrated by the low average doses received by members of the public from reactor operations. Inspection data since 1982 shows that effluents and direct radiation dose rates continue to decline. As doses to members of the public are calculated from this information, it is reasonable to assume that public doses have continued to decline as well.

Appendix E of this document presents historical data on effluents and doses to members of the public. While those who live nearest to NRC-licensed fuel-cycle facilities are in principle allowed to receive up to the 10 CFR Part 20 limit of 100 mrem/year, modified by the 25/75/25 mrem/year dose limits of 40 CFR 190, most receive only a small fraction of the allowable exposure. The ALARA programs in place to supplement the dose limit result in a system of dose control which achieves doses significantly below the limits. As a consequence of this approach, the average dose to most members of the public from NRC-licensed power reactor facilities is well below 1 mrem/yr (e.g., see Table 4.6, which shows that even for maximally exposed individuals, there are few instances of doses above 1 mrem/year, and Table 4.9, which presents 1988 data), and the contributions to this average dose from

LLW storage activities are significantly less than this average.

The effectiveness of controls at power reactors was also confirmed in EPA's proposed rule to rescind Subpart I of EPA's Clean Air Act regulations in 40 CFR 61 (56 FR 37196; August 5, 1991). The annual dose limits in 40 CFR 61 are 10 mrems total effective dose equivalent, of which no more than 3 mrems effective dose equivalent can be from radioiodines. EPA stated:

> Upon reconsideration of the standard, EPA conducted a review of the nuclear power reactor sector of the uranium fuel cycle and determined that the individual doses associated with nuclear power reactors are even lower than was previously estimated. This latest analysis revealed that the most exposed individual from emissions of nuclear power plants would be expected to receive a dose of less than 1.0 mrem/year EDE (effective dose equivalent) from all radionuclides and a dose of less than 0.01 mrem/year EDE from radioiodine. The estimated doses for these facilities are a factor of 10 less than the standard and are likely to remain low in the future.

Section 3.8 includes occupational and effluent data from actual steam generator replacements. The conclusion in 3.8.1.5 is that the effluents and doses have not been seen to differ significantly from normal operations. It is reasonable to conclude, then, that the incremental effluents and associated potential doses should be negligible from wastes after placement in storage facilities and/or packaging. Section 3.8.1.6 includes an estimate of 0.1 mrem/year as a maximum dose to an off-site person due to direct gamma dose from stored steam generators. This estimate should bound the potential public doses from on-site storage of refurbishment wastes. Section 3.8.1.6 also indicates that past storage facilities for the generators have provided sufficient shielding to limit the dose rate to less than 1 mrem/h outside the building.

Given its experience in inspecting licensees and in making determinations regarding compliance with existing requirements in this area, NRC has found that the actual doses and releases from LLW storage at plants have fallen within the applicable standards discussed above. Based on this past experience and the fact that NRC's regulatory program will continue to require compliance with the applicable regulations, including ALARA, NRC expects that the radiological impacts from LLW storage resulting from license renewal will neither deviate significantly from the kinds of impacts identified in the past nor exceed current regulatory requirements. NRC believes that doses and releases from LLW storage that fall within the range of current regulatory requirements should be considered small. The expected impact from on-site storage facility radiological effluents have been demonstrated to be a small fraction of those impacts allowed by regulation (Appendix I and 40 CFR 190).

6.4.4.5.3 LLW—Occupational

Tables B.4 and B.5 of Appendix B show total incremental occupational doses for refurbishing a BWR and a PWR. For the typical case, the values are 457 man-rem (4.57 man-sieverts) and 261 man-rem (2.61 man-sieverts), respectively. For the conservative case, the estimates are 2666 and 2374 man-rem (26.66 and 23.74 man-sieverts), respectively. These two sets of estimates compare to the actual exposure ranges for refurbishing projects mentioned in Section 3.8.2.2 of 2 to 3500 man-rem. Baseline data through 1992 is presented in Table 3.11 for the collective occupational dose per plant and average individual whole body dose. Anticipated average individual doses for refurbishing activities are based on experience in the early 1980s when significant post-TMI refurbishment took place and are estimated to be between 0.4 and 0.8 rem; the 1992 average dose was about 0.3 rem. It is reasonable to assume that the doses due to emplacement of the steam generators or piping or other LLW into on-site storage would be undetectable in view of the nature of the activities and the range of uncertainty in estimating doses. Doses from inspection in storage and further handling after significant decay should be similarly undetectable. Assuming the continued application of ALARA to mitigate and reduce occupational exposures, the staff is unaware of any reason that average occupational exposures from on-site storage of refurbishment LLW would not also be well within regulatory limits.

For routine operations, Section 4.6.3 presents baseline data and projected doses for license renewal. Baseline data (1992) includes a 0.28-rem average occupational dose and the fact that less than 0.5 percent of the workers received doses in excess of 2 rem. As plants age, slight increases in inventories and added maintenance, testing, and inspection would result in slight increases in occupational doses. Doses are projected to increase by 5 percent for the typical case and 8 percent for the conservative case. Considering the range and uncertainties of doses and the projected annual increase, occupational doses during the license renewal term are estimated to remain well within current regulatory limits (Section 4.6.3.3). The staff does not believe that on-site occupational exposures from LLW extended storage activities would be detectable in view of the range of doses and associated uncertainties.

Assuming the continued application of ALARA to mitigate and reduce occupational exposures, staff is unaware of any reason that occupational exposures from extended on-site storage of operational LLW would not continue to be well within current regulatory limits.

6.4.4.5.4 Nonradiological Impacts

Potential nonradiological impacts to be considered for extended on-site storage of LLW are the same as those considered for refurbishment in Sections 3.1 through 3.6 and include land use, fugitive dust, air quality impacts, erosion, sedimentation, and disturbance of ecosystems. Section 3.2 indicates that land use during a recent steam generator replacement was about 1 ha (about 2.5 acres) and that up to 4 ha (10 acres) may be needed. This calculation included training areas and other operational needs in addition to temporary storage of the steam generator. This disturbed area might be used for extended storage, or more remote locations on the site may be used to keep occupational exposures ALARA. Only a fraction of the area should be needed for extended storage of refurbishment or operational LLW. Earlier in this chapter, areas are estimated to be a few tenths of an acre for a storage facility and a few acres for a buffer zone around the facility, based on current experience at several reactors. The facilities might need to double or quadruple the storage volumes for the operational waste during the renewal term, but land use would still be small. Any land used would already be under the control of the utility.

Section 3.3 concludes that the small size of the area to be disturbed for refurbishing activities and the likely mitigating management practices should result in minimal fugitive dust. Because the amount of land for extended storage facilities should be even smaller and the mitigating practices should apply, fugitive dust is not a concern for storage. Section 3.3 concludes that vehicle exhaust emissions could be a concern for a large number (e.g., 2300) of additional worker vehicles in nonattainment zones. Extended on-site storage facility construction would involve far fewer workers, and inspection and maintenance even fewer. As noted in Section 3.4.1, only modest amounts of site excavation and grading should be involved in construction of any LLW storage facility, and no unusual practices are involved. Mitigating measures routinely practiced at the plants should mitigate surface water impacts, including erosion and sedimentation. Ecological impacts could be associated with any new construction at a site, including LLW storage facilities. However, with the small size of the facilities and the flexibility of location for extended storage facilities (as opposed to short-term storage near the plant during refurbishing), it is expected that ecological concerns will be routinely addressed by the applicant in the design of the project. Routine monitoring and inspection of LLW extended storage facilities during the license renewal period should not have any significant nonradiological impacts.

6.4.4.6 LLW Conclusions

The comprehensive regulatory controls that are in place and the low public doses being achieved at reactors ensure that the radiological impacts to the environment will remain within regulatory standards and therefore will be small during the term of a renewed license. The maximum additional on-site land that may be required for LLW storage during the term of a renewed license and associated impacts will be small. Nonradiological impacts on air and water will be negligible. The radiological and nonradiological environmental impacts of long-term disposal of LLW from any individual plant at licensed sites are small. The need for the consideration of mitigation alternatives within the context of renewal of a power reactor license has been considered, and the Commission concludes that its regulatory requirements already in place provide adequate mitigation incentives. In addition, the Commission concludes that there is reasonable assurance that sufficient LLW disposal capacity will be made available when needed for facilities to be decommissioned consistent with NRC decommissioning requirements. LLW storage and disposal will have small environmental impacts. This is a Category 1 issue.

Although the impacts of limited and extended on-site storage of LLW that would be generated during the renewal period have been evaluated and found to be small, concern has been expressed that the slow progress that has been made in developing disposal capacity for LLW could result in extended storage of LLW at nuclear power plants. NRC recognizes that no state or compact has completed its work in developing new LLW disposal facilities. However, in NRC's view, there are no unsolvable technical issues that will inevitably preclude successful development of new sites or other off-site disposal capacity by the time they will be needed. NRC's experience in developing the requirements and guidance for licensing LLW disposal facilities under 10 CFR Part 61, as well as the successful licensing of the Envirocare disposal facility by the state of Utah, support the conclusion that safe LLW disposal is technically feasible. Opening the Barnwell site to all states but North Carolina in July 1995 also reflects the lack of insolvable technical issues. There are uncertainties in the licensing process and in the length of time needed to resolve technical issues, but we would expect that they are resolvable. For example, in California, the proposed Ward Valley disposal facility was unexpectedly delayed by the need to resolve technical issues raised by several scientists independent of the project after the license was issued. These were recently reviewed and largely resolved by an independent review group. In North Carolina, Texas, and Nebraska, the license application review period has been longer than what is required by the Low-Level Radioactive Waste Policy Amendments Act of 1985, but many issues for each of the proposed facilities have been resolved, and progress on other issues continues to be made. Further, it should not be unexpected today that states and compacts would face difficult obstacles of a political and legal nature as they seek to fulfill their responsibilities for providing disposal capacity. Nonetheless, we believe that the states and compacts possess the determination and the processes to address these obstacles, and we are not prepared to say they will be unsuccessful in doing so; on the contrary, their progress, although slow, supports our conclusion of eventual success. Therefore, the staff conclusion that either on-site or off-site storage of LLW as a Category I issue is appropriate because states are proceeding, albeit slowly, with the development of new disposal facilities and because LLW has been and can be safely stored at reactor sites until new disposal capacity becomes available.

6.4.5 Mixed Waste

Mixed waste contains both hazardous waste and source, special nuclear, or byproduct material as defined in the Atomic Energy Act (AEA) of 1954 (42 U.S.C. 2011 et seq.). Although nuclear power plants, on average, are not significant generators of mixed waste, the management of this waste is problematic because of a lack of sufficient waste treatment and disposal capacity for specific types of mixed wastes. The current situation may be complicated by a lack of economic incentives (i.e., sufficient market demand for commercial mixed waste treatment) necessary to accelerate the development of new treatment or disposal capacity. Currently, there is only one facility providing disposal for certain types of mixed waste, while four other companies provide treatment for a limited number of mixed-waste streams. A lack of treatment capabilities and technologies, in combination with a complex regulatory system, makes the environmentally sound management of mixed-waste a significant challenge for all commercial mixed-waste generators, including nuclear power plant operators.

The management of mixed waste at nuclear power plants is jointly regulated by NRC under the AEA and by EPA or authorized states under the Resource Conservation and Recovery Act of 1976 (RCRA). The NRC or the NRC agreement states and EPA or EPA authorized states regulate off-site disposal. Nuclear power plants managing mixed waste must meet the NRC requirements for general radiation protection and emission control requirements and for LLW specified in

10 CFR 61 and EPA's requirements for hazardous waste in 40 CFR Parts 261, 264, and 265 (DOE/RW-0006) before final transfer off site in route to burial. Mixed wastes are also subject to land disposal restrictions (LDRs) in 40 CFR 268, except for newly listed hazardous wastes that are mixed with radioactive material and do not yet have EPA standards. The requirement for treating specific hazardous constituents of mixed waste (chlorinated fluorocarbons, lead, etc.) before land disposal is a contingency not faced in the management of LLW.

6.4.5.1 Generation

U.S. commercial low-level mixed waste consists of a variety of waste streams from a diverse set of generators, including government, academic, and industrial sectors, as well as nuclear utilities and medical facilities. Mixed-waste generation in the United States for 1990 was estimated at 139,441 ft^3 (3,949 m^3), of which nuclear power plants produced about 13,626 ft^3 (385.8 m^3) (less than 10 percent).

Mixed waste generated by nuclear power plants covers a broad spectrum of waste types. As shown in Table 6.13, the vast majority of mixed waste in storage at nuclear power plants was chlorinated fluorocarbons (CFCs) and waste oil. These wastes represented approximately 40 percent and 23 percent of the total stored mixed waste, respectively. In contrast to other commercial mixed-waste generators, nuclear power plants produce relatively small volumes of liquid scintillation fluids. Overall, mixed waste from nuclear power plants represented approximately 34 percent of the total mixed-waste volume in storage at the end of 1990. Table 6.13 is based on data from 76 of 78 nuclear facilities surveyed for the NRC and EPA (a facility may contain one or more reactors with common waste handling).

Based on data from the *National Profile on Commercially Generated Low-Level Radioactive Mixed Waste* (NUREG/CR-5938), mixed waste is not distributed uniformly among all nuclear power plants but is concentrated at a relatively few power plants. The average mixed waste generation in 1990 for the category "nuclear utilities" was 175 ft^3 (5 m^3) per facility. Twenty-four facilities reported no mixed-waste generation in 1990, while four facilities reported over 1000 ft^3 (28 m^3) of mixed-waste generation. One facility was responsible for approximately 24 percent of the mixed waste generated, while that facility and three others were responsible for over 60 percent of the mixed waste generated during 1990 (J. Klein, Oak Ridge National Laboratory, letter to L. N. McCold, Oak Ridge National Laboratory, July 3, 1993).

Variability in volume and type of mixed waste produced by nuclear power plants means that those plant operators that produce relatively large mixed-waste volumes annually may find it more difficult to comply with mixed-waste storage regulations. Specifically, the current EPA policy of ascribing a lower enforcement priority for violations of its storage prohibitions for LDR mixed waste expressly excludes generators that produce more than 1000 ft^3/year (28 m^3/year) of hazardous and mixed waste (L-S/488364).

6.4.5.2 Storage

The current lack of mixed-waste treatment and disposal capacity requires nuclear

Table 6.13 Nuclear power plant mixed waste generation profile for 1990, in cubic feet

Hazardous stream	Amount generated in 1990	Amount treated on site in 1990	Amount treated off site in 1990	Amount generated in 1990 that cannot be currently treated	Amount in storage at the end of 1990
Organics					
Liquid scintillation fluids	11	0	4	0	168
Waste oil	4,709	4,326	562	303	5,061
Chlorinated organics	50	0	0	5	512
Fluorinated organics	0	0	0	0	0
Chlorinated fluorocarbons	3,679	118	12	889	8,600
Other organics	1,154	15	7	79	1,284
Metals					
Lead	1,231	0	8	123	4,451
Mercury	4	0	0	2	416
Chromium	254	138	0	38	757
Cadmium	8	3	0	0	11
Aqueous corrosives	156	24	0	23	361
Other hazardous materials	2,369	168	2,274	8	363
Total	13,625	4,792	2,867	1,470	21,984

Note: Treatment and storage data are not necessarily additive because waste in either category may have been generated before 1990. Mixed waste that currently cannot be treated represents waste that may be difficult or even impossible to dispose of because of a lack of acceptable treatment capability or disposal capacity.

Source: NUREG/CR-5938.

power plant operators to store much of their mixed waste on site. As noted above, only one company in the United States (Envirocare of Utah, Inc.) currently provides disposal capacity for certain types of mixed waste, while four companies have treatment capabilities for certain types of mixed-waste constituents. The joint EPA and NRC survey referenced above estimated a treatment capacity shortfall of at least 12,000 ft^3 (340 m^3) based on treatment demand in 1990. The shortfall particularly affects CFCs, solid lead, and mercury mixed-waste streams. In 1991, EPA officially recognized that a treatment shortfall exists for many commercial low-level mixed-waste streams, including those generated by nuclear power reactors. Subsequent interviews by EPA with waste treatment vendors revealed that there has been little change in the availability of treatment capacity since EPA announced in 1991 that it would not pursue civil fines for those mixed-waste generators where sufficient treatment capacity of LDR-prohibited waste was not available.

Occupational exposures occur during the testing of mixed wastes (particularly decontamination wastes and ion exchange resins) to determine if constituents are chemically hazardous. A second occupational exposure impact of mixed waste is from on-site storage and handling (Rogers 1990). It has been estimated that the largest single exposures result from samples being collected when lead blankets have not been used to shield pipes and valves (Rogers 1990).

Occupational exposures from on-site storage have been shown to be reduced by the application of waste-minimization technologies and procedures (Rogers 1990). In addition, the potential for exposure can be reduced by remote sampling methods currently under development. Remote evaluation methods include classifying waste streams as mixed through the application of knowledge about processes that generate waste streams and substituting closed-circuit television using high-resolution monitors for weekly inspections by facility personnel (Rogers 1990). The latter method can determine if sufficient deterioration of a container has occurred to warrant proximate visual inspections.

Pursuing environmentally responsible management of mixed wastes is critical to minimizing occupational exposures as well as preventing waste from entering the accessible environment through various air and groundwater pathways. Specifically, records must be maintained identifying each physical location or unit where mixed waste is stored and identifying the method of storage [40 CFR 264.73(b) and 265.73(b)]. An inspection of these storage areas for compliance with applicable RCRA standards for storage methods, including an assessment of compliance with storage facility standards of 40 CFR 264 or 265 (interim status) should be performed regularly (see 40 CFR 264.15 and 265.15).

Facility owners/operators are required by RCRA regulations to maintain sufficient information to identify their mixed wastes. The information required includes RCRA waste codes for the hazardous components, the source of the hazardous constituents and discussion of how the waste was generated, the generation rate and volumes of mixed waste in storage, and any information relied upon to identify mixed wastes or make determinations that the wastes are prohibited by LDRs.

Finally, under RCRA regulations, each facility owner/operator is required to develop a waste-minimization plan that identifies process changes that can be made to reduce or eliminate mixed wastes, methods to minimize the volume of regulated wastes through better segregation of materials, and the substitution of nonhazardous materials. The plan must include a schedule for implementation, projections of volume reductions to be achieved, and assumptions that are critical to the accomplishment of the projected volume reductions (L-S/488364).

6.4.5.3 Disposal

There is currently only one facility that provides disposal capacity for certain types of mixed waste: Envirocare of Utah, Inc. Envirocare has a RCRA Part B permit from the Utah Division of Solid and Hazardous Waste, allowing the receipt, storage, and disposal of certain types of low-activity mixed wastes that are both radioactive and hazardous at its South Clive facility. The combination of stringent LDRs for hazardous waste constituents, the associated lack of treatment capacity for particular types of mixed wastes, and the absence of permitted disposal facilities all contribute to the need for many utilities to store their mixed wastes on site.

6.4.5.4 Effects of License Renewal

Mixed waste will continue to be generated by routine maintenance activities, refueling outages, health physics activities, and radiochemical laboratory activities both before and after the completion of license renewal. However, plant refurbishments and extended power plant operations are not expected to increase volumes of mixed waste generated significantly because of continued progress in reducing mixed-waste generation (Rogers 1990). Because refurbishments and nuclear power plant operations are conducted in compliance with applicable NRC and EPA regulations governing the storage and disposal of mixed wastes, exposures will be minimized (10 CFR 20; 10 CFR 61; 40 CFR 264 and 268).

The development and commercialization of noninvasive mixed-waste characterization technologies and treatment capacity would produce several benefits: it would reduce (1) the generation of secondary waste streams, (2) worker exposures to hazardous and radioactive materials, and (3) on-site inventories of untreated mixed waste. While there is reason to be optimistic that lower generation rates and new treatment capabilities will reduce on-site inventories, certain inventories will continue to grow because the relatively small amount of mixed waste generated across all generator categories has not provided sufficient economic incentives (i.e., market demand) required to stimulate a rapid expansion in treatment capabilities.

Despite the current lack of mixed-waste treatment and disposal capacity, new-mixed waste treatment and disposal capacity may still occur prior to license renewal activities. Specifically, DOE's need to develop extensive new mixed-waste treatment capabilities should benefit utilities requiring additional off-site treatment capabilities. DOE generates approximately 2,860,000 ft^3 (81,000 m^3) of mixed waste per year and has approximately 6,320,000 ft^3 (179,000 m^3) of mixed waste in storage, dwarfing the mixed-waste management requirements of other commercial generators (DOE/LLW-180). The mixed-waste inventory conducted by NRC and EPA has revealed that the characteristics of commercial mixed wastes are, for the most part, very similar to those produced by DOE. The development by DOE of new mixed-waste technologies and/or its willingness to accept nuclear utility low-level mixed waste for treatment and disposal could dramatically reduce on-site waste inventories associated with license renewal as well as produce significant economies of scale.

6.4.5.5 Regulations Applicable

NRC (10 CFR Part 20 and LLW requirements in 10 CFR Part 61) and EPA RCRA regulations.

6.4.5.6 Impacts of Extended On-Site Storage of Mixed Low-Level Waste

Preceding sections have discussed mixed waste from refurbishment and continued operations and presented the more likely events and impacts. The earlier discussion indicated that mixed-waste treatment and disposal capacity may become available before or during the license renewal period and that DOE acceptance of commercial

LLW for treatment and disposal may provide relief. This additional section separately addresses the less likely scenario of on-site storage of both refurbishment and operational mixed LLW for the renewal period of approximately 20 years. Summary data are provided and radiological and nonradiological impacts are addressed. Radiological impacts to members of the public and workers are considered.

6.4.5.6.1 Mixed Waste Off-Site Radiological Impacts to Members of the Public

Mixed LLW generation is highly variable but projected to be about 5 m^3/year per plant, which is less than 3 percent of the LLW volumes (see Section 2.3.7.3 and the discussion in earlier in this chapter). Mixed waste is subject to additional regulatory requirements on containment. For example, RCRA hazardous regulations require maintenance of container integrity, berms, and other catchment means for capturing leaks to prevent or minimize releases of hazardous materials to the environment. Based on the results of the national mixed-waste profile discussed earlier, the predominant waste forms generated by the utilities were slightly contaminated waste oil (35 percent), chlorofluorocarbons (27 percent) and others (38 percent). The Rogers report (Rogers 1990) evaluated potential mixed-waste forms, including three types of resins, sludges, dry active waste, and absorbed liquids. While all mixed waste generated might be stored on site for the license renewal period if adequate treatment and disposal capacities or DOE acceptance of commercial mixed waste are delayed until near the end of the renewal period, the accumulated volumes will be small when compared to LLW volumes. Incremental effluents and doses to members of the public should be minimal and are subject to the same regulatory limits and enforcement as LLW and are included in the overall facility performance findings.

Off-site disposal impacts, as well as the impacts of limited and extended on-site storage of mixed waste that would be generated during the renewal period have been evaluated and found to be small. However, concern has been expressed that the limited progress that has been made in developing disposal capacity for LLW and mixed waste could result in extended storage of mixed waste at nuclear power reactors. Mixed-waste-disposal facility developers face the same types of legal and political challenges as LLW site developers. In addition, the administrative uncertainties of joint regulation and the economics of developing treatment and disposal capacity for the small volumes of mixed waste that are generated at licensed facilities have proven to be disincentives to the development of mixed-waste-disposal facilities.

In NRC's view, however, there are no technical reasons why off-site disposal capacity for all types of mixed waste should not become available when needed. NRC and EPA have developed guidance on the siting of mixed-waste-disposal facilities as well as a conceptual design for a mixed-waste-disposal facility. The agencies are currently cooperating on developing additional guidance on testing and storage of mixed waste. A disposal facility for certain types of mixed waste has been developed by Envirocare in Utah. Depending on the characteristics of the mixed waste, on-site or off-site treatment may allow disposal of certain mixed wastes as purely LLW. As discussed above, DOE is working to establish treatment technologies for its mixed wastes, many of which have characteristics similar to commercial mixed waste, and EPA is issuing treatment standards that will permit mixed wastes to be land disposed. In NRC's view, the foregoing activities support the conclusion that safe disposal of mixed waste is technically feasible. Further, states have begun discussions with DOE about accepting commercial mixed for treatment and disposal at DOE facilities. Although these discussions have yet to result in DOE's accepting commercial mixed waste at DOE facilities, it appears that progress is being made towards DOE's eventual acceptance of some portion of commercial mixed waste at its facilities.

Given the technical feasibility of mixed-waste disposal, the states' responsibilities for providing LLW (and thus mixed-waste) disposal capacity and DOE's obligations under the FFCA to develop treatment and disposal capacity for its mixed waste, NRC believes that there will eventually be sufficient economic incentives to overcome nontechnical obstacles and to find cost effective ways to dispose of mixed waste. While the NRC understands that there have been some delays and that uncertainties exist, the staff concludes that there is reasonable assurance that sufficient mixed-LLW-disposal capacity will be made available when needed for facilities to be decommissioned consistent with NRC decommissioning requirements. Thus, in summary, mixed LLW will result in only a small environmental impact, taking into account both storage at a reactor site and disposal at an appropriate disposal site.

6.4.5.6.2 Occupational

Estimates of incremental occupational exposures from short-term and extended storage of mixed LLW have been made (Rogers 1990). The estimates were developed to evaluate ALARA problems for radiation exposures from compliance with RCRA sampling and inspecting requirements. When mixed LLW can be shipped immediately, doses from inspections were estimated to be about 3 man-rem per plant. With five years of accumulated mixed wastes, inspection exposures could rise to 100 man-rem/year per plant. Mitigating measures, including remote inspection, were considered essential to meet ALARA requirements. The doses in these estimates were based on assumed volumes and activities that should bound potential doses, since "these inventories are believed to represent conservatively high estimates of reactor-generated mixed wastes." (Rogers 1990). While sampling and handling were estimated to potentially result in significant doses in the 1990 study, absent ALARA mitigation such as use of lead blankets on contaminated piping with high exposure rates, they are included in current baseline exposures. The staff concludes that ALARA mitigating measures will continue to be developed and implemented by the utilities and RCRA regulatory authorities and that, even with the contribution of incremental occupational doses from extended storage, total individual occupational doses will continue to be will within regulatory limits and thus will be small.

6.4.5.6.3 Nonradiological

Because the volumes of mixed waste represent 3 percent or less of LLW volumes and because no significant emissions or releases of hazardous materials are expected, the staff concludes that the findings for LLW remain valid when both LLW and mixed-LLW impacts are considered.

6.4.5.6.4 Conclusion

The storage and disposal of mixed waste will continue to be accomplished well within regulatory limits. The comprehensive regulatory controls and the facilities and procedures that are in place ensure proper handling and storage, as well as negligible doses and exposure to toxic materials for the public and the environment at all plants. License renewal will not increase the small, continuing risk to human health and the environment posed by mixed waste at all plants. The radiological and nonradiological environmental impacts of long-term disposal of mixed waste from any individual plant at licensed sites are small. The need for consideration of mitigation alternatives within the context of renewal of a power reactor license has been considered and the Commission concludes that its regulatory requirements already in place provide adequate mitigation incentives for on-site storage of mixed waste and that, for off-site disposal, mitigation would be a site-specific consideration in the licensing of each facility. In addition, the Commission concludes that there is reasonable assurance that sufficient mixed-waste-disposal capacity will be made available when needed for facilities to be decommissioned consistent with NRC decommissioning requirements. The environmental impacts of mixed-waste storage and disposal will continue to be small during the license renewal period. This is a Category 1 issue.

6.4.6 Spent Fuel

Spent nuclear fuel is fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated. When spent fuel is removed from reactors, it is stored in racks placed in pools to isolate it from the environment and to allow the fuel rods to cool. Licensing plans contemplate disposal of spent fuel in a deep geological repository. Delays in siting an interim monitored retrievable storage (MRS) facility and permanent repository, as required by the Nuclear Waste Policy Act of 1982 as amended (Pub. L. 97-425 and 100-123), coupled with rapidly filling spent-fuel pools at some plants, have led utilities to seek means of continued on-site storage. These include expanded pool storage (through repacking and double tiering), above-ground dry storage, longer fuel burnup to reduce the amount of spent fuel requiring interim storage, and shipment of spent fuel to other plants. The total inventory of spent fuel in storage in the United States as of December 31, 1992, was 91,039 assemblies. Of these, 87,591 assemblies were in storage at 118 reactors that have been or are discharging and/or storing nuclear fuel assemblies, including 903 assemblies in independent spent-fuel storage installations (ISFSIs) at Virginia Power's Surry plant, Carolina Power and Light Company's Robinson 2 plant, and Duke Power Company's Oconee plant. An additional 3,448 assemblies have been shipped to away-from-reactor storage facilities. This compares to the total licensed capacity for storage of spent nuclear fuel in the U.S. of 205,731 assemblies (SR/CNEAF/94-01). This section addresses the availability of interim on-site storage capacity for spent fuel (until an MRS or permanent repository is available) and the potential environmental effects of that interim storage.

6.4.6.1 Baseline

DOE is responsible for taking possession of spent fuel from nuclear power plants in 1998 for interim storage in an MRS, followed by permanent disposal in an underground repository (Pub. L. 97-425; Pub. L. 100-123; Gerstberger; DOE March 1987; Parker; Bartlett). However, the original 1998 target date for opening the repository will not be met, and the availability of an MRS on that date is also in serious doubt. DOE now expects to complete site characterization work at Yucca Mountain, the only location being investigated as a permanent repository, by 2002 and expects that a geologic repository will be ready no sooner than 2010 (NWTRB 1993; DOE/RW-0307P-6). Many plants have limited in-pool storage capacities and are turning to fuel pool expansion, above-ground dry storage, and longer fuel (Gilbert et al. 1990). Industry-wide, 24 plants may run out of pool storage space by the year 2000, and 81 will have run out of pool storage space by 2010, if DOE is unable to accept spent fuel in an MRS or for disposal in a permanent repository (SR/CNEAF/94-01). Of the ten sample plants, three will have exhausted their pools by 2000. The projected year of pool storage space exhaustion for the ten sample plants is given in Table 6.14. Deferral of an MRS or permanent repository would necessitate longer at-reactor storage and would exacerbate current storage capacity limitations (SR/CNEAF/94-01).

Table 6.14 Projected year of pool storage space exhaustion for the ten sample plants

Plant	Year of storage space exhaustion
Hatch 1	2003
Hatch 2	2004
Limerick 1	2000
Limerick 2	1996
Vermont Yankee	2004
WNP-2[a]	1999
Comanche Peak 1	2020
Comanche Peak 2	2021
D. C. Cook 1 and 2	2011
Indian Point 2	2003
Indian Point 3	2006
Robinson	2002
San Onofre 2 and 3	2005
Surry 1	2012
Surry 2	2013

[a] WNP-2 = Washington Nuclear Project 2.

Although plants running out of storage space may enter into agreements with others that have space for sale or lease, this approach is widely viewed as an interim measure practical only for utilities that own more than one nuclear plant (Asselstine 1985; DOE/RW-0187). Interim storage needs vary among plants, with older units likely to lose pool storage capacity sooner than newer ones. Robinson, for example, owned by Carolina Power and Light, has shipped some spent fuel to Shearon Harris, which is owned by the same utility. Transfer of spent fuel from one nuclear plant site to another requires authorization by the receiving plant's operating license (55 FR 29181).

Table 6.15 lists historic and projected trends for spent-fuel discharges and radioactivity levels for LWRs. Projections in Table 6.15 are based on the assumptions that (1) no new units will enter operation, (2) installed capacity will gradually decline, (3) no spent fuel removed from reactors will be reinserted for further irradiation later, and (4) average burnup rate of spent fuel at all LWRs will increase by nearly one-third by 2000 (DOE/RW-0006). In the conservative scenario depicted in Table 6.15, annual spent-fuel discharges are expected to decline for BWRs and PWRs early in the next century. However, total accumulated spent-fuel volumes will more than triple between 1990 and 2020. Thus, continued storage of spent fuel on site may be an issue for some utilities regardless of their license renewal plans. At-reactor pool storage capacity has been increased under original operating licenses through (1) enlarging the capacity of spent-fuel racks, (2) adding racks to existing pool arrays ("dense-racking"), (3) reconfiguring spent fuel with neutron-absorbing racks, and (4) employing double-tiered storage (installing a second tier of racks above those on the pool floor). Each of these methods requires both the repackaging of spent-fuel rods and the handling associated with fuel bundles and racks.

Zircalloy-clad fuel bundles do not appear to degrade as a result of long-term pool storage (Gilbert et al. 1990), and accidental damage to spent-fuel bundles through mishandling or component failure during emplacement or removal from pools has occurred infrequently. A few spent-fuel assemblies have been inadvertently dropped or mishandled. A small fraction of these assemblies has suffered major mechanical damage through such incidents. In most cases, when spent-fuel assemblies were damaged during handling (mostly during refueling operations, with only 10 percent occurring within the spent-fuel pool), only minor degradation of fuel-bundle components occurred. No cases of breaching of fuel cladding or release of radioactive gases or solids to the environment have been reported (EPRI NP-3765; Bailey 1990). Operational incidents involving spent-fuel pools have occurred infrequently. One incident, at Hatch in December 1986, took place during an exceptional handling procedure in a transfer canal between two pools. At Turkey Point, the failure of a circulation pump in August 1988 led to a breach of pool containment and the flow of water into a closed-loop canal, confining the radiation release on site. While the safety significance of both events appears to have been low, subsequent inspection and enforcement actions have been instituted by NRC to reduce the likelihood of such occurrences in the future (55 FR 38472). NRC has also found that, even under the worst probable cause of a loss of spent-fuel pool coolant (a severe seismic-generated accident causing a catastrophic failure of

Table 6.15 Historic and projected spent-fuel inventories from commercial light-water reactors, 1970–2030 (not including license renewal)

Year	Fuel assemblies		Mass (MTIHM)[a]		Radioactivity (10^6 Ci)[b]	
	Annual	Total	Annual	Total	Annual	Total
			Boiling-water reactors			
Historic						
1970		6	16	1	11	
1971		64	80	190	197	
1972		142	222	431	466	
1973		95	317	349	441	
1974		245	561	908	1,042	
1975		226	787	920	1,218	
1976		297	1,084	1,151	1,581	
1977		383	1,467	1,566	2,129	
1978		383	1,850	1,618	2,412	
1979		400	2,250	1,734	2,728	
1980		620	2,870	2,685	3,888	
1981		459	3,329	2,014	3,664	
1982		357	3,686	1,582	3,362	
1983		491	4,177	2,218	4,015	
1984		498	4,675	2,211	4,283	
1985		515	5,190	2,246	4,519	
1986		458	5,648	1,963	4,404	
1987		699	6,347	2,919	5,411	
1988		536	6,883	2,363	5,177	
1989		715	7,598	3,090	6,038	
1990		633	8,231	2,821	6,101	
1991		588	8,819	2,696	6,186	
1992		729	9,547	3,359	7,037	
Projected						
1995	4,700	64,600	800	11,700	4,000	8,600
2000	3,900	82,400	700	14,800	3,300	9,100
2005	3,100	100,500	500	18,000	2,700	9,600
2010	3,800	120,500	700	21,500	3,200	11,100

See footnotes at end of table.

Table 6.15 Historic and projected spent-fuel inventories from commercial light-water reactors, 1970–2030 (not including license renewal)

Year	Fuel assemblies		Mass (MTIHM)[a]		Radioactivity (10^6 Ci)[b]	
	Annual	Total	Annual	Total	Annual	Total
2015	2,100	139,600	400	24,800	1,900	10,800
2020	1,700	150,000	300	26,700	1,500	9,600
2025	2,200	162,000	400	28,800	1,900	10,000
2030	0	165,900	0	29,500	0	7,000
			Pressurized-water reactors			
Historic						
1970		39	39	204	204	
1971		44	83	247	296	
1972		100	183	545	638	
1973		67	250	374	571	
1974		208	458	1,098	1,320	
1975		322	780	1,683	2,098	
1976		401	1,181	2,222	2,894	
1977		467	1,648	2,660	3,677	
1978		699	2,347	4,030	5,428	
1979		721	3,068	4,185	6,254	
1980		618	3,686	3,667	6,248	
1981		676	4,362	4,025	6,887	
1982		640	5,002	3,797	7,037	
1983		772	5,775	4,590	8,077	
1984		842	6,616	4,978	8,943	
1985		861	7,478	5,196	9,641	
1986		1,001	8,478	5,969	10,909	
1987		1,114	9,592	6,687	12,240	
1988		1,125	10,717	6,865	13,132	
1989		1,227	11,944	7,422	14,347	
1990		1,532	13,476	9,405	17,026	
1991		1,298	14,774	8,049	16,881	
1992		1,601	16,375	10,032	19,374	

See footnotes at end of table.

Table 6.15 Historic and projected spent-fuel inventories from commercial light-water reactors, 1970–2030 (not including license renewal)

Year	Fuel assemblies		Mass (MTIHM)[a]		Radioactivity (10^6 Ci)[b]	
	Annual	Total	Annual	Total	Annual	Total
Projected						
1995	3,500	48,200	1,500	20,700	9,800	21,400
2000	3,300	63,400	1,400	27,300	9,400	23,700
2005	2,900	78,700	1,300	33,800	8,500	25,500
2010	2,500	93,600	1,100	40,200	7,400	26,900
2015	1,900	106,900	800	46,000	5,600	26,800
2020	1,600	116,000	700	50,000	4,800	24,900
2025	1,200	123,200	500	53,100	3,500	23,000
2030	300	127,000	100	54,800	900	18,000
		Total spent fuel (all light-water reactors)—projections				
1995	8,200	112,800	2,300	32,400	13,800	29,900
2000	7,200	145,800	2,100	42,100	12,700	32,800
2005	6,100	179,200	1,800	51,800	11,200	35,100
2010	6,400	214,100	1,800	61,700	10,600	38,000
2015	4,000	246,400	1,200	70,800	7,500	37,600
2020	3,300	266,000	1,000	76,700	6,300	34,500

[a] MTIHM = metric tons of initial heavy metal; 1 metric ton equals 2204.62 lb.

[b] Curies; 1 curie = 37 × 10^9 becquerels.

Source: DOE/RW-0006, Rev. 9.

the pool), the likelihood of a fuel-cladding fire is highly remote (55 FR 38474).

Inadvertent criticality and acute occupational exposure are remote risks of dense-racking (DOE/RW-0220). NRC requires licensees to ensure against inadvertent criticality in fuel storage facilities by limiting quantities of stored fuel and by regulating the configuration of fuel bundles (NUREG-0575; 10 CFR 50). The latter includes regulating proper spacing between spent-fuel assemblies and using boron carbide in storage racks (DOE/RW-0220).

Dry storage technologies such as casks, silos, dry wells, and vaults have been developed in conjunction with dry-rod consolidation (EPRI NP-3765; Gilbert et al. 1990; Schneider et al. 1992). Monitoring of occupational exposure in pilot studies of dry-rod consolidation indicates that, because of reliance on remote manipulation techniques, doses received by workers are similar to those from normal fuel movement, in-service inspection, and repair activities (Gerstberger 1987; Zacha 1988; Johnson 1989). In addition, dry storage generates no LLW. Ten countries have at least small amounts of spent nuclear fuel in dry storage, with Canada, the United Kingdom, and the United States having industrial-scale facilities (Schneider et al. 1992). Dry storage appears to be a safe, economical method of spent-fuel storage (Roberts 1987; Johnson 1989). Fuel rods in dry storage appear to be environmentally secure for long periods of time (EPRI NP-3765). Dry storage is also simpler and more readily maintained than spent-fuel pools (DOE/RW-0220; 55 FR 38472).

All U.S. commercial nuclear reactors that are storing or planning to store nuclear fuel assemblies in an ISFSI are covered in Table 6.14, which lists data for each of these utilities and affected reactors. Utilities are listed by the date the dry storage license was issued. Environmental assessments for operational ISFSIs at these plants (in a number of different regions) indicate that long-term material and system degradation effects are minimal and that licensees can ensure the use of such systems in full compliance with health, safety, environmental, and safeguards and security criteria (55 FR 29181).

The three utilities that currently use the Nutec Horizontal Modular Storage (NUHOMS) Spent Fuel Storage System are Baltimore Gas and Electric Company, Carolina Power and Light Company, and Duke Power Company. Both GPU Nuclear Corporation and Sacramento Municipal Utility District plan to employ the NUHOMS system. The system consists of three major safety-related components: a dry shielded canister (DSC), which provides a high-integrity containment boundary; a controlled concrete horizontal storage module (HSM), which houses the stored DSC and provides radiation shielding, protection against natural phenomena, and an efficient means for decay heat removal; and a transfer cask, which provides for the safe shielded transfer of the DSC from the plant spent-fuel pool to the storage module. The NUHOMS system is designed and licensed to meet the requirements of 10 CFR 72 and ANS/ANSI 57.9 for ISFSIs.

From the standpoint of emergency preparedness, the impacts of dry cask storage installations should be minor for three reasons. First, because of the reduced radioactive inventory in the fuel stored in dry cask facilities, accidents involving such storage facilities are likely to develop more slowly than those involving the nearby operating reactors. Second, accident impacts should be low, again because of the reduced inventories of radioactive materials in the stored fuel but also because of the correspondingly reduced level of decay heat compared with fuel still in-reactor. Thus, emergency plans formulated for operating reactors should encompass accidents at dry cask storage facilities. Third, it is NRC policy that plants with dry cask storage facilities incorporate the potential sources of hazard from these storage facilities in their emergency plans, as well as the potential hazard from all radiological source terms at the plant site.

Table 6.16 shows present and anticipated spent-fuel management methods in 8 of the 10 plants in the study sample. Practices in these eight plants are illustrative of industry-wide trends. While pool storage remains the most widespread method of spent-fuel management, dry storage and extended burnup are actively under development, mirroring national trends. NRC-licensed, full-scale demonstrations of

Table 6.16 Spent-fuel management in eight sample plants and industry-wide: present and anticipated

Plant	Reracking[a]	Dry storage	Longer burnup[b]	Other[c]	Additional[d] construction
		Plant sample			
Hatch	Yes	No	Yes	No	No
Robinson	Yes	Yes	Yes	Yes	Yes
Indian Point 2	Yes	Under study	Under study	Yes	No
Surry	Yes	Yes[e]	Yes	No	Yes
Vermont Yankee	Yes	Under study	Yes	No	Yes
Limerick	Yes	Under study[f]	Yes	Yes	Yes
WNP-2[g]	No[h]	In planning	No	No	Yes
Cook	Yes	Under study[i]	Yes	No	Yes
		Industry-wide survey			
Industry-wide response, percent (n = 64)[j]	90.6	4.7	43.8	7.8	37.5
Industry-wide anticipated reliance on techniques until off-site disposal space becomes available, percent (n = 64)[j]	34.4	73.4	40.6	37.4	

[a] Indian Point 2's reracking is good through 2007; Vermont Yankee's, through 1998; and Limerick's, through 2011 and 2012 (Units 2 and 1, respectively). Cook reracked its spent-fuel pool in 1979 and plans to rerack its pool again in the 1993–1994 time frame. This is expected to yield sufficient storage until 2009.

[b] Surry and Vermont Yankee employ an 18-month fuel burnup cycle; Limerick is planning to be the first plant on a 24-month cycle.

[c] Robinson is planning transshipment, Indian Point will employ rod consolidation, and Limerick intends to employ a combination of high-enriched fuel, smaller reload batches, and rod consolidation.

[d] Robinson, Surry, Vermont Yankee, Limerick, Washington Nuclear Project 2, and Cook are planning either to build above-ground dry storage or to expand current storage facilities. Surry is building two additional storage "pads," and Limerick is planning a 165,000-ft^2 (15,300-m^2) facility for pool and dry storage.

[e] Surry's current dry storage facility will be full in 2010.

[f] Limerick will decide on the dry storage option in 2008.

[g] WNP-2 = Washington Nuclear Project 2.

[h] WNP-2 employs high-density racks.

[i] If pool storage proves insufficient for Cook after 2009, dry storage will be pursued.

[j] In updating data for the Final GEIS, the sample plants were resurveyed and published updates were used. However, no new industry-wide survey was undertaken because neither published updates nor sample plant data showed significant departures from previous trends.

Note: Of the 10 plants depicted in Section 6.1.1, Comanche Peak and San Onofre did not respond. Comanche Peak has not discharged spent fuel from its reactor as of February 1991 (SR/CNEAF/94-01). Because of multiple answers, percentages do not add up to 100 percent.

dry storage techniques at two plants (Surry and Robinson 2) provide insight into measures taken to reduce worker and population exposures under current operations.

To meet the demand for additional storage space, Robinson has built an ISFSI with eight concrete HSMs to provide radiation shielding, protection against natural phenomena, and an efficient means of decay heat removal. The ISFSI is located inside the fence area of the Robinson 2 plant site. Each HSM is a steel-reinforced structure that holds seven intact assemblies in each module. The ISFSI was licensed by the NRC in August 1986.

Virginia Power was the first U.S. utility to use dry storage for spent nuclear fuel. The Virginia Power ISFSI located at the Surry Power Station, Surry, Virginia, houses metal storage casks. It was licensed by the NRC in July 1986. Each cask is 16 ft (4.9 m) high and 8 ft (2.4 m) in diameter, weighs 110 to 120 tons when loaded with fuel, and holds between 21 and 28 fuel assemblies. The casks sit on a reinforced-concrete pad 230 ft (70 m) long, 32 ft (9.7 m) wide, and 3 ft (1 m) thick. The facility and casks have been evaluated for extreme temperatures, extreme wind, snow and ice, loss of electrical power, loss of cask radiation shielding, tornadoes, gas pipeline explosions, and cask seal leakage and drops. By the end of 1990, a total of 252 assemblies had been stored in the ISFSI. By the end of 1991, 53 more assemblies were stored. In 1992, 63 more assemblies were stored, increasing the total number of assemblies in dry storage at Surry to 367 by the end of 1992. By 1995, an additional 250 assemblies will be in storage. The ISFSI has been licensed to hold up to 1764 assemblies.

Before these casks are placed into the ISFSI, they are filled with water and then submerged in the fuel pool to be loaded with spent-fuel assemblies (Godlewski 1987; Wakeman 1989). This procedure limits occupational exposure because the water is a radiation barrier. Individual and collective radiation doses to workers and the public are small (NRC Docket No. 72-2). Also, because the filling operation takes place within the pool containment area, contact with groundwater or surface water and other resources is also prevented. After filling, the casks are fastened with lids, water is pumped out, and the casks are backfilled with helium to prevent corrosion.

For the ISFSI facility itself, a few tenths of an acre are disturbed and occupied; in addition, a few acres are maintained for "intruder" exclusion or controlled access, as well as to limit worker dose. This additional acreage is still relatively small. At Surry, the ISFSI is designed to hold about 63 casks in an area of about 15 acres (6 ha), while Prairie Island will be able to store 48 casks on about 10 acres (4 ha) (Minnesota EQB 1991). Exclusion areas (included in these totals) usually occupy an already disturbed plant site and do not entail additional construction.

Longer fuel burnup reduces the volume of spent fuel removed from the core, deferring the need for additional storage space. An increase in fuel burnup to a maximum of 45 GWd/MTU for PWRs and 38 GWd/MTU for BWRs could halve the amount of spent fuel requiring off-site disposal (Gilbert et al. 1990). Increased burnup can also increase the specific activity of activation products in the radioactive waste system as well as fission products and transuranic-waste concentrations in plant waste streams

(AIF/NESP-032; EPRI NP-5983). Extended burnup has not resulted in a higher incidence of failed fuel rods or breached cladding (EPRI NP-3765; SR/CNEAF/94-01). Several plants in the study sample are using or contemplating longer burnup (see Table 6.16).

Indian Point 2 is reracking its fuel pool for storage through 2007. Dry storage, rod consolidation, and longer burnup also will be considered. Vermont Yankee and Cook have reracked their pools to provide higher-density packing and are considering additional reracks. Limerick intends to rerack its pool to permit storage until 2011 at Unit 2 and until 2012 at Unit 1. If dry storage is undertaken, current economics favor the use of concrete casks at Limerick. If no repository is available after 2011, Limerick will employ a combination of dry storage and rod consolidation. Because of initial use of high-density fuel racks, WNP-2 plans no reracking. Surry's current ISFSI will be full by 2010, necessitating consideration of other options during the remainder of the plant's current license, including longer fuel burnup (the plant currently operates on an 18-month cycle) and possible construction of two additional storage pads for dry storage of spent fuel.

6.4.6.2 Effects of License Renewal

During the period encompassed by plant life extension, the amount of spent fuel generated annually by nuclear power plants will be a function of each plant's refueling schedule. The amount of spent fuel generated will be roughly proportional to the electrical energy produced by each plant. If all currently operating plants were to request renewed licenses, annual spent fuel generation should be comparable to those amounts generated under original licenses. Thus, total accumulated volumes of spent fuel after an additional 20 years of operation would amount to 50 percent more fuel than at the end of 40 years of operation (DOE/RW-0006). Projections of spent-fuel generation depicted in Table 6.15 are conservative estimates that do not account for nuclear plant life extension.

Under the Waste Confidence Rule, NRC has determined that spent fuel can be stored on-site for at least 30 years beyond the licensed (and license renewal) operating life of nuclear power plants safely and with minimal environmental impact (54 FR 39765; 55 FR 38472). This decision does not address the environmental impacts of storage during the additional 20 years of operation after license renewal. The additional spent fuel generated during this 20-year period poses three potential issues.

First, under the Nuclear Waste Policy Act of 1982 (NWPA) as amended, DOE is authorized to dispose of up to 70,000 metric tonnes of heavy metal (MTHM) in the first repository before granting a construction authorization for a second. Under existing licenses, projected spent-fuel generation could exceed 70,000 MTHM as early as the year 2010. Possible extensions or renewals of operating licenses also need to be considered in assessing the need for and scheduling the second repository. It now appears that unless Congress lifts the capacity limit on the first repository—and unless this repository has the physical capacity to dispose of all spent fuel generated under both the original and extended or renewed licenses—it will be necessary to have at least one additional repository. Assuming that the first repository is available by 2025 and has a capacity on the order of 70,000 MTHM, additional disposal capacity would probably not be needed before about the year 2040 to avoid storing spent fuel at a reactor for more than 30 years after expiration of reactor operating licenses.

Second, the NWPA prohibits the opening of an MRS until a permanent repository has been selected and constructed (Pub. L. 97-425). Moreover, the findings of environmental assessments for the MRS and permanent repository must be incorporated in facility design (DOE/RW-0187; GAO/RCED-90-103). Both of these requirements could cause additional delays in the availability of an MRS or permanent repository, necessitating longer on-site storage of the additional spent fuel. Current efforts to identify a host site for an MRS are unlikely to provide for a completed facility by 1998 (GAO/RCED-91-194).

Third, plant refurbishment during license renewal may also adversely affect spent-fuel storage capacity. Utilities may use fuel pools for interim storage of reactor components, as is being done at Vermont Yankee.

During the license renewal period, utilities will focus increasingly on dry storage methods for spent fuel. Either wet or dry storage would meet NRC's Waste Management Confidence Decision Review (49 FR 171; 10 CFR 50 and 51; 54 FR 187), but dry storage is growing in favor because it is more stable. Enlarging spent-fuel racks, adding racks to existing pool arrays, reconfiguring spent fuel with neutron-absorbing racks, and employing double-tiered storage will continue to be pursued; however, above-ground dry storage, utility sharing of spent fuel, and increased fuel burnup to reduce spent-fuel volumes will be the most favored methods until a permanent off-site repository or MRS becomes available, as shown by the study sample and industry-wide survey (Roberts 1987; Mullen et al. 1988; Zacha 1988; Johnson 1989; Fisher 1988).

Industry experience with spent-fuel storage, coupled with supplemental studies of the integrity of pool and dry storage systems, indicates that spent fuel generally can be stored safely on site with minimal environmental impacts (55 FR 38474; NUREG-1092). However, a maintenance concern with spent-fuel pools at permanently closed power plants was identified recently (*Nuclear Waste News* 1994). In January 1994, at the permanently shutdown (since 1978) Dresden Unit 1, a large amount of pool water leaked from a frozen service-water pipe located in the unheated containment building. Because the spent fuel had cooled for 15 years, lowering the pool water depth in this case did not cause significant increases in worker exposure. However, this incident has led to additional safety precautions' being implemented at all permanently shutdown plants.

Extended pool storage provides a benign environment that does not lead to degradation of the integrity of spent-fuel rods. Moreover, continuing advances in dry storage techniques, particularly in standardization of procedures and equipment, indicate that these systems are simple, passive, and easily maintained (53 FR 31651; NUREG-1092; Mullen et al. 1988).

For pool storage, while plant life extension could possibly increase the likelihood of inadvertent criticality through dense-racking or spent-fuel handling accidents, NRC regulations are in place to satisfactorily address this problem. In addition, studies of fuel rod or cladding failures indicate that fuel rods should remain secure well beyond the period of plant life extension, if it becomes necessary to continue pool storage on site (EPRI NP-3765; AIF/NESP-032; EPRI NP-5983; Bailey 1990; Gilbert et al. 1990; 55 FR 38474).

As a result of the operational experience demonstrated by Surry, Robinson, Oconee, and Ft. St. Vrain, NRC has determined that ISFSI methods of dry storage are sufficiently well developed, safe, and dependable to permit the generic licensing for any nuclear plant licensee (provided the plant licensee notifies NRC of the intent to use an ISFSI, uses NRC-certified casks, follows all specified conditions for their use, and provides a full description and safety assessment of the proposed site for an ISFSI) (55 FR 29181; 53 FR 31651). Worker and population exposures are minimal, and ISFSIs use only a small fraction of available land. Environmental assessments undertaken for all ISFSIs have resulted in issuance of findings of no significant impact (NRC Dockets 72-2, 72-3, 72-4, and 72-9).

The principal occupational exposures from spent-fuel management will occur during repackaging of spent-fuel rods and during construction and handling activities associated with moving and storing spent-fuel bundles and racks. While these impacts are expected to vary by the amount of fuel requiring storage, occupational doses during the period of license renewal are not expected to result in doses in excess of present levels (Section 4.6.3). Environmental impacts to on-site land availability should be minimal, given the small amount of land required for expanded spent-fuel pools and dry storage facilities.

6.4.6.3 On-Site Storage of Spent Fuel

Current and potential environmental impacts from spent-fuel storage have been studied extensively and are well understood. Storage of spent fuel in spent-fuel pools was considered for each plant in the safety and environmental reviews at the construction permit and operating license stage. The Commission has studied the safety and environmental effects of the temporary storage of spent fuel after cessation of reactor operation and published a generic determination of no significant environmental impact in its regulations at 10 CFR 51.23. The environmental impacts of storing spent fuel on site in a fuel pool for 10 years prior to shipping for off-site disposal were assessed and are included within the environmental data given by Table S-3, found in the Commission's regulations at 10 CFR 51.51. Environmental assessments (EA) for expanding the fuel-pool storage capacity have been conducted for more than 50 plants. A finding of no significant environmental impact was reached for each fuel-pool capacity expansion. Dry cask storage at an ISFSI is the other technology used for spent-fuel storage on site. The Commission has conducted EAs for seven site-specific licensed ISFSIs and has reached a finding of no significant environmental impact for each. The Commission has recently amended its regulations in 10 CFR 72 to allow power reactor licensees to store spent fuel on their sites under a general license. The environmental impacts of implementing this rule were analyzed in an EA that incorporated EAs performed for previous rulemakings related to 10 CFR 72 and for the Commission's Waste Confidence Decision.

At the construction permit and operating license stage, both the 10 CFR 50 safety review and the 10 CFR 51 environmental review contributed to understanding the potential radiological and nonradiological environmental impacts of fuel-pool construction and operation. The design and operating conditions of spent-fuel pools and their various auxiliary systems were reviewed to ensure that the design criteria of Appendix A to 10 CFR 50 are met. These criteria address (1) control of releases of radioactive materials to the environment, (2) fuel storage and handling and radioactivity control, (3) prevention of criticality in fuel storage and handling, (4) monitoring fuel and waste storage, and (5) monitoring radioactive releases. These criteria ensure that radioactive releases to the environment are controlled and acceptable and that effluent discharge paths and the plant environs are monitored for radioactivity. Appendix I to 10 CFR 50 provides the numerical objectives for the design objectives and limiting conditions for operation required to meet the ALARA criterion for radioactive material in the total effluent from an LWR. The objectives were quoted earlier in this chapter and include an objective that total radioactive material in liquid effluent should not result in an annual dose or dose commitment to the total body or to any organ of an individual in an unrestricted area for all pathways of exposure in excess of 5 mrem. In addition, the calculated annual total quantity of radioactive material, except tritium and dissolved gases, should not exceed 5 Ci for each reactor at a site. Appendix I objectives for annual total gaseous effluent of radioactive material for all reactors at a site is that gamma radiation doses should not exceed 10 mrad and beta radiation doses should not exceed 20 mrad for an individual located at or beyond the site boundary. Radioactive materials from the spent-fuel pool contribute a small fraction of the total radioactive materials released from a plant. It is the total releases that need to meet Appendix I numerical objectives. In the construction permit and operating license review for each plant, a thorough assessment is made of calculated releases of curies per year of radioactive materials in both liquid effluent and in gaseous effluent, the exposure pathways, and the impacts to man and biota other than man.

The Commission has considered whether radioactive wastes generated in nuclear power reactors can be subsequently disposed of without undue risk to the public health and safety and the environment. As stated in its regulations at 10 CFR 51.23:

> (a) The Commission has made a generic determination that, if necessary, spent fuel generated in any reactor can be stored safely and without significant environmental impact for at least 30 years beyond the licensed life for operation (which may include the term of a revised or renewed license) of that reactor at its spent-fuel storage basin or at either on-site or off-site independent fuel storage installations. Further, the Commission believes that there is reasonable assurance that at least one mined geological repository will be available within the first quarter of the twenty-first century, and sufficient repository capacity will be available within 30 years beyond the licensed life for operation of any reactor to dispose of the commercial high-level waste and spent fuel originating in such reactor and generated up to that time.

In accordance with this determination the rule also provides that no discussion is required concerning environmental impacts of spent-fuel storage for the period following the term of the reactor operating license, including a renewed license. The waste confidence determination was first published in 1984 at 49 FR 34694, August 31, 1984 and was amended in 1990 at 55 FR 38474, September 18, 1990. Additional information and explanation of the safety and environmental considerations supporting the waste confidence determination are given in the notice of the proposed rule amendment, 54 FR 39767, September 28, 1989.

The environmental impacts of storing spent fuel on site in a fuel pool for 10 years prior to shipping for off-site disposal are incorporated in the data presented in Table S-3. The environmental impacts of storage of spent fuel in a fuel pool are given in Table 2.5 of NUREG-0116, *Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle*. Commitment of land, water consumption, chemical effluent, gaseous, liquid and solid radiological effluent, and thermal effluent are all negligible.

Since 1984, licensees have continued to provide safe and environmentally innocuous additional reactor-pool storage capacity through reracking. Over 50 reviews for the expansion of fuel-pool capacity have been completed by the Commission. Each review has resulted in a finding of no significant environmental impact. The reracking activities take place within existing structures and already disturbed land areas, and the changes in radiological, nonradiological, and thermal effluent are negligible.

Dry storage of spent fuel at ISFSI has been extensively studied by the Commission, and the environmental impacts are well understood. Licensing requirements for the independent storage of spent fuel and HLW are given in 10 CFR 72. In part, these regulations cover siting evaluation factors, general design criteria, general license for storage of spent fuel at power reactor sites, and approval of spent-fuel storage casks.

6.4.6.4 On-Site Dry Cask Storage

On-site dry cask storage of spent fuel can be accomplished either by a specific license issued under 10 CFR 72.40 or by the provisions of a general license issued under 10 CFR 72.210 for an ISFSI at operating power reactors. To date, seven specific licenses have been issued under 10 CFR 72.40 and one general license issued under 10 CFR 72.210 is operational. For each specific license the Commission has prepared an EA and a finding of no significant impact. Each EA addressed the impacts of construction, use, and decommissioning, including fugitive dust; erosion, noise, heat, and radiological impacts. The Commission also prepared an EA for the general license issued on July 18, 1990 (55 FR 29191). The Commission does not prepare an EA for each general licensee but does prepare an EA for each dry storage cask listed under 10 CFR 72.214 which is approved for use by general licensees. Currently seven casks are listed under 10 CFR 27.214 and it is anticipated that more will be added. General licensees can use only casks listed under 10 CFR 72.214.

EAs prepared for site-specific licenses include site description, need for action, alternatives, site and environment, description of the ISFSI, environmental impacts of proposed action, safeguards for spent fuel, decommissioning, and finding of no significant impact. Under the environmental impacts of the action, the following are considered: land use and terrestrial resources, water use and aquatic resources, noise and air-quality impacts of construction, socioeconomic impacts of construction, radiological impacts of construction, radiological impacts of routine operations, off-site dose, collective occupational dose, radiological impacts of off-normal events and accidents, land use and terrestrial resources, water use and aquatic resources, other effects of operation, and resources committed.

Using the Calvert Cliffs Nuclear Power Plant Site ISFSI EA as typical, the following impacts are evaluated. Land use is about six acres, which is within the owner-controlled area of 2300 acres. During construction of the pad, water for cleaning, drinking, and fugitive dust control was transported to the site by truck. Storm-water runoff and sediment were controlled according to local codes. Air quality had a temporary increase of suspended particulate material, hydrocarbons, carbon monoxide, and oxides of nitrogen from construction activities. The size of the work force was not expected to exceed 50 people. This expanded work force had little impact in the area with large population growth. During initial construction there were no radiological impacts. As construction proceeded, after filling some storage modules, radiation was controlled with temporary shielding to meet NRC and ALARA exposure requirements. Dry storage of spent fuel in welded canisters has no gaseous or liquid effluents. The exposure of the nearest resident, 4705 ft from the facility, when the facility is filled with design-basis spent fuel in 120 modules, the license limit, is less than one mrem/year. The exposure of that resident from other operations at the site is 13.5 mrem/year. These exposures are well within the requirements of 10 CFR 72.104 and 40 CFR Part 190 limits of 25 mrem/year. By year 2010 there are projected to be about 500 people living between 1 and 2 miles of the Calvert Cliffs Station. The collective dose is estimated to be about 101 man-rem/year. Occupational exposure in constructing additional modules after the initial set has been loaded is expected to total about 4 man-rem. Once all 120 modules are loaded, the radiation exposure from the ISFSI is expected to be less than 5 percent of the total site yearly exposure of 350 man-rem. Worst-case accident dose was calculated to be 23 mrem to the whole body and 111 mrem to the thyroid at the nearest residence. Heat from the modules is not expected to be high enough to affect vegetation growth. Fences will discourage some wildlife species from using the area adjacent to the modules. There is no planned use of water or liquid discharge to local surface or groundwater supplies. Surface runoff from precipitation will enter the Chesapeake Bay under existing drainage routes, but it is not expected to result in negative impact to water quality. Rain may vaporize and form a localized fog over the modules that would not extend beyond the plant exclusion boundary. Noise during construction and movement of fuel would not be distinguishable from other operational noise at the site or to result in adverse impact to local residents. The Commission believes that the impacts discussed above reasonably describe the impacts from existing dry cask storage facilities, as well as the likely impacts from those dry cask storage facilities that are expected to be constructed as a result of license renewal.

The Commission prepares an EA for each approved cask listed in 10 CFR 72.214. These EAs are tiered off the "Final Waste Confidence Decision," August 31, 1984 (49 FR 34688), the *Environment Assessment for 10 CFR 72 "Requirements for the Independent Storage of Spent Fuel and High-Level Radioactive Waste,"* NUREG-1092 (August 1984), and the "Environmental Assessment for Proposed Rule Entitled 'Storage of Spent Nuclear Fuel in NRC-Approved Storage Casks at Nuclear Power Reactor Sites,'" for the proposed rule published on May 5, 1989 (54 FR 19379). Additional impacts evaluated are those associated with the construction, use, and disposal of the cask. These impacts are very small compared to the total impact of the steel industry, plastics industry, and the concrete industry. The incremental impacts of cask use are considered small. No effluents, either gaseous or liquid, are expected from the sealed casks. Incremental radiation doses off site are also considered to be small compared to those from the other operations on the site. Based on the above summary a finding of no significant impact is appropriate. This finding has been made for each of the seven casks listed in 10 CFR 72.214. Power reactor licensees using one of the listed casks under a general license do not need to prepare an environmental report, nor does the NRC have to prepare an EA.

6.4.6.5 Expanding Fuel-Pool Capacity

The Commission prepares an EA for each request to expand the capacity of a spent-fuel pool. The EA prepared for the increase in the allowed fuel assembly storage for the Pilgrim Nuclear Power Station is a typical example of this type of action. Alternatives looked at include (1) shipment of fuel to a permanent federal fuel-storage/disposal facility, (2) shipment of fuel to a reprocessing facility, (3) shipment of fuel to another utility or site for storage, (4) reduction of spent-fuel generation, (5) construction of a new independent spent-fuel storage installation, and (6) no action. After evaluating the alternatives, the proposed action of increasing the capacity of the spent-fuel pool is the best one at the time; however, in the longer term, an ISFSI is the solution. Radioactive exposures, waste generation, and releases were evaluated and found to be incrementally small. The only nonradiological effluent is additional heat rejected from the plant. This additional heat is small compared to the total rejected by the rest of the plant, and it will have a negligible effect on the environment. The risks due to accidents and their environmental effects are found to be not significant.

6.4.6.6 Regulations Applicable

10 CFR Parts 72, 60, and 61.

6.4.6.7 Conclusion

The Commission's waste confidence finding at 10 CFR 51.23 leaves only the on-site storage of spent fuel during the term of plant operation as a high-level-waste storage and disposal issue at the time of license renewal. The Commission's regulatory requirements and the experience with on-site storage of spent fuel in fuel pools and dry storage has been reviewed. Within the context of a license renewal review and determination, the Commission finds that there is ample basis to conclude that continued storage of existing spent fuel and storage of spent fuel generated during the license renewal period can be accomplished safely and without significant environmental impacts. Radiological impacts will be well within regulatory limits; thus radiological impacts of on-site storage meet the standard for a conclusion of small impact. The nonradiological environmental impacts have been shown to be not significant; thus they are classified as small. The overall conclusion for on-site storage of spent fuel during the term of a renewed license is that the environmental impacts will be small for each plant. The need for the consideration of mitigation alternatives within the context of renewal of a power reactor license has been considered, and the Commission concludes that its regulatory requirements already in place provide adequate mitigation incentives for on-site storage of spent fuel. On-site storage of spent fuel during the term of a renewed operating license is a Category 1 issue.

6.5 NONRADIOLOGICAL WASTES

Nonradiological wastes from routine plant operations include those from cooling system blowdown (continual or periodic purging of impurities from cooling systems), water treatment wastes (sludges and high-saline streams whose residues are disposed of as solid waste), boiler metal cleaning, floor and yard drains, storm-water runoff, sewage wastes, and cleaning solvents (NUREG-0020). Descriptions of these waste-generating systems are provided in Section 2.1.6. If nonradiological sanitary wastes cannot be processed by on-site water treatment systems, they are collected by independent contractors and trucked to off-site treatment facilities. If wastes have hazardous constituents, proper handling and disposal are required to minimize potential contamination of surface water and groundwater. In this section, a review of literature on nonradiological waste management throughout the industry was used to depict baseline conditions and to infer the effects of license renewal.

6.5.1 Baseline

Stringent regulations governing the generation of nonradioactive solid waste and the resulting efforts of utilities to establish waste minimization and pollution prevention programs are expected to produce a general decline in the general production of waste by nuclear power plants during the period prior to license renewal. Nonradioactive hazardous solid waste disposal from all nuclear power plants is governed by RCRA (Pub. L. 94-580). RCRA requires EPA and state agencies to establish a permit system for disposal of these wastes in licensed landfills. Utilities have undertaken changes in operation to ensure proper handling and disposal of these wastes in accordance with RCRA, including periodic removal of septic tank sludge by a licensed contractor and disposal on or off site in an approved sanitary system. Construction-related solid wastes are discharged to holding ponds until chemical discharges and runoff are suitable for discharge to surface waters on a batch basis. These latter discharges must comply with allowable standards under RCRA permits.

6.5.2 Effects of License Renewal

Solid nonradiological waste from blowdown, water treatment, boiler metal cleaning, floor and yard drains, storm-water runoff, and sewage wastes will likely remain of limited concern during license renewal for three reasons. First, no changes to the systems that generate these wastes are anticipated as a result of license renewal for all plants. Second, existing regulations, including National Pollutant

Discharge Elimination System permitting for low-volume wastewater and RCRA permitting for solid wastes such as chemical solvents, are also likely to become increasingly stringent through further amendment (OTA-O-426). Third, statutorily mandated waste-minimization programs, which are expected to incorporate new waste-management technologies, should reduce further the volume of solid nonradioactive waste produced by nuclear power plants.

Some plants may require construction of interim storage facilities for LLW and spent fuel. Construction of these facilities would generate rubble and other debris on a short-term basis. This temporary increase of waste would be typical of that generated by any construction activity in an industrial complex and would be controlled by federal and state regulations. Hence, management of this waste stream would not pose any new or unique issues and would not be expected to result in impacts of concern.

6.5.3 Conclusion

Generation and management of solid nonradioactive waste during the terms of an extended license are not expected to result in significant environmental impacts. No changes to plant systems or mode of operation have been identified that would increase the quantities of waste generated or change the nature and types of waste in a manner that would be of environmental concern. In fact, regulatory and operational trends suggest a gradual decrease in quantities generated annually and the impacts during the terms of renewed licenses. Facilities and procedures are in place to ensure continued proper handling and disposal at all plants. Consequently, the generation and management of solid nonradioactive waste for up to 20 years beyond the terms of the original 40-year license of nuclear power plants is anticipated to result in only small impacts to the environment. Because the facilities and procedures that are in place are expected to ensure continued proper handling and disposal at each plant, additional mitigative measures are not a consideration in the context of a license renewal review. This is a Category 1 issue.

6.6 SUMMARY

The following conclusions have been drawn with regard to the environmental impacts associated with the uranium fuel cycle and with the management of waste generated during nuclear power plant operations beyond the terms of their original 40-year licenses.

- The radiological and nonradiological environmental impacts of the uranium fuel cycle have been reviewed. The review included a discussion of the values presented in Table S-3, an assessment of the release and impact of ^{222}Rn and of ^{99}Tc, and a review of the regulatory standards and experience of fuel-cycle facilities. For the purpose of assessing the radiological impacts of license renewal, the Commission uses the standard that the impacts are of small significance if doses and releases do not exceed permissible levels in the Commission's regulations. Given the available information regarding the compliance of fuel-cycle facilities with applicable regulatory requirements, the Commission has concluded that, other than for the disposal of spent fuel and high-level waste, these impacts on individuals from radioactive gaseous and liquid releases will remain at or below the Commission's regulatory limits. Accordingly, the Commission concludes that off-site radiological impacts of the fuel cycle (individual effects from other than the disposal of spent fuel and high-level waste) are small. ALARA efforts will continue to apply to fuel-cycle activities. This is a Category 1 issue.

- The radiological impacts of the uranium fuel cycle on human populations over time (collective effects) have been considered within the framework of Table S-3. The 100-year environmental dose commitment to the U.S. population from the fuel cycle, high-level-waste and spent-fuel disposal excepted, is calculated to be about 14,800 man-rem, or 12 cancer fatalities, for each additional 20-year power reactor operating term. Much of this, especially the contribution of radon releases from mines and tailing piles, consists of tiny doses summed over large populations. This same dose calculation can theoretically be extended to include many tiny doses over additional thousands of years as well as doses outside the U.S. The result of such a calculation would be thousands of cancer fatalities from the fuel cycle, but this result assumes that even tiny doses have some statistical adverse health effect that will not ever be mitigated (for example, no cancer cure in the next thousand years) and that these dose projections over thousands of years are meaningful. However, these assumptions are questionable. In particular, science cannot rule out the possibility that there will be no cancer fatalities from these tiny doses. For perspective, the doses are very small fractions of regulatory limits, and even smaller fractions of natural background exposure to the same populations. No standards exist that can be used to reach a conclusion as to the significance of the magnitude of the collective radiological effects. Nevertheless, some judgment as to the regulatory NEPA implication of this issue should be made, and it makes no sense to repeat the same judgment in every case. The Commission concludes that these impacts are acceptable in that these impacts would not be sufficiently large to require the NEPA conclusion, for any plant, that the option of extended operation under 10 CFR 54 should be eliminated. Accordingly, while the Commission has not assigned a single level of significance for the collective effects of the fuel cycle, this issue is considered Category 1.

- There are no current regulatory limits for off-site releases of radionuclides for the current candidate repository site. However, if we assume that limits are developed along the lines of the 1995 NAS report and that, in accordance with the Commission's Waste Confidence Decision, a repository can and likely will be developed at some site that will comply with such limits, peak doses to virtually all individuals will be 100 mrem/year or less. However, while the Commission has reasonable confidence that these assumptions will prove correct, there is considerable uncertainty because the limits are yet to be developed, no repository application has been completed or reviewed, and uncertainty is inherent in the models used to evaluate possible pathways to the human environment. The National Academy report indicated that 100 mrem/year should be considered as a starting point for limits for individual doses, but notes that some measure of consensus exists among national and international bodies that the limits should be a fraction of the 100 mrem/year. The lifetime individual risk from 100 mrem/year dose limit is about 3×10^{-3}. Doses to populations from disposal cannot now (or possibly ever) be estimated without very great uncertainty.

Estimating cumulative doses to populations over thousands of years is more problematic. The likelihood and consequences of events that could seriously compromise the integrity of a deep geologic repository were evaluated by the Department of Energy in the *Final Environmental Impact Statement: Management of Commercially Generated Radioactive Waste*, October 1980. The evaluation estimated the 70-year whole-body dose commitment to the maximum individual and to the regional population resulting from several modes of breaching a reference repository in the year of closure, after 1,000 years, after 100,000 years, and after 100,000,000 years. The release scenarios covered a wide range of consequences from the limited consequences of humans accidentally drilling into a waste package in the repository to the catastrophic release of the repository inventory by a direct meteor strike. Subsequently, the NRC and other federal agencies have expended considerable effort to develop models for the design and for the licensing of a high-level-waste repository, especially for the candidate repository at Yucca Mountain. More meaningful estimates of doses to population may be possible in the future as more is understood about the performance of the proposed Yucca Mountain repository. Such estimates would involve very great uncertainty, especially with respect to cumulative population doses over thousands of years. The standard proposed by the NAS is a limit on maximum individual dose. The relationship of potential new regulatory requirements, based on the NAS report, and cumulative population impacts has not been determined, although the report articulates the view that protection of individuals will adequately protect the population for a repository at Yucca Mountain. However, EPA's generic repository standards in 40 CFR 191 generally provide an indication of the order of magnitude of cumulative risk to population that could result from the licensing of a Yucca Mountain repository, assuming the ultimate standards will be within the range of standards now under consideration. The standards in 40 CFR 191 protects the population by imposing "containment requirements" that limit the cumulative amount of radioactive material released over 10,000 years. The cumulative release limits are based on EPA's population impact goal of 1,000 premature cancer deaths worldwide for a 100,000-metric tonne (MTHM) repository.

Nevertheless, despite all the uncertainty surrounding the effects of the disposal of spent fuel and high-level waste, some judgment as to the regulatory NEPA implications of these matters should be made, and it makes no sense to repeat the same judgment in every case. Even taking the uncertainties into account, the

Commission concludes that these impacts are acceptable in that these impacts would not be sufficiently large to require the NEPA conclusion, for any plant, that the option of extended operation under 10 CFR 54 should be eliminated. Accordingly, while the Commission has not assigned a single level of significance for the impacts of spent-fuel and high-level-waste disposal, this issue is considered Category 1.

- With respect to the nonradiological impact of the uranium fuel cycle, data concerning land requirements, water requirements, the use of fossil fuel, gaseous effluent, liquid effluent, and tailings solutions and solids, all listed in Table S-3, have been reviewed to determine the significance of the environmental impacts of a power reactor operating an additional 20 years. The nonradiological impacts attributable to the relicensing of an individual power reactor are found to be of small significance. License renewal of an individual plant is so indirectly connected to the operation of fuel-cycle facilities that it is meaningless to address the mitigation of impacts identified above. This is a Category 1 issue.

- The radiological and nonradiological environmental impacts from the transportation of fuel and waste attributable to license renewal of a power reactor have been reviewed. Environmental impact data for transportation are provided in Table S-4. The estimated radiological effects are within the Commission's regulatory standards. Radiological impacts of transportation are therefore found to be of small significance. The nonradiological impacts are those from periodic shipments of fuel and waste by individual trucks or rail cars and thus would result in infrequent and localized minor contributions to traffic density. These nonradiological impacts are found to be small. Programs designed to further reduce risk, which are already in place, provide for adequate mitigation. However, because a detailed analysis of the environmental impacts of transportation to the proposed repository at Yucca Mountain is not yet available, transportation of fuel and waste is Category 2.

- The radiological and nonradiological environmental impacts from the storage and disposal of low-level radiological waste attributable to license renewal of a power reactor have been reviewed. The comprehensive regulatory controls that are in place and the low public doses being achieved at reactors ensure that the radiological impacts to the environment will remain small during the term of the renewed license. The maximum additional on-site land that may be required for low-level waste storage during the term of a renewed license and associated impacts will be small. Nonradiological environmental impacts on air and water will be negligible. The radiological and nonradiological environmental impacts of long-term disposal of low-level waste from any individual plants at licensed sites are small. The need for the consideration of mitigation alternatives within the context of renewal of a power reactor license has been considered, and the Commission concludes that its regulatory requirements already in place provide adequate mitigation incentives for on-site storage of low-level waste and that for off-site disposal mitigation would be a site-specific consideration in the licensing of each facility. In addition, the Commission concludes that there is reasonable assurance that sufficient low-level waste disposal capacity will be made available when needed for facilities to be decommissioned consistent with NRC decommissioning requirements. Low-level waste is a Category 1 issue.

- The radiological and nonradiological environmental impacts from the storage and disposal of mixed waste attributable to license renewal of a power reactor have been reviewed. The comprehensive regulatory controls and the facilities and procedures that are in place ensure proper handling and storage, as well as negligible doses and exposure to toxic materials for the public and the environment at all plants. License renewal will not increase the small, continuing risk to human health and the environment posed by mixed waste at all plants. The radiological and nonradiological environmental impacts of long-term disposal of mixed waste from any individual plant at licensed sites are small. The maximum additional on-site land that may be required for mixed waste is a small fraction of that needed for low-level waste storage during the term of a renewed license, and associated impacts will be small. Nonradiological environmental impacts on air and water will be negligible. The radiological and nonradiological environmental impacts of long-term disposal of mixed waste from any individual plants at licensed sites are small. The need for the consideration of mitigation alternatives within the context of renewal of a power reactor license has been considered and the Commission concludes that its regulatory requirements already in place provide adequate mitigation incentives for on-site storage of mixed waste and that for off-site disposal mitigation would be a site-specific consideration in the licensing of each facility. In addition, the Commission concludes that there is reasonable assurance that sufficient mixed-waste-disposal capacity will be made available when needed for faculties to be decommissioned consistent with NRC decommissioning requirements. Mixed waste is a Category 1 issue.

- The Commission's waste confidence finding at 10 CFR 51.23 leaves only the on-site storage of spent fuel during the term of plant operation as a high-level waste storage and disposal issue at the time of license renewal. The Commission's regulatory requirements and the experience with on-site storage of spent fuel in fuel pools and dry storage has been reviewed. Within the context of a license renewal review and determination, the Commission finds that there is ample basis to conclude that continued storage of existing spent fuel and storage of spent fuel generated during the license renewal period can be accomplished safely and without significant environmental impacts. Radiological impacts will be well within regulatory limits, thus radiological impacts of on-site storage meet the standard for a conclusion of small impact. The nonradiological environmental impacts have been shown to be not significant; thus they are classified as small. The overall conclusion for on-site storage of spent fuel during the term of a renewed license is that the environmental impacts will be small for each plant. The need for the consideration of mitigation alternatives within the context of renewal of a power reactor license has been considered, and the Commission concludes that its regulatory requirements already in place provide adequate mitigation incentives for on-site storage of spent fuel. On-site storage of spent fuel during the term of a renewed operating license is a Category 1 issue.

- The environmental impacts from the storage and disposal of nonradiological waste attributable to the license renewal of a power reactor have been reviewed. Regulatory and operational trends suggest a gradual decrease in quantifies generated annually and the impacts during the terms of renewed licenses. Facilities and procedures are in place to ensure continued proper handling and disposal at all plants. Consequently, the generation and management of solid nonradioactive waste during the term of a renewed license is anticipated to result in only small impacts to the environment. Because the facilities and procedures that are in place are expected to ensure continued proper handling and disposal at each plant, additional mitigative measures are not a consideration in the context of a license renewal review. Nonradiological waste is a Category 1 issue.

6.7 ENDNOTES

1. The expiration dates of the 109 operating reactor licenses are presented in Table 12 of NUREG-1350, Vol 7. Nine expire in the period 2000–2009, 55 in 2010–2019, 43 in 2020–2029, 1 in 2030, and 1 in 2033.
2. The first new LLW sites are forecast in 1997 and 1998 (California, North Carolina, and Texas) and seven in the period 1999–2002.
3. 40 CFR 190.10 Standards for normal operations—"Operations covered by this Subpart shall be conducted in such a manner as to provide reasonable assurance that:
   (a) The annual dose equivalent does not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public as the result of exposures to planned discharges of radioactive materials, radon and its daughters excepted, to the general environment from uranium fuel cycle operations and to radiation from these operations.
   (b) The total quantity of radioactive materials entering the general environment from the entire uranium fuel cycle, per gigawatt-year of electrical energy produced by the fuel cycle, contains less than 50,000 curies of krypton-85, 5 millicuries of iodine-129, and 0.5 millicuries combined of plutonium-239 and other alpha-emitting transuranic radionuclides with half-lives greater than one year."

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7. DECOMMISSIONING

7.1 INTRODUCTION

Decommissioning is defined as the safe removal of a nuclear facility from service and the reduction of residual radioactivity to a level that permits release of the property for unrestricted use and termination of the license (10 CFR Part 50.82). Decommissioning must occur because a licensee is not permitted to abandon a facility after ceasing operation. Decommissioning activities do not include the removal of spent fuel, which is considered to be an operational activity; the storage of spent fuel, which is addressed in the Waste Confidence Rule (10 CFR Part 51.23); or the removal and disposal of nonradioactive structures and materials beyond that necessary to terminate the U.S. Nuclear Regulatory Commission (NRC) license. Disposal of the nonradioactive hazardous waste that is not necessary for NRC license termination is not considered part of the decommissioning process for which NRC is responsible.

The purpose of this chapter is to determine whether license renewal of nuclear power plants would change the impacts of decommissioning to such an extent that those impacts would need to be assessed and mitigative measures considered as part of the environmental review for license renewal. Current licenses allow nuclear power plants to operate for as long as 40 years. License renewal would extend the period of operation by as much as 20 years. This chapter addresses incremental impacts of decommissioning after a 20-year license renewal compared with operating for 40 years.

The following potential impacts are addressed: radiation exposures to workers and the public, socioeconomic effects, waste management impacts, air and water quality impacts, and ecological impacts. The principal impacts of decommissioning are expected to result from radiation exposures to workers and from disposal of radioactive materials. Decommissioning is expected to have only minor radiological impacts on the public (primarily as a result of transporting radioactive waste). Socioeconomic impacts of decommissioning would result from the demands on, and contributions to, the community by the workers employed to decommission a power plant. As shown in this chapter, the air quality, water quality, and ecological impacts of decommissioning are all expected to be substantially smaller than those of power plant construction or operation because the level of activity and the releases to the environment are all expected to be smaller during decommissioning than during construction and operation. The effect of license renewal on the costs of decommissioning are also examined because the costs of decommissioning continues to be a public concern; however, no category conclusion is reached because the impact of license renewal on decommissioning cost is not a consideration in the environmental review and the decision to renew a license.

The impacts resulting from decommissioning at 40 years (baseline) are taken from NUREG-0586, the two source documents NUREG/CR-0130 and NUREG/CR-0672, and updates to those source documents such as draft reports NUREG/CR-5884 and NUREG/CR-6174. The same methods used in those documents were used to project the impacts of decommissioning after 60 years of operation. Where the source documents did not address a potential impact, other available data and staff members' professional judgments were used to assess the potential for impacts to change as a result of extended operation. The analysis in this chapter is based on large "reference" pressurized-water reactor (PWR) and boiling-water reactor (BWR) nuclear power plants; consequently, the impacts of decommissioning all U.S. nuclear power plants that reach the end of their operating lives without a serious accident should be encompassed by those described here. The changes in impacts resulting from the extended operation and in the environment at the time of decommissioning were considered. [The discussion is built around a "reference" PWR identified by NUREG/CR-0130, the 1175-MW Trojan Nuclear Plant at Rainier, Oregon, and a "reference" BWR, the 1155-MW(e) Washington Public Power Supply System Nuclear Project 2, which was being built near Richland, Washington (NUREG/CR-0672).]

7.2 THE DECOMMISSIONING PROCESS

This section describes the locations of radioactive materials in nuclear power plants, notes the three commonly discussed decommissioning methods, summarizes experience to date with decommissioning nuclear power plants, and provides information on the wastes generated during decommissioning. Except as noted, the information for this section is from NUREG-0586.

7.2.1 Nuclear Power Plants

Nuclear power plants in the United States use two types of nuclear reactors (Chapter 2); the most common type is the PWR. Most of the 118 licensed power reactors in the United States are PWRs. The other type is the BWR. The locations of radioactive components in these two types of power plants are described briefly to aid the reader's understanding of decommissioning.

7.2.1.1 Pressurized-Water Reactors

Buildings or structures associated with a typical large PWR (Figure 7.1) include (1) the heavily reinforced concrete containment building, which houses the pressure vessel, the steam generators, and the pressurizer system; (2) the turbine building, which contains the turbines and the generator; (3) the cooling water system, which may include the cooling tower and other components; (4) the fuel building, which contains fresh and spent fuel, fuel handling facilities, the spent-fuel storage pool and its cooling system, and the solid radioactive waste system; (5) the auxiliary building, which contains the liquid radioactive waste treatment systems, the filter and ion exchanger vaults, the gaseous radioactive waste treatment system, and the ventilation systems for the containment, fuel, and auxiliary buildings; (6) the control building, which houses the reactor control room and personnel facilities; (7) water intake structures; (8) the administration building; and (9) other structures such as warehouses and nonradioactive shops.

The major radioactive components encountered in decommissioning are associated with the reactor itself—the primary coolant loop, the steam generators, the radioactive waste handling systems, and the concrete biological shield that surrounds the pressure vessel. The reactor core, pressure vessel, steam generators, and piping between the reactor and steam generators are highly radioactive. Because some primary-to-secondary leakage is

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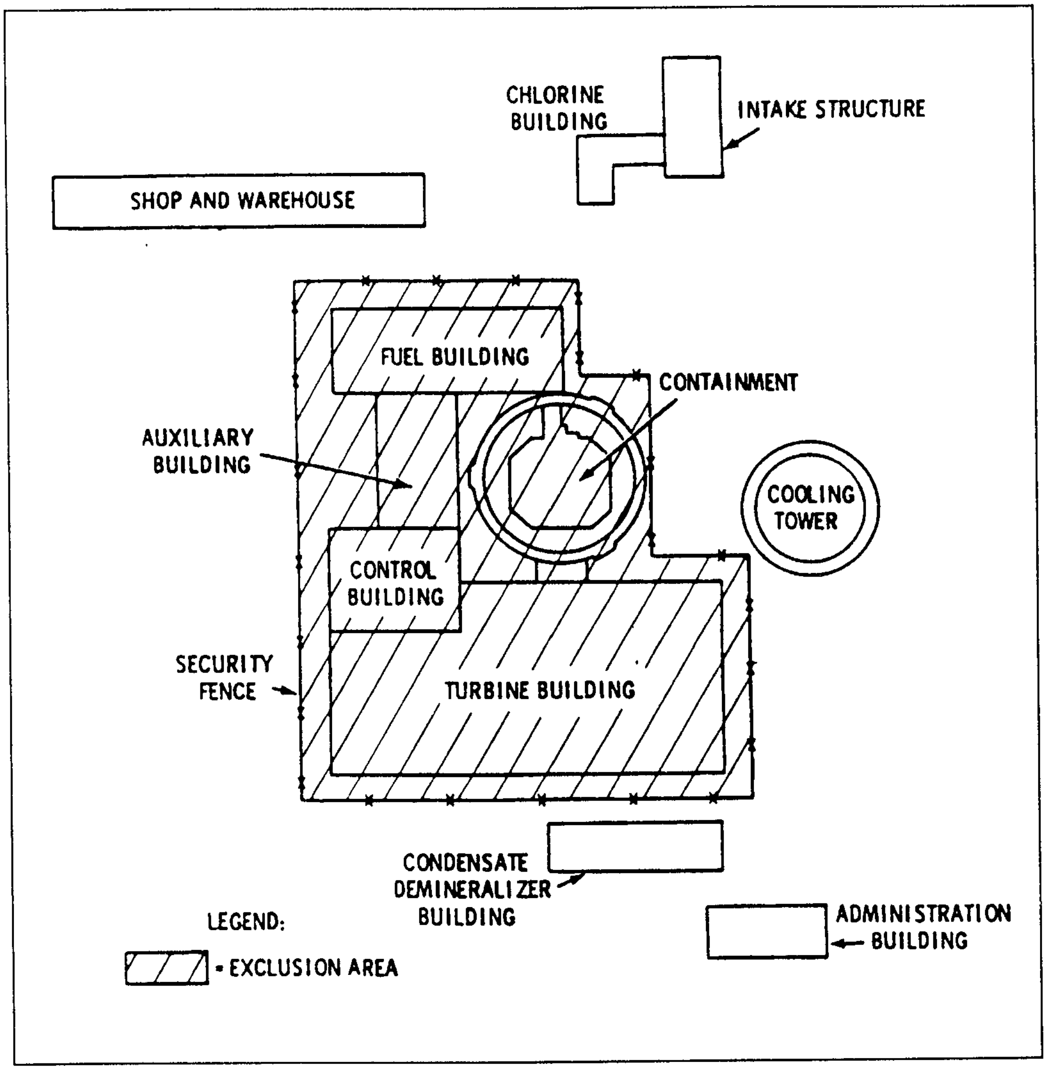

Figure 7.1 **Typical pressurized-water reactor generating station layout.** Adapted from NUREG/CR-0130.

impossible to avoid, the secondary loop, including the turbines, is slightly contaminated. Because of leakage and blowdown, the cooling water is very slightly contaminated. Much equipment in the auxiliary building is contaminated, as is the spent-fuel storage pool and its associated equipment.

7.2.1.2 Boiling-Water Reactors

Buildings and structures associated with a typical large BWR (Figure 7.2) include (1) the reactor building, which houses the reactor pressure vessel, the containment structure, the biological shield, the spent-fuel pool, and fuel handling equipment; (2) the turbine building, which houses the

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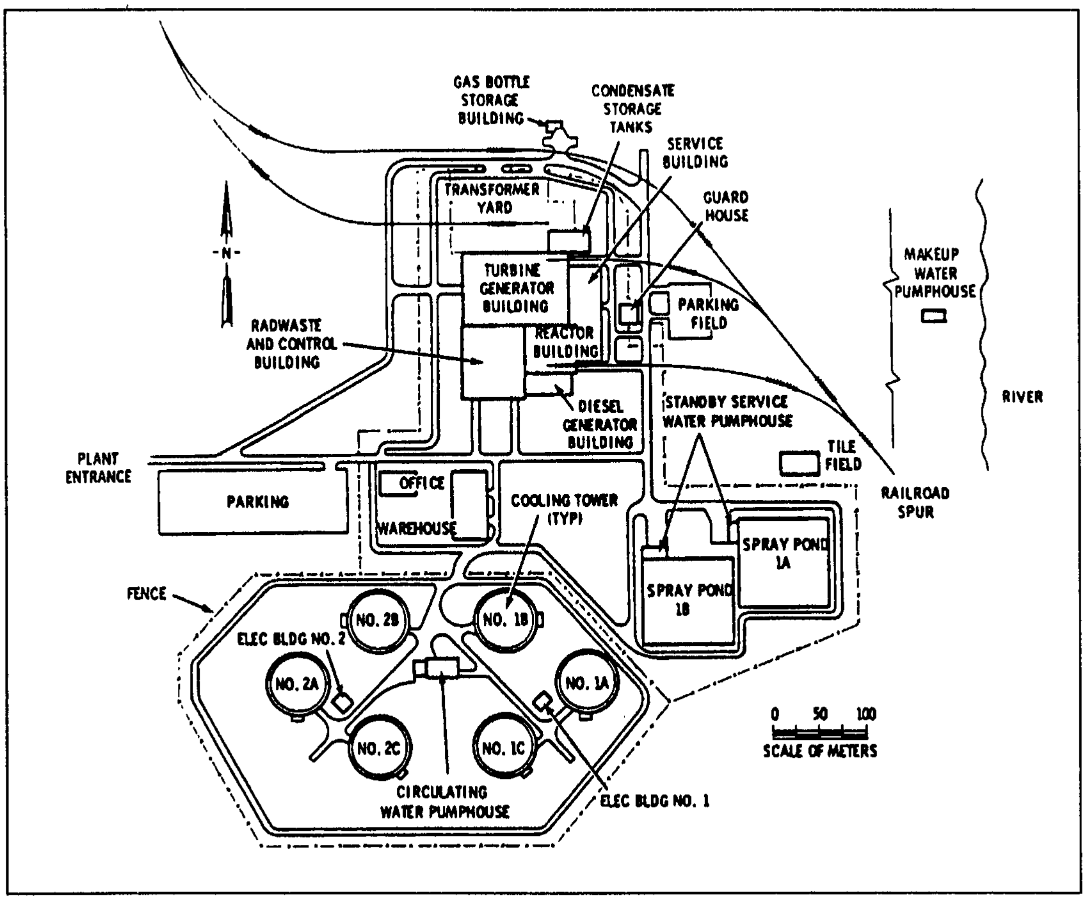

Figure 7.2 Site layout on a typical boiling-water reactor power plant. Adapted from NUREG-0672.

turbine and electric generator; (3) the radioactive waste and control building, which houses the solid, liquid, and gaseous radioactive waste treatment systems and the main control room; (4) the cooling system; (5) water intake structures and pump houses; (6) the service building, which houses the makeup water treatment system, machine shops, and offices; and (7) other minor structures.

The major sources of radiation in decommissioning a BWR are associated with the reactor itself, the containment structure, the concrete biological shield, the primary coolant loop, the turbines, and the radioactive waste handling systems. The reactor building, the turbine generator building, and the radioactive waste building are the only buildings containing radioactive materials. The reactor core and its pressure vessel are highly contaminated, as is the piping to the turbines. The turbines are also contaminated, but the cooling towers and associated piping are not. Much equipment in the radioactive waste building is contaminated, as is the spent-fuel pool in the reactor building.

7.2.2 Decommissioning Methods

In the NRC's original decommissioning studies (NUREG/CR-0130 for PWRs and NUREG/CR-0672 for BWRs), three alternatives were defined: DECON (decontamination/dismantlement as rapidly after reactor shutdown as possible to achieve termination of the nuclear license); SAFSTOR (a period of safe storage of the stabilized and defueled facility followed by final decontamination/dismantlement and license termination); and ENTOMB (immediate removal of the highly activated reactor vessel internals for disposal and relocation of the remainder of the radioactively contaminated materials to the reactor containment building, which is then sealed. With sufficient time, the radioactivity on the entombed materials will have decayed to levels that permit termination of the nuclear license). However, because current regulations require decommissioning to be complete within 60 years, ENTOMB may not be a viable option.

Changes in the industrial and regulatory situation in the United States since the late 1970s have forced revisions to the scenarios of the NRC's original decommissioning alternatives. The most recently revised decommissioning scenarios are described for PWRs in NUREG/CR-5884 and for BWRs in NUREG/CR-6174. There are two principal changes in the revised scenarios. One is the delay of major decommissioning actions for at least 5 to 7 years following reactor shutdown because of a Department of Energy (DOE) requirement to cool the spent fuel in the reactor pool to avoid cladding failures in dry storage. The other is the assumption that decommissioning will be complete within 60 years, as required by current regulations. This delay results in an increase in decommissioning costs during the short safe storage period while the spent fuel pool continues to operate. Changes in cumulative occupational radiation doses also result from the decommissioning scenario changes.

The basic concept of the three alternatives remains unchanged. However, because of the accumulated inventory of spent fuel in the reactor storage pool and the requirement for at least 5 years of storage for the spent fuel before transfer to DOE for disposal, the timing and steps in the process for each alternative have been adjusted to reflect present conditions and possibilities. For the DECON alternative, it is assumed that the owner has strong incentives to decontaminate and dismantle the retired reactor facility as promptly as possible [i.e., future availability and cost of low-level radioactive waste (LLW) disposal and the need to reuse or dispose of the site, necessitating transfer of the stored spent fuel from the pool to a dry storage facility on the reactor site]. Although continued storage of spent fuel in the pool would be acceptable, the modified Part 50 license could not be terminated until the pool was emptied. It is also assumed that an acceptable dry transfer system would be available to remove the spent fuel from the dry storage facility and place it into licensed transport casks when the time came for DOE to accept the spent fuel for disposal. Similar assumptions are made for the SAFSTOR and ENTOMB alternatives for convenience of analysis, even though extended use of the spent fuel pool might be more cost-effective for SAFSTOR.

7.2.2.1 DECON

DECON is the decommissioning method in which the equipment, structures, and portions of the facility and site containing radioactive contaminants are removed or decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of operations. It is the only decommissioning alternative that leads to termination of the facility license and release of the facility and site for unrestricted use shortly after cessation of facility operations. DECON activities are expected to require about 9 years for large light-water reactors; less time should be required for smaller facilities.

Because DECON operations are expected to be completed within a few years following shutdown, radiation exposures to workers generally are higher than for decommissioning methods that allow for radioactive decay by delaying or extending the work over a longer period. DECON also requires larger commitments of money and commercial waste disposal site space than do other decommissioning methods. The principal advantage of DECON is that the site is available for unrestricted use promptly.

Nonradioactive equipment and structures need not be dismantled or removed for termination of the NRC license and release for unrestricted use. Once the facility's radioactive structures are decontaminated to levels permitting unrestricted use of the facility, nonradioactive facilities may either be put to some other use or demolished at the owner's discretion. [NRC has issued proposed amendments to 10 CFR Part 20 containing radiological criteria for decommissioning of NRC-licensed nuclear facilities (FR 59, 43200, August 22, 1994). Currently, NRC uses, on a case-by-case basis, criteria and practices contained in Regulatory Guide 1.86 and in a letter to Stanford University from J. Miller, Office of Nuclear Reactor Regulation, NRC, dated April 21, 1982.]

DECON, as defined by NUREG/CR-5884 and NUREG/CR-6174, comprises four distinct periods of effort: (1) preshutdown planning/engineering and regulatory reviews, (2) plant deactivation and preparation for storage (no dismantling activities are conducted during this period that would affect the safe operation of the spent fuel pool), (3) plant safe storage with concurrent operations in the spent-fuel pool until the pool inventory is zero, and (4) decontamination and dismantlement of the radioactive portions of the plant, leading to license termination. Because of the delays in development of the federal waste management system, it may be necessary to continue operation of a dry fuel storage facility on the reactor site after the reactor systems have been dismantled and the reactor nuclear license terminated. However, these latter storage costs are considered operations costs under 10 CFR 50.54(b)(b) and are not considered part of decommissioning.

7.2.2.2 SAFSTOR

SAFSTOR is the decommissioning method in which the nuclear facility is placed and maintained in a condition that allows the safe storage of radioactive components of the nuclear plant and subsequent decontamination to levels that permit release for unrestricted use. SAFSTOR was initially conceived of as having three successive stages: (1) a short period of preparation for safe storage (expected to be up to 2 years after final reactor shutdown); (2) a variable safe storage period of continuing care consisting of security, surveillance, and maintenance during which much of the reactor's radioactivity decays; and finally, (3) a relatively short period of decontamination (NUREG-0586). In NUREG/CR-5884 and NUREG/CR-6174, SAFSTOR is described as five distinct periods of effort, with the initial three periods identical to those of DECON. The fourth period is extended safe storage (50 years) with no fuel in the reactor storage pool, and the fifth period is decontamination and dismantlement of the radioactive portions of the plant.

The radioactive or contaminated material must be decontaminated or removed, packaged, and disposed of at a regulated disposal facility. After it has been determined that residual radioactivity is at acceptable levels, the license will be terminated and the facility can be released for unrestricted use. After termination of the NRC license, disassembly or demolition of nonradioactive facilities would be performed at the owner's discretion.

SAFSTOR may be used as a means of satisfying requirements for protection of the public while minimizing the initial commitments of time, money, radiation exposure, and waste disposal capacity. SAFSTOR may also have some advantage where there are other operational nuclear facilities at the same site or where a shortage of radioactive waste disposal capacity occurs. The disadvantages of SAFSTOR are that the site is unavailable for other uses for an extended time; maintenance, security, and surveillance are required until the final decontamination is complete; and few, if any, personnel familiar with the facility are available at the time of decontamination (up to 60 years after plant shutdown).

7.2.2.3 ENTOMB

ENTOMB is the alternative in which radioactive contaminants are encased in a long-lasting material, such as concrete. The entombed structure is maintained and surveillance is performed until the radioactivity decays to a level permitting release of the property for unrestricted use. ENTOMB also comprises five distinct periods of effort, with the initial three periods identical to those of DECON (NUREG/CR-5884 and NUREG/CR-6174). The fourth period is preparation for entombment, when all of the radioactive materials are consolidated within the containment building and entombed. The fifth period is entombed storage for an extended time, between 60 and 300 years.

ENTOMB is intended for use where the residual radioactivity will decay to levels permitting unrestricted release of the facility within reasonable time periods (100 years). However, a few radioactive isotopes produced in nuclear reactors have long half-life periods (Section 7.3.1) that prevent the release of the facilities for unrestricted use within the foreseeable lifetime of any man-made structure. ENTOMB would be a viable alternative only for facilities where radioactive isotopes would be expected to decay to safe levels within the expected lifetime of the entombment structure. This condition likely would not pertain to nuclear power reactors. In addition, the use of the ENTOMB alternative contributes to problems associated with increased numbers of sites dedicated to "interim" storage of radioactive materials for long periods of time.

7.2.3 Decommissioning Experience

U.S. commercial nuclear power reactors that have been shut down through 1992 are listed in Table 7.1. An additional 24 reactors have been or are being decommissioned in France, West Germany, Canada, the United Kingdom, Sweden, and Japan (Gaunt et al. 1990).

7.2.4 Inventory and Disposition of Radioactive Materials

Radioactive materials can be classified as activated or radioactively contaminated materials. Materials become activated when they have been exposed to (irradiated by) high levels of neutron radiation (such as in a reactor). When normal (stable) atoms in

Table 7.1 U.S. commercial nuclear power reactors formerly licensed to operate

Unit/ location	Construction type[a]/ MW(t)	Operating license issued/ shut down	Decommissioning alternative selected/ current status
Bonus[b] Punta Higuera, PR	BWR/50	04/02/64 06/01/68	ENTOMB ENTOMB
Carolina Virginia Tube Reactor[c] Parr, SC	PTHW/65	11/27/62 01/01/67	SAFSTOR SAFSTOR
Dresden 1 Morris, IL	BWR/700	09/28/59 10/31/78	SAFSTOR SAFSTOR
Elk River[b] Elk River, MN	BWR/58	11/06/62 02/01/68	DECON DECON completed
Fermi 1 Lagoona Beach, MI	SCF/200	05/10/63 09/22/72	SAFSTOR SAFSTOR
Fort St. Vrain Platteville, CO	HTG/842	12/21/73 08/18/89	DECON DECON in progress
GE Vallecitos Boiling Water Reactor Pleasanton, CA	BWR/50	08/31/57 12/09/63	SAFSTOR SAFSTOR
Hallam[b] Hallam, NE	SCGM/256	01/02/62 09/01/64	ENTOMB ENTOMB
Humboldt Bay 3 Eureka, CA	BWR/200	08/28/62 07/02/76	SAFSTOR SAFSTOR
Indian Point 1 Buchanan, NY	PWR/615	03/26/62 10/31/74	SAFSTOR NRC review
La Crosse Genoa, WI	BWR/165	07/03/67 04/30/87	SAFSTOR SAFSTOR
Pathfinder Sioux Falls, SD	BWR/190	03/12/64 09/16/67	SAFSTOR DECON in progress
Peach Bottom 1 Peach Bottom, PA	HTG/115	01/24/66 10/31/74	SAFSTOR SAFSTOR
Piqua[b] Piqua, OH	OCM/46	08/23/62 01/01/66	ENTOMB ENTOMB
Rancho Seco Herald, CA	PWR/2772	08/16/74 06/07/89	SAFSTOR NRC review

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See notes at end of table.

Table 7.1 (continued)

Unit/ location	Construction type[a]/ MW(t)	Operating license issued/ shut down	Decommissioning alternative selected/ current status
San Onofre 1 San Clemente, CA	PWR/1347	03/27/67 11/30/92	SAFSTOR[d]
Shippingport[b] Shippingport, PA	PWR/236	N/A 82	DECON DECON completed
Shoreham Wading River, NY	BWR/2436	04/21/89 06/28/89	DECON DECON in progress
Three Mile Island 2 Londonderry Township, PA	PWR/2770	02/08/78 03/28/79	e
Trojan Portland, OR	PWR/3411	11/21/75 11/09/92	f
Yankee-Rowe Franklin County, MA	PWR/600	12/24/63 10/01/91	g

[a] BWR = boiling-water reactor; HTG = high-temperature gas-cooled; OCM = organically cooled and moderated; PTHW = pressure tube, heavy water cooled and moderated; PWR = pressurized-water reactor; SCF = sodium cooled,
fast; SCGM = sodium cooled, graphite moderated.
[b] Atomic Energy Commission/Department of Energy owned; not regulated by the Nuclear Regulatory Commission.
[c] Holds by-product license from state of South Carolina.
[d] San Onofre 1 decommissioning plan was due to the Nuclear Regulatory Commission in November 1994.
[e] Three Mile Island 2 has been placed in a monitored storage mode. The licensee plans to maintain the facility in monitored storage until Three Mile Island 1 permanently ceases operation, at which time both units are to be decommissioned simultaneously.
[f] Trojan received a possession-only license on 05/05/93. The license is evaluating SAFSTOR and DECON decommissioning alternatives. A decommissioning plan was due to the Nuclear Regulatory Commission in January 1995.
[g] Yankee Rowe received a possession-only license on 08/05/92. The licensee submitted a decommissioning plan on 12/20/93. Decommissioning alternative depends on the availability of low-level waste disposal facilities.
Source: DOE/RW-0006, rev. 6.

a material absorb neutrons, they become unstable (radioactive) and subsequently emit energy in the form of radiation. Radioactive contamination is radioactive material in the form of fine particles, liquids, or gases that are deposited on the surface of, or mixed with, materials that otherwise are not radioactive. Contaminated materials can generally be decontaminated to various degrees by several techniques. These techniques range from simply washing with soap and water to sandblasting contaminated surfaces. Decontamination techniques for liquids and gases include filtration and chemical ion exchange. Activated materials cannot be decontaminated; they remain radioactive until the radioactive constituents decay to stable isotopes.

Reactor components are generally both activated and contaminated. The principal activated components of a power plant are the reactor internals and the biological shield. Other reactor system components, such as the primary and possibly the secondary coolant loops, the turbines in BWRs, and the radioactive waste handling systems, are not activated but are highly contaminated by the contaminated fluids they contain. The major source of contamination in reactor coolant is the plant corrosion and wear material suspended in the coolant that becomes activated as it passes through the reactor core. Surface contamination can also be found in areas of the plant where leaks from contaminated systems have occurred.

The inventory of radionuclides for PWRs and BWRs is slightly different. A typical large PWR would have a radioactivity level of about 4.8 million Ci (1Ci = 3.7×10^{10} Bq) in the major reactor components, 4800 Ci of radioactive corrosion products in the primary coolant system, and 1200 Ci of radioactivity in the concrete biological shield at the time of shutdown (NUREG/CR-0130). A typical large BWR would have a radioactivity level of about 6.3 million Ci in the major reactor components, 8600 Ci of radioactive corrosion products in the primary coolant system, and 1000 Ci of radioactivity in the concrete biological shield at the time of shutdown (NUREG/CR-0672).

The principal radioactive isotopes from irradiated steel and concrete, with their modes of decay and their half-lives, are listed in Table 7.2. By the end of 40 years of operation, the radionuclides with half-lives of less than about 5 years are at equilibrium, because their rates of decay equal their rates of generation. No matter how much longer a power plant is operated, the concentration of short-half-life radionuclides will not increase. The longer-lived radionuclides are generated much faster than they decay; thus their concentrations increase approximately in proportion to the reactor operating time. Figure 7.3 illustrates the buildup of some important radionuclides as a function of nuclear plant operating life.

Radioactive isotopes that are mainly beta emitters or that have very short half-lives do not contribute significantly to the personnel radiation dose associated with decommissioning. Because beta radiation is weakly penetrating, it can be shielded easily and presents a hazard mainly if ingested or inhaled by operations personnel. Isotopes with very short half-life periods can be allowed to decay to insignificant levels before decommissioning operations begin.

At the time of decommissioning, radioactive materials are found in the reactor building, the auxiliary building, and the fuel building (Section 7.2.1). Immediately after operations are terminated, these parts of the plant are highly radioactive because of short-lived activation products. The highest levels of radioactivity subside very quickly as short-lived radionuclides decay and progressively longer-lived radionuclides dominate the overall radioactivity. After about a year, ^{60}Co dominates the radiation dose to workers. After about 100 years, ^{94}Nb dominates the radiation dose to workers or persons in the vicinity (Figure 7.4). For all practical purposes, the radiation dose to workers will not decrease further because ^{94}Nb has a 20,000-year half-life. Because ^{60}Co and ^{94}Nb dominate the radiation dose during the time of decommissioning, their characteristics affect the decommissioning process.

Both ^{60}Co and ^{94}Nb are activation products—isotopes created when neutrons from nuclear fission convert nonradioactive elements (^{59}Co and ^{93}Nb) in the structural components of the plant into radioactive

Table 7.2 **Principal activated radioactive isotopes found in operating nuclear power plants (excluding fuel)**

Element	Isotope	Decay mode[a]	Half-life (years)
Hydrogen	^{3}H	β	1.23×10^{1}
Carbon	^{14}C	β	5.73×10^{3}
Phosphorus	^{33}P	β	6.9×10^{-2}
Silicon	^{35}S	β	2.4×10^{-1}
Chlorine	^{36}Cl	β, γ	3.01×10^{5}
Argon	^{37}Ar	γ	9.5×10^{-2}
Argon	^{39}Ar	β	2.99×10^{2}
Potassium	^{40}K	β, γ	1.28×10^{9}
Calcium	^{41}Ca	γ	8.0×10^{4}
Calcium	^{45}Ca	β	4.5×10^{-1}
Scandium	^{46}Sc	β	2.3×10^{-1}
Chromium	^{46}Cr	γ	7.6×10^{-2}
Manganese	^{54}Mn	γ	$8. \times 10^{-1}$
Iron	^{55}Fe	γ	2.7×10^{0}
Iron	^{59}Fe	β, γ	1.2×10^{-1}
Cobalt	^{58}Co	γ	2.1×10^{-1}
Cobalt	^{60}Co	β, γ	5.27×10^{0}
Nickel	^{59}Ni	γ	8.0×10^{4}
Nickel	^{63}Ni	β	9.2×10^{1}
Zinc	^{65}Zn	γ	6.7×10^{-1}
Niobium	^{93m}Nb	γ	1.36×10^{1}
Niobium	^{94}Nb	β, γ	2.03×10^{4}
Niobium	^{95}Nb	β, γ	9.6×10^{-2}
Molybdenum	^{93}Mo	γ	3.5×10^{3}
Zirconium	^{95}Zr	β, γ	1.8×10^{-1}
Technetium	^{99}Tc	β	2.13×10^{5}
Silver	^{108m}Ag	β, γ	1.27×10^{2}
Silver	^{110m}Ag	β, γ	6.8×10^{-1}
Cadmium	^{109}Cd	γ	1.3×10^{0}
Samarium	^{151}Sm	β, γ	9.0×10^{1}
Europium	^{152}Eu	β, γ	1.33×10^{1}
Europium	^{154}Eu	β, γ	8.8×10^{0}
Holmium	^{166m}Ho	γ	1.2×10^{3}

[a] β = beta, γ = gamma (including x-rays).

Source: R. C. Weast, ed. *Handbook of Chemistry and Physics*, 53rd ed. 1972–73, Chemical Rubber Company, Cleveland, 1972.

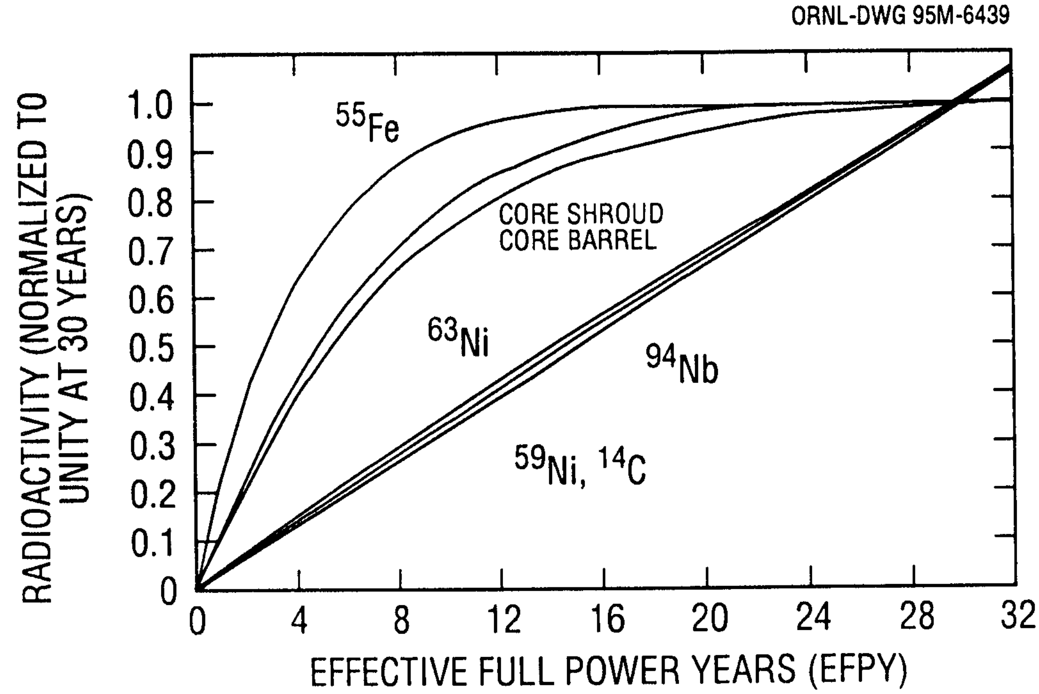

Figure 7.3 **Buildup of activation products in pressurized-water reactor internal components as a function of effective full-power years.** *Source:* NUREG/CR-0130.

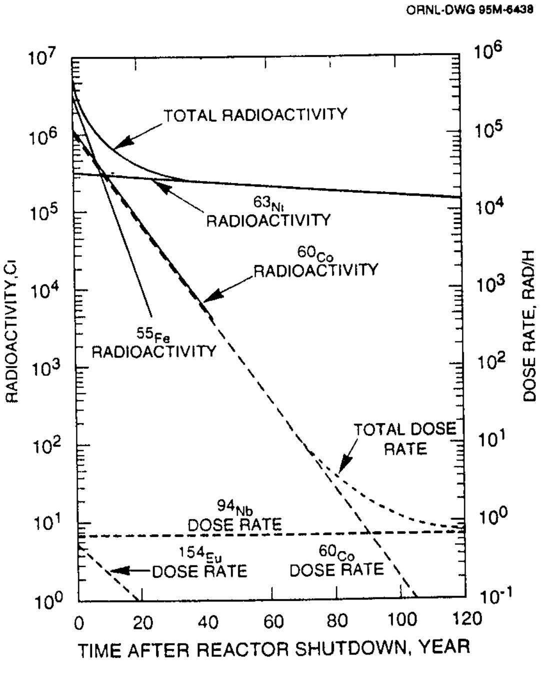

Figure 7.4 **Time dependence of radioactivity and dose rate in a boiling-water reactor core shroud after 40 years of operation.** *Source:* NUREG/CR-0672.

isotopes. An important difference is that ^{94}Nb in the steel reactor vessel and components, formed by activation of ^{93}Nb, is not subject to corrosion and movement throughout the primary system to the extent that ^{60}Co is. Consequently, equipment in the reactor containment building that is not exposed to high neutron fluxes and parts of the fuel and auxiliary buildings may be highly contaminated with ^{60}Co but only slightly so with ^{94}Nb.

Extending operations to 60 years would not increase the shutdown radioactivity level of either a PWR or BWR to any appreciable extent. This is because most of the radioactivity at shutdown results from short-half-life radionuclides, such as ^{60}Co, that are already in equilibrium by the time 40 years of operations have transpired. The only change in radioactive inventory resulting from the additional 20 years of operations is the further accumulation of long-half-life radionuclides such as ^{63}Ni and ^{94}Nb, but these long-half-life radionuclides produce only a small fraction of the total radioactivity at shutdown. Of the long-half-life radionuclides, ^{63}Ni contributes most at shutdown but composes less than 3 percent of the total radioactivity. Twenty additional years of operation would increase its contribution to about 4 percent of total shutdown radioactivity. Because ^{63}Ni is a beta emitter, it contributes only a very small part of the dose to workers or the public. Gamma-emitting ^{94}Nb is the most important long-half-life radionuclide with regard to producing external radiation exposure. Based on Figure 7.4, it can be determined that at shutdown ^{94}Nb contributes less than 0.001 percent of the total potential dose. Even though 20 additional years of operation would increase the amount of ^{94}Nb by 50 percent, it would not increase its contribution to the dose much above 0.001 percent.

7.2.5 Waste Generated During Decommissioning

This section summarizes the quantities and types of radioactive waste and emissions generated in decommissioning after 40 and 60 years of operation, respectively. Because the demolition and disposal of nonradioactive parts of nuclear facilities are not considered part of decommissioning, almost all waste generated during decommissioning is radioactive. Although the demolition and disposal of the nonradioactive parts may continue during and after decommissioning, these activities are not regulated by NRC. The impacts of radioactive wastes and emissions are described in Section 7.3. This section does not take into account volume reduction or aggressive processing that could allow release for unrestricted use.

7.2.5.1 Atmospheric Emissions

As shown in Table 7.3, the total atmospheric releases for decommissioning are less than 100 mCi, whereas normal operations average about 3000 Ci/year. Atmospheric releases are expected to consist largely of dust, aerosols, and smokelike particulates produced during the dismantling and handling of reactor components. These releases were estimated by assuming that the airborne concentrations of radionuclides will be a fraction of the contamination level on and in the radioactive components (NUREG/CR-0130 and NUREG/CR-0672). Because the radioactive inventory would be nearly unchanged by operations during a 20-year license renewal term, no difference exists between the base case and 20 years of additional operation.

Table 7.3 **Airborne radioactive releases resulting from decommissioning typical pressurized-water reactors (PWRs) and boiling-water reactors (BWRs) with normal operating releases, base case (40 years of operation)[a]**

	DECON (mCi)	SAFSTOR (mCi)	ENTOMB (mCi)	Normal operations (Ci/year)
PWR	0.86[b]	0.003[b]	NA[c]	2,600[d]
BWR	87[e]	0.21d[d]	2.25[d]	3,400[d]

[a] Decommissioning releases are for 40 years of operation. Releases for 60 years of operation would be essentially the same.

[b] *Source:* NUREG/CR-0130, Table 11.2-2.

[c] Not available.

[d] *Source:* DOE/EP-0093.

[e] *Source:* NUREG/CR-0672, Tables N.2-12, N.3-4, N.4-4, E.2-11. Decommissioning is assumed to last 5 years.

7.2.5.2 Liquid Effluents

No estimates of liquid waste releases are available for decommissioning nuclear power plants. However, liquids will be produced by decontamination procedures (e.g., some cutting operations and possibly some chemical decontamination procedures) and by disposal of plant fluids (e.g., cooling water and water from fuel storage pools). Filtration and ion exchange methods will be used to decontaminate liquids, as would be done during normal operations. Some liquid effluents may be contaminated with chelating agents and may require further processing. These methods are expected to keep waterborne effluents of most radionuclides within the values of normal operations. Tritium (^{3}H) is the only radioactive isotope that cannot be removed from waste water by these means.

Tritium is found principally in the primary coolant-loop water. Tritium cannot be removed from water except by extraordinary means and is normally discharged to a surface water body. Normal ^{3}H discharges from PWRs range from a few hundred to a few thousand curies per year. BWR ^{3}H discharges are generally only about 10 percent as high as ^{3}H discharges from PWRs. About 500 Ci of ^{3}H can be found in PWR primary coolant-loop water. Discharge of the entire volume of primary coolant-loop water over a period of 1 to 5 years after shutdown would be feasible without exceeding normal operating period discharge rates. The amounts or characteristics of liquid effluents discharged during decommissioning would not be changed by operation during a 20-year license renewal term. Discharge of primary coolant water during normal operations limits the accumulation of ^{3}H in the primary coolant loop; thus ^{3}H is in equilibrium in the primary coolant water well before 40 years of operation.

7.2.5.3 Solid Waste

Table 7.4 summarizes the quantities of LLW generated by decommissioning of large PWRs and BWRs. The table shows that the largest amount of LLW is

Table 7.4 **Estimated burial volume of low-level waste and rubble for large pressurized-water reactor (PWR) and boiling-water reactor (BWR) decommissioning, base case (40 years of operation)**

Decommissioning alternative	PWR (m^3)[a]	BWR (m^3)
DECON	6,992	14,282
SAFSTOR 1	763	1,117
SAFSTOR 2	6,992	14,282
ENTOMB 1	305	490
ENTOMB 2	754	1,139
ENTOMB 3	305	490

[a] 1 m^3 = 35.3 ft^3

Source: NUREG/CR-5884, Table ES.1 and NUREG/CR-6174, Table ES.1.

generated by the DECON method and the least is generated by the SAFSTOR method. The quantities listed for the ENTOMB method do not include the volume of the entombing structure or the wastes within.

The decommissioning waste volumes for all three methods of decommissioning also would not be affected by extending the volume of radioactive materials would not increase. (Operational waste quantities would continue, but they do not affect the amount of decommissioning waste.) An additional 20 years of operation would slightly affect the waste characteristics. As discussed in Section 7.2.4, the quantity of long-lived activation products such as ^{94}Nb would continue to increase, essentially in proportion to the additional operational time. As a result, the long-half-life radionuclides in the waste would increase by 50 percent if the plants were operated an additional 20 years. However, as explained earlier, these long-lived radionuclides contribute only a small fraction of the shutdown radioactivity level.

7.3 DECOMMISSIONING IMPACTS AND CHANGES RESULTING FROM LIFE EXTENSION

Estimated decommissioning impacts for 40 years of operation—the base case (taken primarily from NUREG-0586, NUREG/CR-0130, and NUREG/CR-0672)—and the change in impacts caused by continued operations for an additional 20 years under license renewal are reported for each impact area in the following sections. These impacts are estimated for PWRs and BWRs. The per-reactor impacts of decommissioning at multiple-reactor sites are not expected to be significantly different from those at single-reactor sites. [The impacts would be smaller at multiple reactor sites if the reactor decommissionings were staggered and if LLW were stored on the site (NUREG-0586)].

7.3.1 Radiation Dose

The estimated occupational and public radiation doses resulting from the three decommissioning methods after 40 years of operation (base case) are summarized in this section. Occupational dose estimates were presented in draft reports NUREG/CR-5884 and NUREG/CR-6174. These reports do not provide estimates of doses to the public. The Atomic Energy Act requires the Nuclear Regulatory Commission to promulgate, inspect, and enforce standards that provide an adequate level of protection of the public health and safety and the environment. These responsibilities, singly and in the aggregate, provide a margin of safety. For the purposes of assessing radiological impacts, the Commission has concluded that impacts are of small significance if doses and releases do not exceed permissible levels in the Commission's regulations.

7.3.1.1 Occupational Dose

For both PWRs and BWRs, there are substantial differences among the occupational radiation doses for the decommissioning methods (Table 7.5). The DECON method has the highest doses, followed by ENTOMB and then SAFSTOR. Although extending operations 20 years would increase the doses from ^{94}Nb and other less-important long-half-life radionuclides, these doses would not have any appreciable effect on the occupational dose because short-lived radionuclides (primarily ^{60}Co) are the principal sources of worker exposure. For each decommissioning method, the bulk of the dose comes during activities in the first few years after termination of plant operations (period four begins less than 5 years after terminating operations for DECON), when the radioactivity level of ^{60}Co is still significant. At the end of 60 years of SAFSTOR, the dose rate would have decayed to about 0.01 percent of the dose rate at the end of operations, at which time ^{94}Nb would contribute only about 2 percent of the total (Figure 7.4). An additional 20 years of operation before 60 years of SAFSTOR would increase the amount of ^{94}Nb by approximately 50 percent. During period 5, occupational exposures from SAFSTOR activities would be no more than 10 person-rem. (Section E.A.3 of Appendix E discusses the International System units used in measuring radioactivity and radiation dose. The contribution from ^{94}Nb would be less than 0.2 person-rem. The increase in dose during decommissioning after 20 additional years of operation would be no more than about 0.1 person-rem.

Although total doses to the decommissioning workforce may increase slightly as a result of an additional 20 years of plant operation, the exposure of individual workers will be maintained well below the existing regulatory limits of 10 CRF Part 20. Accordingly, the Commission concludes that radiological impacts to the decontamination workforce as a result of license renewal is of small significance.

The potential increase in total dose to the decommissioning work force may be mitigated by programs that are responsive to 10 CFR 20.1101(b), which requires that "The licensee shall use, to the extent practicable, procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA)." The ongoing ALARA programs within the industry already employ measures that would be considered for mitigating the generation or the accumulation of long-lived activation products during 20 additional years of operation. Two examples of mitigation measures that are already in use are (1) replacing components using cobalt alloys with those using low-cobalt or cobalt-free alloys and (2) full system decontamination (e.g., see

Table 7.5 Estimated occupational radiation doses for decommissioning a large reactor (person-rem), base case (40 years of operation)[a]

Decommissioning period[b]	DECON[c,d]	SAFSTOR[c,e]	ENTOMB[c,f]
Pressurized-water reactor[g]			
1	—	—	—
2	207	207	207
3	21	21	21
4	704	88	562–589
5	NA	0-6	0
Totals[h]	931	315–322	790–816
Boiling-water reactor[i]			
1	—	—	—
2	425	425	425
3	10	10	10
4	528	123	166–230
5	NA	0–10	0
Totals[h]	962	558–568	601–665

[a] Occupational radiation exposures are for decommissioning after 40 years of operations.
[b] Decommissioning periods are defined in NUREG/CR-6174 and NUREG/CR-5884.
[c] DECON, SAFSTOR, and ENTOMB are defined differently by NUREG/CR-5884 and NUREG/CR-6174 than by previous analyses.
[d] Table 3.1.
[e] Table 4.1.
[f] Table 5.2.
[g] *Source:* NUREG/CR-5884.
[h] Totals may not equal sum of entries because of rounding.
[i] *Source:* NUREG/CR-6174.

Moore 1995). No additional mitigation measures warranted. This is a Category 1 issue.

7.3.1.2 Dose to the Public

For both PWRs and BWRs, the radiation dose to the public results primarily from waste shipment (Table 7.6). Furthermore, the dose is almost exclusively caused by shipment of ^{60}Co and shorter-lived radionuclides; for truck shipments, the SAFSTOR 100-years alternative shows negligible dose to the public. Because only the quantities of long-lived radionuclides would increase if plants were operated an additional 20 years, only the dose caused by the long-lived radionuclides would increase. Because the dose to the public from long-lived radionuclides after 40 years

Table 7.6 Estimated radiation dose to the public for decommissioning a large reactor (person-rem), base case (40 years of operation)[a,b]

	DECON	SAFSTOR 30 years	SAFSTOR 100 years	ENTOMB
Pressurized-water reactor				
SAFSTOR preparation	NA	neg	neg	NA
Continuing care	NA	neg	neg	neg
Decontamination	neg[c]	neg[c]	neg[c]	NA
Entombment	NA	NA	NA	neg
SAFSTOR preparation truck shipments	NA	2	2	NA
Decontamination truck shipments	21[c]	0.4[c]	neg[c]	NA
Entombment truck shipments	NA	NA	NA	4
Totals	21	3	2	4
Boiling-water reactor				
SAFSTOR preparation	NA	neg	neg	NA
Continuing care	NA	neg	neg	neg
Decontamination	neg[c]	neg[c]	neg[c]	NA
Entombment	NA	NA	NA	neg
SAFSTOR preparation truck shipments	NA	2	2	NA
Decontamination truck shipments	10[c]	neg[c]	neg[c]	NA
Entombment truck shipments	NA	NA	NA	5–7[d]
Totals	10	2	2	5–7[d]

[a] Public radiation exposures are for decommissioning after 40 years of operation (NUREG-0586). Decommissioning exposures after 60 years would be identical, except as noted. Draft reports NUREG/CR-5884 and NUREG/CR-6174 do not provide updates for this information.

[b] NA means not applicable and neg means negligible.

[c] Decommissioning after 60 years of operation would increase occupational and public exposure during (1) decontamination and (2) decontamination truck shipments by only negligible amounts.

[d] Ranges are for removing or leaving internal components or leaving them in place. The higher exposures are associated with removing the internals.

Note: To convert person-rem to person-sievert, multiply by 0.01.

of operation is negligible (see the SAFSTOR 100-years alternative in Table 7.6), an increase of 50 percent of this negligible amount would still remain a negligible dose (less than 0.1 person-rem).

The negligible public radiation exposures for SAFSTOR preparation, continuing care, and decontamination (Table 7.6) include exposures from atmospheric and liquid releases during routine decommissioning operations. There are no historical records of significant releases during decommissioning, and no reliable estimates can be made of the probability and consequences of such events.

However, the probability and consequences of such releases are not expected to be different for decommissioning a base case facility versus decommissioning a facility that has had 20 years of additional operation.

Extending reactor operating life from 40 to 60 years is expected to increase the concentration of long-half-life radionuclides in the facility by up to 50 percent. By the end of the initial 40 years of operation, the radionuclides with half-lives of less than about 5 years are at equilibrium because their rates of decay equal their rates of generation. The release of radioactivity to the atmosphere during decontamination is negligibly small and primarily involves short-lived nuclides. Public exposure even with the increased concentration of long-lived nuclides would remain negligible. The exposure of individual members of the public will be maintained well below existing regulatory limits. Accordingly, the staff concludes that the contribution of license renewal to radiological impacts from decontamination is of small significance. As discussed in Section 7.3.1.1, measures that can reduce possible dose levels to the public are available and are being employed in pursuit of ALARA.

Radiation doses (public and occupational) from decommissioning that are attributable to license renewal are a Category 1 issue.

7.3.2 Waste Management Impacts

An operating 1000-MW(e) reactor generates about 38 m^3 (1300 ft^3) of spent fuel and about 52,000 m^3 (1,800,000 ft^3) of LLW over its 40-year life (NUREG-0586, pp. 2-21). (LLW is defined in Chapter 6.) The reference PWR and BWR are about 15 percent larger, so they would be expected to generate about 15 percent more waste than a 1000-MW(e) plant. As shown by Table 7.4, decommissioning either type of plant after 40 years of operation (base case) would generate less than 15,000 m^3 (530,000 ft^3) of LLW for DECON or short-term SAFSTOR and less than 1,200 m^3 (42,000 ft^3) of LLW for SAFSTOR of 50 years or longer. These waste volumes include spent chelating agent used to decontaminate liquids. The 15,000 m^3 (530,000 ft^3) of decommissioning LLW is about 25 percent, and 1,200 m^3 (42,000 ft^3) is only about 2 percent, of the LLW generated by 40 years of operations. None of these estimates of waste volume includes waste generation during refurbishment.

Extending operations by 20 years would not increase decommissioning waste volumes, so the ratio of decommissioning waste volume to operating waste volume would be even lower. After 60 years of operation, decommissioning LLW would be less than about 20 percent of the operational LLW. If SAFSTOR were used, the decommissioning LLW would be only about 1 percent of the LLW generated by operations.

While the volume of decommissioning waste will not increase with 20 years of additional operating time, the concentration of long-half-life radionuclides will increase. LLW is classified by 10 CFR Part 61 into three waste classes denoted A, B, and C and a category of LLW designated "greater than Class C" (GTCC). Classes A and B are wastes that are contaminated with relatively short-half-life radionuclides and may be safely disposed of near the earth's surface because they will decay to a nonhazardous condition within about 100 years. Class C waste can be disposed of at a moderate depth or near the earth's surface with engineered barriers to prevent inadvertent intrusion into the wastes. GTCC waste cannot safely be disposed of near the earth's surface (Section 6.2.2.2; 10 CFR Part 61.7).

Table 7.7 gives the estimated decommissioning LLW breakdown (DECON scenario) for the base case by waste class per 10 CFR Part 61. Items classified as C and GTCC consist of highly activated metal located in the high-flux neutron field. For the PWR, the GTCC items include the lower core barrel, the thermal shields, the core shroud, and the lower grid plate. The class C items are the upper grid plate and the lower support column. The class B wastes consist of spent resins used during decommissioning, part of the combustible contaminated wastes, and part of the cylindrical pressure vessel wall. The only GTCC wastes from a BWR are the core shroud and top fuel guide. BWR class C wastes are from the control rods and in-core instrumentation, jet pump assemblies, and the top fuel guide. The class B wastes are from the steam separator assembly, the reactor vessel wall, and portions of the clean-up wastes.

Table 7.7 Decommissioning waste volumes for reference pressurized-water reactor (PWR) and boiling-water reactor (BWR) after 40 years of operation[a]

	Class A	Class B/C	GTCC[b]
PWR	6,797 m^3	184 m^3	11 m^3
BWR	13,903 m^3	372 m^3	6.9 m^3

[a] DECON decommissioning method. Other methods would have smaller volumes of Class A and B wastes; Class C and GTCC wastes volumes would not change for other methods. A plant that has operated 60 years would have essentially the same waste volumes and classifications.

[b] GTCC = greater than Class C.

Source: NUREG/CR-5884 and NUREG/CR-6174.

Note: 1 m^3 - 35.3 ft^3.

The radionuclides of most importance for determining the classification of these LLWs are those that have relatively long half-life periods, such as ^{59}Ni and ^{94}Nb. These are also the radionuclides that accumulate in proportion with the length of reactor operation. The estimates in Table 7.7 are made for a plant that has operated 40 years. A plant that has operated 60 years would have essentially the same decommissioning waste volumes and classifications. Because the radionuclide concentration differences among waste classes are large (factors of 10 or more) and because the concentrations of radionuclides increase by no more than 50 percent, few components would be advanced to a higher classification by an additional 20 years of operations. Because the decommissioning waste volumes and classifications are essentially unchanged by an additional 20 years of plant operation, the Commission finds that the environmental impacts of decommissioning waste due to license renewal are of small significance. Measures employed within the context of ALARA, as discussed in Section 7.3.1.1, have the potential to reduce slightly the volume of LLW generated by decommissioning. The impact on decommissioning waste management attributable to license renewal is a Category 1 issue.

7.3.3 Air Quality Impacts

Air quality impacts of decommissioning are expected to be negligible. No major land disturbance for construction laydown or temporary waste storage areas is anticipated. The principal air quality impacts would result from motor vehicles operated by workers for transportation on-site and for movement of people and materials to and from the site. Most decommissioning activities would be conducted inside the containment, the auxiliary building, and the fuel-handling buildings. Because there would be a possibility of airborne releases of radioactivity within these buildings during decommissioning, releases to the ambient environment would be controlled. These impacts would be much smaller than those associated with construction or demolition of the facilities on-site and would not change with 20 additional years of operation. License renewal and an additional 20 years of reactor operation will have no impact on air quality during decommissioning; thus the impact of license renewal on decommissioning air quality impacts is of small significance for all plants. Because license renewal does not affect the level of air pollution during decommissioning, there is no need for the consideration of mitigation as part of the license renewal environmental review. The impact of decommissioning on air quality attributable to license renewal is a Category 1 issue.

7.3.4 Water Quality Impacts

The principal water quality impacts expected from decommissioning are those associated with sanitary sewer operations. Because the decommissioning work force is likely to be smaller than those of construction and certain operational activities (see Section 7.3.7), no increase in water quality impacts is expected. Soil erosion and chemical spills associated with increased site activities during decommissioning have the potential to degrade water quality, but such effects are readily controllable. The potential for significant water quality impacts from erosion or spills is no greater if decommissioning occurs after a 20-year license renewal instead of after the original 40 years of operation. Measures to minimize occupational and public radiation exposure will also protect water quality. License renewal and an additional 20 years of reactor operation will have no impact on water quality during decommissioning; thus the impact is of small significance. Because license renewal does not affect water quality impacts during decommissioning, there is no need for the consideration of mitigation as part of the license renewal environmental review. The impact of decommissioning on water quality impacts attributable to license renewal is a Category 1 issue.

7.3.5 Ecological Impacts

Terrestrial biota impacts, if any, would be associated with land disturbance for laydown or temporary waste storage areas, and no such land disturbance is anticipated. No direct impacts to aquatic biota are expected from routine decommissioning activities. Measures employed to protect water quality will also prevent toxic effects to aquatic organisms from liquid effluents. Therefore, the ecological impacts associated with decommissioning are not expected to vary with the length of time the plant is operated. Decommissioning after a 20-year license renewal would have the same ecological impacts, if any, as decommissioning after 40 years of operation; thus the impact is of small significance. Because license renewal does not affect ecological impacts during decommissioning, there is no need for the consideration of mitigation as part of the license renewal environmental review. The impact of decommissioning on ecological resources attributable to license renewal is a Category 1 issue.

7.3.6 Economic Impacts

In general, the nature of the activities and the elements of the costs associated with decommissioning are well understood, and the necessary skills and equipment should be readily available when needed. Table 7.8 lists percentage estimates of total costs for decommissioning large PWR and BWR reactors by the DECON method.

A 1991 national survey had estimates that averaged $218 million per 1000 MW for a PWR reactor and $283 million per 1000 MW for a BWR. The standard deviation was $74 million for PWRs and $144 million for BWRs. For both types of reactors, the range for plus and minus one standard deviation was $131 million to $350 million (OTA-E-575). These varying estimates reflect the uncertainty of projecting costs well into the future. Additionally, the unique aspects of a plant's design and operating history can affect decommissioning costs (e.g., Three Mile Island Unit 2 and Fort St. Vrain).

The largest cost category is "undistributed"; the largest component of this cost is utility support staff. The timing of decommissioning could influence disposal costs depending on the price of disposal services. The current trend is steeply increasing cost per units of radioactive waste disposal. If this trend continues over the long run, then one effect of license renewal could be to increase decommissioning costs. However, disposal costs should stabilize by the time that most existing plants would be eligible for license renewal. If this is the case, license renewal would have a minimal effect on the undiscounted costs of decommissioning after a 20-year extended operation period, compared with after 40 years of operation.

For the cost estimates included in Table 7.8, doubling the cost per cubic foot of waste disposal would increase total decommissioning costs by about 13 percent for PWRs and 20 percent for BWRs. The assumed rate charged for disposal would have to increase by a factor of about 6 to double the total cost of decommissioning. If the rate of disposal costs turns out to be significantly more than has been assumed in decommissioning cost estimates, there would tend to be significantly more attention devoted to volume reduction; thus, total cost of disposal would tend to increase less than the proportional increase in the rate charged per cubic foot (NUREG/CR-5884, vol. 1, pp. 3.56, 3.57, and NUREG/CR-6174, vol. 1, p. 3.55).

The timing of decommissioning could also affect costs if progress in robotics technology reduces costs and worker radiation exposure. This progress would affect a relatively small part of the decommissioning process and thus is unlikely to reduce the total cost of decommissioning significantly; however, it could result in substantial dose reductions.

The preceding sections show that there is no reason to expect the physical requirements of decommissioning to be materially different when comparing the base case to a 20-year extended operation period. The undiscounted economic costs, although uncertain, should also be relatively stable and thus unaffected by license renewal. However, because of financial considerations, the timing of

Table 7.8 **Summary and distribution of decommissioning costs for large pressurized-water reactors (PWRs) and boiling-water reactors (BWRs)** (thousands of 1993 dollars)

Decommissioning alternative	Duration[a] (years)	Decon[b] (%)	Removal[c] (%)	Packaging[d] (%)	Transport[e] (%)	Disposal[f] (%)	Undistributed[g] (%)	Present value[h] of total cost ($ × 10^3)	Present value[h] of savings[i] for license renewal ($ × 10^3)
Pressurized-water reactor									
DECON	11	16.7	9.5	1.6	3.3	17.0	51.9	101,600	41,032
SAFESTOR1	59	11.0	0.5	0.3	1.0	3.4	83.8	93,000	37,559
SAFESTOR2	60	9.1	5.2	0.9	1.8	9.1	74.0	101,900	41,153
ENTOMB1	60	NA	NA	NA	NA	NA	NA	104,300	42,123
ENTOMB2	60	NA	NA	NA	NA	NA	NA	106,100	42,850
ENTOMB3	300	NA	NA	NA	NA	NA	NA	109,500	44,223
Boiling-water reactor									
DECON	9	11.1	9.2	2.6	0.9	27.3	48.9	133,250	53,814
SAFESTOR1	59	7.6	1.0	0.2	0.5	3.1	87.5	121,600	49,109
SAFESTOR2	60	5.8	4.8	1.4	0.5	14.1	73.5	134,200	54,198
ENTOMB1	60	NA	NA	NA	NA	NA	NA	151,900	61,346
ENTOMB2	60	NA	NA	NA	NA	NA	NA	155,200	62,679
ENTOMB3	300	NA	NA	NA	NA	NA	NA	164,500	66,435

[a] Preshutdown period not included in duration total.

[b] Includes direct decommissioning labor and materials for chemical decontamination of systems, cleaning of surfaces, and waste water treatment.

[c] Includes direct labor and materials costs of removal.

[d] Includes direct costs of waste disposal packages.

[e] Includes cask rental costs and transportation costs.

[f] Includes all costs of disposal at the LLW disposal facility.

[g] Includes all costs that are period-dependent—e.g., decommissioning operations contractor (DOC) mobilization/demobilization, utility and DOC overhead staff, nuclear insurance, regulatory costs, plant power usage, taxes, laundry services, environmental monitoring. Most of the undistributed costs are for staffing.

[h] At 3 percent discount rate.

[i] The decommissioning costs have been discounted at a rate of 3 percent real (assumes no inflation). At this rate, delaying decommissioning by the 20-year period of license renewal saves about 45 percent of the decommissioning cost; however, present value total costs have been figured at 2.5 years from final plant shutdown, resulting in savings from license renewal of about 40 percent.

Source: Tables 3.1 and 4.1 and pp. 3.59, 4.13, and 5.13 of NUREG/CR-5884, Vol. 1; Tables 3.1 and 4.1 and pp. 3.58, 4.12, and 5.11 of NUREG/CR-6174, Vol. 1.

decommissioning costs is important. To compare costs of activities that occur at different times, it is necessary to discount these costs to a common point in time. This is accomplished through present worth calculations, which account for the real opportunity cost or time value of money. Delaying decommissioning will allow any funds accumulated for this purpose to earn a return over the additional 20 years of license renewal and thus to reduce the present value of the decommissioning costs. The reduction in the present value is a function of the delay (license renewal period) and the time value of money, so the present value would be reduced by the same amount even if no fund were established and decommissioning were financed with borrowed money at the end of the plant operations. Regardless of how it is financed, the present value of delaying decommissioning costs will result in significant financial cost savings if a positive real discount rate is assumed.

Because total decommissioning costs are uncertain, the amount of financial savings that results from delaying decommissioning is also uncertain. Higher-than-expected decommissioning costs would result in higher cost savings resulting from delaying these costs, and vice versa. At a 3 percent real (i.e., above general inflation) discount rate, the present value savings associated with license renewal is about 40 percent of decommissioning costs (Table 7.8). Real cost increases, which might occur for waste disposal costs, could reduce the cost advantage of license renewal, but waste disposal costs are expected to stabilize before the current licenses of most plants expire. The impact of license renewal on decommissioning costs is not a consideration in the environmental review and decision whether to renew a license.

7.3.7 Socioeconomic Impacts

Socioeconomic impacts associated with decommissioning will be induced by the net change in the labor force as incoming decommissioning workers replace emigrating operations workers. The nature of these impacts will depend on the vitality of local economic activity at the time of decommissioning.

One of the difficulties of attempting to evaluate the socioeconomic impacts of decommissioning in year 40 of a plant's life compared with decommissioning in year 60 relates to the uncertainties about the size of the work force required. The largest nuclear power plant decommissioned to date has been the 150-MW(e) Shippingport Station (Section 7.2.3), which required an average work force during the peak year of approximately 230 workers (DOE/SSDP-0081); this work force was larger than the estimated work forces for very large power plants examined in studies prepared before the Shippingport experience (NUREG/CR-0130, Table 9.1-1; NUREG/CR-0672, Table 9.1-3). Because more-recent manpower estimates for large nuclear power plants are not available, the actual work force required in the future might be substantially larger than currently expected.

If the decommissioning process requires a smaller work force than the on-site operating staff and if the local economy is stable or declining, the result could be economic hardships, including declining property values and business activity, and problems for local government as it adjusts to lower levels of tax revenues. However, even this reduced work force will tend to mitigate temporarily the full adverse socioeconomic effects of terminating operations.

If there is a net reduction in the community work force but the economy is growing, the adverse impacts of this ongoing growth (e.g., housing shortages and school overcrowding) could be reduced.

If the decommissioning work force were substantially larger than the operational work force, the result could be increased demand for housing and public services but also increased tax revenues and higher real estate values. If the economy is characterized by decline, decommissioning could temporarily reverse the adverse economic effects.

In a stable economy, a net increase in the community work force could lead to some shortages in housing and public services, as well as to the higher tax revenues and real estate values mentioned previously. In a growing economy, decommissioning could act as an exacerbating factor to the ongoing shortages that already might exist.

Although the staff cannot project with certainty either the size of the required decommissioning work force or the state of the local economy at the time of decommissioning, the staff has assumed that the baseline conditions will be negligibly different in year 40, compared with year 60. Therefore, the staff expects that the socioeconomic impacts of decommissioning would be essentially similar whether that action were taken in year 60 or in year 40. The impact of license renewal on the socioeconomic impacts of decommissioning are of small significance. Because license renewal does not affect the socioeconomic impacts that will occur at the time of decommissioning, there is no need for the consideration of mitigation as part of the license renewal environmental review. The impact of decommissioning on socioeconomic resources attributable to license renewal is a Category 1 issue.

7.4 CONCLUSIONS

The physical requirements and attendant effects of decommissioning nuclear power plants after a 20-year license renewal are not expected to differ from those of decommissioning at the end of 40 years of operation. Decommissioning after a 20-year license renewal would increase the occupational dose no more than 0.1 person-rem (compared with 7,000 to 14,000 person-rem for DECON decommissioning at 40 years) and the public dose by a negligible amount (Section 7.3.1). License renewal would not increase to any appreciable extent the quantity or classification of LLW generated by decommissioning (Section 7.3.2). Air quality, water quality, and ecological impacts of decommissioning would not change as a result of license renewal (Sections 7.3.3, 7.3.4, and 7.3.5). There is considerable uncertainty about the cost of decommissioning; however, while license renewal would not be expected to change the ultimate cost of decommissioning, it would reduce the present value of the cost (Section 7.3.6). The socioeconomic effects of decommissioning will depend on the magnitude of the decommissioning effort, the size of the community, and the other economic activities at the time, but the impacts will not be increased by decommissioning at the end of a 20-year license renewal instead of at the end of 40 years of operation (Section 7.3.7). Incremental radiation doses, waste management, air quality, water quality, ecological, and socioeconomic impacts of decommissioning due to operations during a 20-year license renewal term would be of small significance. No mitigation measures beyond those provided by ALARA are warranted within the context of the license renewal process. The impacts of license renewal on radiation doses, waste management, air quality, water quality, ecological resources, and socioeconomics impacts from decommissioning are Category 1 issues.

7.5 REFERENCES

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8. ALTERNATIVES TO LICENSE RENEWAL

8.1 INTRODUCTION

The Nuclear Regulatory Commission's (NRC's) environmental review regulations implementing the National Environmental Policy Act (NEPA) (10 CFR Part 51) require that the NRC consider all reasonable alternatives to a proposed action before acting on a proposal, including consideration of the no-action alternative. The intent of such a consideration is to enable the agency to consider the relative environmental consequences of an action given the environmental consequences of other activities that also meet the purpose of the action, as well as the environmental consequences of taking no action at all. The information in this chapter does not constitute NRC's final consideration of alternatives to license renewal. Therefore, the rule accompanying this Generic Environmental Impact Statement (GEIS) does not contain any conclusions regarding the environmental impact or acceptability of alternatives to license renewal. Accordingly, the NRC will conduct a full analysis of alternatives at individual license renewal reviews. NRC expects that information contained in this chapter will be used in the analysis of alternatives for the supplemental environmental impact statements prepared for individual license renewals. As defined in Chapter 1, the proposed action is the granting of a renewed license. Additionally, the purpose of such a proposal is to provide an option that allows for power generation capability beyond the term of a current nuclear power plant operating license in order to meet future system generating needs as such needs may be determined by state, utility, and, where authorized, federal (other than NRC) decision makers. This chapter examines the potential environmental impacts associated with denying a renewed license (i.e., the no action alternative); the potential environmental impacts from electric generating sources other than nuclear license renewal; the potential impacts from instituting additional conservation resources to reduce the total demand for power; and the potential impacts from power imports.

The no-action alternative is the denial of a renewed license. In general, if a renewed license were denied, a plant would be decommissioned and other electric generating sources would be pursued if power were still needed. It is important to note that NRC's consideration of the no-action alternative does not involve the determination of whether any power is needed or should be generated. The decision to generate power and the determination of how much power is needed are at the discretion of state and utility officials.

While many methods are available for generating electricity, and a huge number of combinations or mixes can be assimilated to meet a defined generating requirement, such expansive consideration would be too unwieldy to perform given the purposes of this analysis. Therefore, NRC has determined that a reasonable set of alternatives should be limited to analysis of single, discrete electric generation sources and only electric generation sources that are technically feasible and commercially viable.

To generate this reasonable set of alternatives, NRC included commonly known generation technologies and consulted various state energy plans to identify the alternative generation sources typically being considered by state authorities across the country. From this review, NRC has established a reasonable set of alternatives to be examined in this chapter. These alternatives include wind energy, photovoltaic (PV) cells, solar thermal energy, hydroelectricity, geothermal energy, incineration of wood waste and municipal solid waste (MSW), energy crops, coal, natural gas, oil, advanced light water reactors (LWRs), and delayed retirement of existing non-nuclear plants. NRC has considered these alternatives pursuant to its statutory responsibility under NEPA. NRC's analysis of these issues in no way preempts or displaces state authority to consider and make decisions regarding energy planning issues.

This chapter also includes a discussion of conservation and power import alternatives. Although these alternatives do not represent discrete power generation sources, they represent options that states and utilities may use to reduce their need for power generation capability. In addition, energy conservation and power imports are possible consequences of the no-action alternative. While these two alternatives are not options that fulfill the stated purpose and need of the proposed action *per se* (i.e., options that provide power generation capability), they nevertheless are considered in this chapter because they are important tools available to energy planners in managing need for power and generating capacity.

The potential environmental impacts evaluated include land use, ecology, aesthetics, water quality, air quality, solid waste, human health, socioeconomics, and culture. These impacts are addressed in terms of construction impacts and operational impacts (Tables 8.1 and 8.2, respectively). This chapter occasionally mentions economic costs of particular alternatives for descriptive purposes; they do not provide a basis for an NRC decision on license renewal. In addition such economic costs may change prior to specific license renewal decisions as improvements occur to particular technologies. Additionally, this chapter discusses the relative construction and operating costs of various technologies where available.

8.2 ENVIRONMENTAL IMPACTS OF THE NO-ACTION ALTERNATIVE

As discussed in the introduction, the no-action alternative is denial of a renewed license. Denial of a renewed license as a power generating capability may lead to a variety of potential outcomes. In some cases, denial may lead to the selection of other electric generating sources to meet energy demands as determined by appropriate state and utility officials. In other cases, denial may lead to conservation measures and/or decisions to import power. In addition, denial may result in a combination of these different outcomes. Therefore, the environmental impacts of such resulting alternatives would be included as the environmental impacts of the no-action alternative. Additionally, a denial of a renewed license would lead to facility decommissioning and its associated impacts; these impacts would also represent impacts of the no-action alternative.

Table 8.1 Environmental impacts of constructing 1000-MW(e)-equivalent electric power plants for non-nuclear alternative generating technologies

	Resource								
Alternative	Land use	Ecology	Aesthetics	Water quality	Air quality	Waste	Human health	Socioeconomic	Cultural
Wind	61,000 ha (150,000 acres) (Pimentel 1994)	Loss of thousands of acres of natural habitat (Pimentel 1994); some stream sedimentation; erosion	Substantial visual impact in any location (Pimentel 1994; SERI/TP-260-3674)	High potential for sedimentation/erosion damage	Considerable vehicle exhaust, dust from earth moving	Considerable amount of vegetation debris from land clearing	Some accident risks for workers (Grubb and Meyer 1993)	No known estimates but believed to be relatively small peak work force—little potential for adverse impacts	High potential for impacts because of large land area
Photovoltaic cells	14,000 ha (35,000 acres) (Pimentel 1994; Pace 1991)	Loss of 14,000 ha (35,000 acres) of natural habitat, some farm land (Pimentel 1994); some stream sedimentation; erosion is a particular threat to arid areas, fragile soil, and plant communities	Substantial visual impact in any location (Hamrin and Rader 1993)	High potential for sedimentation/erosion damage	Considerable vehicle exhaust, dust from earth moving (Pace 1991)	Considerable amount of vegetation debris from land clearing	Some accident risks for workers	No known estimates but believed to be moderate size peak work force—little potential for adverse impacts	High potential for impacts because of large land area

Table 8.1 (continued)

Alternative	Resource								
	Land use	Ecology	Aesthetics	Water quality	Air quality	Waste	Human health	Socioeconomic	Cultural
Solar thermal	5,700 ha (14,000 acres) (Pimentel 1994; Pace 1991)	Loss of 5,700 ha (14,000 acres) (Pimentel 1994); some stream sedimentation; erosion is a particular threat to arid areas, fragile soil, and plant communities (Pace 1991)	Substantial visual impact to 5,700 ha (14,000 acres) affected (Pimentel 1994; Pace 1991; Hamrin and Rader 1993)	High potential for sedimentation/erosion damage	Considerable vehicle exhaust, dust from earth moving (Pace 1991)	Considerable amount of vegetation debris from land clearing	Some accident risks for workers	No known estimates but believed to be moderate size peak work force—little potential for adverse impacts	High potential for impacts because of large land area
Hydroelectric	400,000 ha (1 million acres) (Pimentel 1994)	Loss of 400,000 ha (1 million acres) of natural habitat, farm land (Pimentel 1994); stream sedimentation, erosion	400,000 ha (1 million acres) visually impacted (Pimentel 1994; Hamrin and Rader 1993)	Considerable sedimentation/erosion	Considerable vehicle exhaust, dust from earth moving	Considerable amount of vegetation debris from land clearing	Some accident risks for workers; spread of diseases from reservoir filling (Moreira and Poole 1993)	Large work force, moderate potential for adverse community impacts; dislocation of residents (Hamrin and Rader 1993)	Almost unavoidable destruction of cultural sites, artifacts typically located on natural edges of water bodies
Geothermal	2800 ha (7000 acres) (DOE/EP-0093)	Loss of 2800 ha (7000 acres) of natural habitat (DOE-0093); some stream sedimentation, erosion	Visual impacts to 2800 ha (7000 acres) (DOE-0093)	High potential for sedimentation/erosion damage	Considerable vehicle exhaust, dust from earth moving	Considerable amount of vegetation, some construction debris	Some accident risks for workers	Moderate size work force; some potential adverse impacts	Moderate potential unless important site-specific resource affected by plant or transmission lines

Table 8.1 (continued)

Alternative	Resource								
	Land use	Ecology	Aesthetics	Water quality	Air quality	Waste	Human health	Socioeconomic	Cultural
Wood wastes	High variable and site specific, perhaps 160,000 to 320,000 ha (400,000 to 800,000 acres) for forest residue recovery. For plant, about 30 acres for each 20-MW facility	Considerable potential for loss of natural habitat and biodiversity; increased soil erosion and nutrient loss (ECO Northwest et al.)	Substantial visual impacts from land clearing. Localized visual impacts with plant construction	High potential for sedimentation/erosion damage. Small sedimentation/erosion damage at plant site (ECO Northwest et al.)	Considerable vehicle exhaust and fugitive dust impacts from earth moving	Considerable amount of vegetation debris and some construction debris	Some accident risks for workers	Source of income and employment in rural areas. Moderate size work force at plant site	High potential for impacts because of large land area
Municipal solid waste (MSW)	For plant, about 12 ha (30 acres) for each 20 MW facility	Small impact—few acres affected and in urban area. Potentially positive impacts if landfills displaced (ECO Northwest et al.)	Localized visual impacts with plant construction	Small sedimentation/erosion damage at plant site (ECO Northwest et al.)	Considerable vehicle exhaust and fugitive dust impacts from earth moving	Moderate amount of vegetation and construction debris	Some accident risks for workers	Moderate size work force at plant site	Relatively small unless important site-specific resource affected by plant or transmission lines

Table 8.1 (continued)

	Resource								
Alternative	Land use	Ecology	Aesthetics	Water quality	Air quality	Waste	Human health	Socioeconomic	Cultural
Energy crops	About 400,000 ha (1 million) acres for crop production. For plant, about 12 ha (30 acres) for each 20 MW facility	Impacts depend on prior land use; if conversion of cropland, then more environmentally benign and would improve biodiversity (OTA; Ranney and Mann)	Minor visual impacts with energy crop establishment. Localized visual impacts with plant construction	Energy crops lower sedimentation, soil erosion, and chemical use relative to agriculture (Ranney and Mann). Small sedimentation and erosion damage at plant site	Moderate vehicle exhaust and fugitive dust impacts from earth moving at plant site	Considerable amount of vegetation debris and some construction debris at plant site	Some accident risks for workers	Source of income and employment in rural areas. Moderate size work force at plant site	Relatively small impacts if cropland and pasture converted to energy crops
Coal	700 ha (1,700 acres) for plant site (DOE/EP-0093)	Loss of 700 ha (1,700 acres) habitat; some erosion, stream sedimentation	Localized visual impacts from land clearing	Potential sedimentation/ erosion damage	Moderate vehicle exhaust, dust from earth moving	Considerable construction debris	Accident risk for workers	1,200–2,500 peak work force (UDI-021-89)	Relatively small unless important site-specific resource affected by plant or transmission lines
Natural gas	45 ha (110 acres) for plant site (DOE/EP-0093)	Loss of 45 ha (110 acres) varied habitat; some erosion, stream sedimentation	Localized visual impacts from land clearing	Potential sedimentation/ erosion damage	Some vehicle exhaust, substantial dust from earth moving	Considerable construction debris	Accident risk for workers	1,200 peak work force (UDI-021-89)	Relatively small unless important site-specific resource affected by plant or transmission lines
Oil	50 ha (120 acres) for plant site (DOE/EP-0093)	Loss of 50 ha (120 acres) varied habitat; some erosion, stream sedimentation	Localized visual impacts from land clearing	Potential sedimentation/ erosion damage	Some vehicle exhaust, substantial dust from earth moving	Considerable construction debris	Accident risk for workers	1,700 peak work force (UDI-021-89)	Relatively small unless important site-specific resource affected by plant or transmission lines

Table 8.1 (continued)

Alternative	Resource Land use	Ecology	Aesthetics	Water quality	Air quality	Waste	Human health	Socioeconomic	Cultural
Advanced light-water reactor	200–400 ha (500–1,000 acres) for plant site plus exclusion area	Loss of 200–400 ha (500–1,000 acres) of habitat; some erosion, stream sedimentation	Localized visual impacts from land clearing	Potential sedimentation/erosion damage	Moderate vehicle exhaust, dust from earth moving	Considerable construction debris	Accident risk for workers	2,000–5,500 peak work force (UDI-021-89)	Relatively small unless important site-specific resource affected by plant or transmission lines
Conservation	Unquantified land lost to resource extraction for conservation technologies	Adverse impacts from resource extraction	Minimal for resource recovery and processing	Minimal for resource recovery and processing	Minimal for resource recovery and processing	Minimal for resource recovery, processing	Some risks from resource recovery	Minor employment, tax revenues from conservation industry	Minimal
Imported power	If excess Canadian capacity is insufficient, impacts will be similar to U.S. coal or hydro plants	If excess Canadian capacity is insufficient, impacts will be similar to U.S. coal or hydro plants	If excess Canadian capacity is insufficient, impacts will be similar to U.S. coal or hydro plants	If excess Canadian capacity is insufficient, impacts will be similar to U.S. coal or hydro plants	If excess Canadian capacity is insufficient, impacts will be similar to U.S. coal or hydro plants	If excess Canadian capacity is insufficient, impacts will be similar to U.S. coal or hydro plants	If excess Canadian capacity is insufficient, impacts will be similar to U.S. coal or hydro plants	If excess Canadian capacity is insufficient, impacts will be similar to U.S. coal or hydro plants	Same impacts as U.S. except northern Canada, where social conflict between tribes and government is substantial
Delayed retirement	Very few acres affected (DOE/EIS-0146)	Very few acres affected—no impact (DOE/EIS-0146)	Minimal changes	Incidental use	Small exhaust, fugitive dust (DOE/EIS-0146)	Moderate construction debris	Potential accidents to workers	Estimated one-half of normal construction work force	Minimal impact

Table 8.2 Environmental impacts of operating 1000-MW(e)-equivalent electric power plants for non-nuclear alternative generating technologies

	Resource								
Alternative	Land use	Ecology	Aesthetics	Water quality	Air quality	Waste	Human health	Socioeconomic	Cultural
Wind	61,000 ha (150,000 acres) of which 3,000 acres occupied by turbines, rest available for agriculture (Pimentel 1994)	Bird collisions, loss of much of thousands of acres of habitat (Pimentel 1994); interference with animal migration routes (Pace 1991)	Substantial visual and some noise impact in any location (Pace 1991; SERI/TP-260-3674; Rader 1989)	Negligible (Pace 1991)	Negligible (Pace 1991)	Very minor amounts from maintenance of equipment, vegetation	Very minor risks from accidents, noise	Relatively low work force, assessed plant value—fewer potential long-term community benefits than large baseload plants	Relatively small unless important site-specific resource affected by plant or transmission lines
Photovoltaic cells	14,000 ha (35,000 acres); no other compatible uses (Pimentel 1994; Pace 1991)	Loss of 14,000 ha (35,000 acres) of natural habitat and some agricultural land (Pimentel 1994)	Substantial visual impact in any location (Hamrin and Rader 1993)	Small runoff from panels could cause sedimentation	Negligible	Very minor amounts from maintenance of equipment, vegetation; some toxics	Some risk to maintenance workers	Relatively small work force, assessed plant value—fewer long-term community benefits than large baseload plants	Relatively small unless important site-specific resource affected by plant or transmission lines
Solar thermal	5,700 ha (14,000 acres); no other uses (Pimentel 1994; Pace 1991)	5,700 ha (14,000 acres) of natural habitat lost and some agricultural land (Pimentel 1994)	Substantial visual impact; reflected sunlight (Pimentel 1994; Pace 1991; Hamrin and Rader 1993)	Minor amounts used except where water is cooling agent (Rader 1989); possible contamination from cleaning agents (Rader 1989); some runoff potential	Minor emissions of pollutants during normal operations, greater risks with accidents (Pimentel 1994)	Very minor amounts from maintenance of equipment, vegetation	Possible eye damage from reflected sunlight; occupational hazards from exposure to heat transfer fluids (Pace 1991); some risk to maintenance workers	Relatively small work force, assessed plant value—fewer long-term community benefits than large baseload plants	Relatively small unless important site-specific resource affected by plant or transmission lines

Table 8.2 (continued)

	Resource								
Alternative	Land use	Ecology	Aesthetics	Water quality	Air quality	Waste	Human health	Socioeconomic	Cultural
Hydroelectric	400,000 ha (1 million acres); no other uses (Pimentel 1994)	400,000 ha (1 million acres) of natural habitat and agricultural lands lost; disruption of spawning, migration routes (Rader 1989); killing of fish thru eutrophication, passage through dam, water temperature change (Moreira and Poole 1993); altered flora, fauna populations	1 million acres visually impacted (Pimentel 1994; Hamrin and Rader 1993)	Increased sedimentation (Moreira and Poole 1993); temperature changes, competition for water and arid regions (Rader 1989)	Negligible	Minor amounts from equipment replacement, reservoir clearing	Some risks for recreational boating, swimming deaths; risk of dam failure; some risk to maintenance workers	Small work force, high assessed value—some potential long-term economic/community impacts, changes in recreation (free-flowing stream to lake)	Relatively small unless important site-specific resource affected by plant or transmission lines

Table 8.2 (continued)

	Resource								
Alternative	Land use	Ecology	Aesthetics	Water quality	Air quality	Waste	Human health	Socioeconomic	Cultural
Geothermal	2800 ha (7000 acres)—possible subsidence; potential for other uses on unused land (DOE/EP-0093; OECD 1987)	Loss of much of 2800 ha (7000 acres) of natural habitat and some agricultural land (DOE/EP-0093)	Visual impacts to portions of affected areas (Rader)	Potential contamination of surface and groundwater from disposal of geothermal fluid (OECD 1987)	Potential release of various toxic gases to atmosphere, especially H_2S; CO_2 is greatest emission (Pace 1991, Brower 1992)	Minor amounts from equipment replacement, vegetation maintenance, heavy metals sludge (Brower 1992)	Very minor risks from toxic gas released, accidents to workers; noise (Brower 1992)	Relatively small work force, assessed plant value—fewer long-term community benefits than large baseload plants	Relatively small unless important site-specific resource affected by plant or transmission lines
Wood wastes	About 160,000 to 320,000 ha (400,000 to 800,000 acres) for forest residue recovery. About 12 ha (30 acres) per 20 MW of facility operated (OTA 1993)	Considerable potential for loss of natural habitat and biodiversity; increased soil erosion and nutrient loss (OTA 1993)	Some visual impacts from residue recovery. Limited visual impacts from plant structure	Approximately same water requirements as coal	Not significant with residue recovery. Emission of regulated pollutants, can be effectively controlled	Considerable fly ash, can be used as fertilizer and soil conditioner	Occupational risks high, same as for agriculture. Particulates important, but can be controlled	Source of income and employment in rural areas. Moderate size work force at plant site	Relatively small unless important site-specific resource affected by residue recovery area, plant or transmission lines
Municipal solid waste	About 12 ha (30 acres) per 20 MW of facility operated	Potentially positive impacts if landfills are displaced	Limited visual impacts from plant structure. Potential odors	Approximately same water requirements as coal	Emissions of regulated pollutants more significant than other technologies	Considerable fly ash, must meet regulations	Risks from toxics and particulates, safety of municipal solid waste handlers	Moderate size work force at plant sites	Relatively small unless important site-specific resource affected by plant or transmission lines

Table 8.2 (continued)

	Resource								
Alternative	Land use	Ecology	Aesthetics	Water quality	Air quality	Waste	Human health	Socioeconomic	Cultural
Energy crops	About 400,000 ha (1 million acres) for crop production. About 12 ha (30 acres) per 20 MW of facility operated	Impacts depend on prior land use, may either enhance or reduce biodiversity, habitat (Wright 1994; Ranney and Mann 1994)	Some visual impacts from harvesting. Limited visual impacts from plant structure	Irrigation not used for growing. Approximately same water requirements as coal	Not significant with production of energy crops. Emissions of regulated pollutants, can be effectively controlled (Wright 1994)	Considerable fly ash, can be used as fertilizer and soil conditioner	Occupational risks high, same as for agriculture. Particulate important, but can be controlled (Rader 1989)	Source of income and employment in rural areas. Moderate size work force at plant site	Relatively small unless important site-specific resource affected by cropping area, plant or transmission lines
Coal	700 ha (1,700 acres) for plant site (DOE/EP-0093) and 9070 ha (22,400 acres) for entire fuel cycle (WASH-1224)	Habitat loss (including nationally from acid precipitation; DOE/EIS-0146); impingement, entrainment; waste heat to receiving water body; cooling tower drift, fogging; bird collisions	Limited visual impacts from plant structure, additional from plume	860,000 m^3 (700 acre-ft) per quad (10^{12} Btu) energy produced (based on thermal efficiency relative to nuclear)	Emission of CO_2, regulated pollutants, more than other technologies (Loftness 1984); also radionuclides	Large amounts of fly ash, scrubber sludge, other solid waste—must meet regulations (DOE/EP-0093)	Public risks (cancer, emphysema) from inhalation of toxics and particulates; safety risk to workers	250 workers—moderate long-term economic community benefits (UDI-021-89)	Relatively small unless important site-specific resource affected by plant or transmission lines

Table 8.2 (continued)

Alternative	Resource								
	Land use	Ecology	Aesthetics	Water quality	Air quality	Waste	Human health	Socioeconomic	Cultural
Natural gas	45 ha (110 acres) for plant site (DOE-EP-0093) and 1500 ha (3,600 acres) for entire fuel cycle (WASH-1224)	Habitat loss, impingement, entrainment; waste heat to receiving water body; cooling tower drift, fogging; bird collisions	Limited visual impacts from plant structure, some from plume	817,000 m^3 (662 acre-ft) water used per quad (10^{12} Btu) energy produced (based on thermal efficiency relative to nuclear)	Emissions of CO_2 and NO_x regulated pollutants, radionuclides less than coal, no SO_2 (Loftness 1984)	Some solid waste produced—must meet regulations (DOE/EP-0093)	Some public risks (cancer, emphysema) from inhalation of toxics and particulates; safety risk to workers	150 workers—moderate long-term economic, community benefits (UDI-021-89)	Relatively small unless important site-specific resource affected by plant or transmission lines
Oil	50 ha (120 acres) for plant site (DOE/EP-0093) and 650 ha (1,600 acres) for entire fuel cycle (WASH-1224)	Habitat loss (including nationally from acid precipitation; DOE/EIS-0146); impingement, entrainment; waste heat to receiving water body; cooling tower drift, fogging; bird collisions	Limited visual impacts from plant structure, some from plume	860,000 m^3 (700 acre-ft) water per quad (10^{12} Btu) energy produced (based on thermal efficiency relative to nuclear)	Emissions of CO_2, SO_2, and NO_x, regulated pollutants, radionuclides less than coal (Loftness)	Moderate (<coal) amounts of scrubber sludge, particulates—must meet regulations (DOE/EP-0093)	Some public risks (cancer, emphysema) from inhalation of toxics and particulates; safety risks to workers	200 workers—moderate long-term economic community benefits (UDI-021-89)	Relatively small unless important site-specific resource affected by plant or transmission lines

Table 8.2 (continued)

Alternative	Resource								
	Land use	Ecology	Aesthetics	Water quality	Air quality	Waste	Human health	Socioeconomic	Cultural
Advanced light-water reactor	80–200 ha (500–1000 acres) for plant site, plus exclusion acres and 400 ha (1500–2000 acres) for entire fuel cycle	Habitat loss, impingement, entrainment; waste heat to receiving water bodies; cooling tower drift and fogging; bird collisions	Limited visual impacts from plant structure, some from plume	910,000 m^3 (740 acre-ft) water per quad (10^{12} Btu) energy produced (based on thermal efficiency relative to nuclear)	Very little CO_2 or regulated pollutants—from vehicles not facility	Some spent fuel, slightly more mixed waste and low-level waste than license renewal	<1% of natural radiation sources; safety risks to workers	700 workers—substantial long-term economic, community benefits (UDI-021-89)	Relatively small unless important site-specific resource affected by plant or transmission lines
Conservation	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Minor impacts regarding radon, perhaps other contaminants (Pace 1991)	Increased jobs in conservation technologies	Minimal
Imported power	Operating impacts of hydro and coal plants similar to those in U.S.	Operating impacts of hydro and coal plants similar to those in U.S.	Operating impacts of hydro and coal plants similar to those in U.S.	Operating impacts of hydro and coal plants similar to those in U.S.	Operating impacts of hydro and coal plants similar to those in U.S.	Operating impacts of hydro and coal plants similar to those in U.S.	Operating impacts of hydro and coal plants similar to those in U.S.	Operating impacts of hydro and coal plants similar to those in U.S.	Cultural impacts to tribes in northern Canada could produce more social conflict than in United States

Table 8.2 (continued)

Alternative	Resource								
	Land use	Ecology	Aesthetics	Water quality	Air quality	Waste	Human health	Socioeconomic	Cultural
Delayed retirement	Very few acres affected (DOE/EIS-0146)	Very few acres affected—no impact	Minimal changes unless cooling tower installed	Substantial improvement if closed-cycle system replaces once-through (Bretz 1994), otherwise little change. Improvement to distant water bodies adversely affected by acid precipitation (DOE/EIS-0146)	> 90% SO_2 and NO_x emissions of conventional coal plant removed (DOE/EIS-0146, Bretz 1994)	For integrated gasification combined cycle: 40% waste of pulverized coal plant; for atmospheric fluidized bed: possibly double the amount from pulverized coal plant (DOE/EIS-0146)	Substantial public health improvement compared with conventional, pulverized coal plant; safety risks to workers	Moderate employment and tax revenue from first coal plant extended for longer period	No change

The environmental impacts expected from decommissioning are analyzed in NUREG-0586, *Final Generic Environmental Impact Statement of Decommissioning of Nuclear Facilities* (1988). Consequently, NUREG-0586 represents some of the environmental impacts associated with denial of a renewed license. The analysis in Section 8.3 is equally applicable to the no-action alternative in that the alternatives analyzed in this section are all possible actions resulting from denial of a renewed license. Therefore, Section 8.3 represents additional impacts of the no-action alternative.

8.3 ENVIRONMENTAL IMPACTS OF ALTERNATIVE ENERGY SOURCES

This section describes the technologies and evaluates the environmental impacts of 13 energy supply or demand alternatives identified by NRC as capable of satisfying the purpose and need of the proposed action [i.e., to provide an option that allows for power generation capability beyond the term of a current nuclear power plant operating license to meet future system generating needs as such needs may be determined by state, utility, and, where authorized, federal (other than NRC) decision makers]. The technologies were selected because they correspond with those generally considered in state energy plans as potential generating technologies, or they were proposed as alternatives to nuclear license renewal in comments to the Draft GEIS. Many of these technologies differ dramatically from nuclear, and it is important to evaluate them using a consistent standard. A reference generating capacity of 1000 MW(e) is used in evaluating environmental impacts, because this is the approximate generating capacity of many nuclear plants.

The section evaluates impacts that could occur during construction (Table 8.1) or operation (Table 8.2) of each alternative technology. Environmental resources considered include land use, ecology, aesthetics, water quality, air quality, human health, socioeconomics, and cultural resources. The tables provide more detailed information, and the text highlights the more important impacts. References are omitted in the text when they are included in the impact tables.

License renewal decisions may vary considerably among states and utilities based on numerous factors, of which environmental factors are but one set. These decisions may be reached by utilities and states prior to NRC involvement. NRC staff evaluated the process used by 10 states with nuclear power plants to decide which electricity supply and demand options to implement. (NRC examined state energy plans of California, Florida, Illinois, Massachusetts, Michigan, Minnesota, New York, Texas, Vermont, and Wisconsin.) NRC determined that integrated resource planning in some form is used in almost all of these states. Nuclear technology and license renewal are not emphasized in most of these plans, which are developed by either state energy offices or state public service commissions. It is apparent in the plans that nuclear generating plants submitted for license renewal would be required to demonstrate the overall benefits of license renewal over alternative technologies before states would approve renewal. The options would include large, central generating stations powered by nonrenewable sources of energy, probably coal or natural gas, or advanced technologies powered by those same fuels. Some states not enamored of conventional nuclear power may be amenable to considering advanced nuclear technologies. Renewable energy sources have the potential to replace at least some of the generating capacity lost through decommissioning nuclear plants. Solar thermal energy, PV cells, wind energy, hydroelectricity, energy crops, and incineration of MSW and wood waste have some potential in most states surveyed. Geothermal energy has potential in states like California where the resource is prevalent.

Besides sources of power generation, other alternatives are mentioned in state energy plans. Demand-side management (DSM) is viewed in every state as a means to help meet electricity forecasts. Other alternatives include end-use conservation and purchases of power from other utility systems in the United States, Canada, or Mexico. While these two alternatives are not options that fulfill the stated purpose and need of the proposed action *per se* (i.e., options that provide power generation capability), they nevertheless are considered in this section because they are important tools available to energy planners in managing needs for power and generating capacity.

Every technology discussed in this section could generate power in much smaller facilities than 1000 MW(e) in dispersed locations throughout a utility's service area. Typically, conservation or demand-side alternatives and renewable technologies lend themselves best to relatively small facilities, whereas conventional, nonrenewable technologies are suited more for large central generating stations. Numerous exceptions to these generalizations exist or are feasible. Thus, multiple alternatives could be selected to replace a single nuclear plant. For example, a utility and state public utility commission could agree that a combination of 500 MW(e) of conventional or advanced-technology coal, 100 MW(e) of conservation, 100 MW(e) of purchased power, 50 MW(e) of wind power, 50 MW(e) of MSW combustion, and 200 MW(e) of combined-cycle-generation would be the preferred set of alternatives to replace a single nuclear plant. This siting scenario would be expected to diffuse over a wider area the construction and operational impacts otherwise expected from a single 1000-MW(e) facility. It also could be feasible to replace a nuclear plant with an equal amount of capacity from a single technology sited in a dispersed fashion. The types and general magnitude of environmental impacts would be about the same as for a central generating facility using that technology, but impacts would be dispersed in smaller concentrations over a wider area.

The following discussion is intended to suggest generic impacts that could occur from each technology as well as approximations of the magnitude of those impacts. In addition, this discussion is intended to address the reasonably foreseeable impacts of the various alternatives and does not attempt to address impacts that are remote or speculative. In the cases of conservation and renewable technologies, where there are no current equivalents to 1000-MW(e) plants, the impact data are less reliable than for nonrenewable technologies. The GEIS depends on data gathered from many studies, and the data may not always be comparable among technologies.

8.3.1 Wind

Of the approximately 33,000 quads of wind resources available annually in the coterminous United States, only about 170 quads per year can be accessed with current technology, and only about 1/6 quad per year can currently be used cost-effectively to generate electricity (DOE/EIA-0561). Wind speeds of at least 21 km/h (13 miles/h) are considered necessary for generating electricity. As shown in Figure 8.1, regions with such speeds include the Great Plains, the West, coastal areas, and parts of the Appalachians (DOE/EIA-0561).

The average annual capacity factor (i.e., the proportion of actual generation to potential generation at 100 percent capacity utilization) is estimated at 21 percent in 1995 and 29 percent in 2010. This relatively low capacity, compared with current baseload technologies, results from the high degree of intermittency of wind energy in many locations (DOE/EIA-0561). Current energy storage technologies are too expensive to permit wind power plants to serve as large baseload plants. The inability to increase the capacity factors of wind power makes the technology an inappropriate choice for baseload power (Johansson et al. 1993)

In 1992, wind provided 1676 MW(e) of electric generating capacity, produced mostly in California by nonutility generators (Hamrin and Rader 1993). Windfarms in areas around the Altamont Pass, the Tehachapi Mountains, and the San Gorgino Pass have more than 15,000 wind turbines (Pace 1991). The U.S. Department of Energy's (DOE's) Energy Information Administration (EIA) projects that the contribution of wind power will rise to 3600 MW(e) in 2000 and 6300 MW(e) in 2010, all of which would be generated by nonutilities (DOE/EIA-0561).

A recent survey of utilities conducted by UDI/McGraw-Hill indicated that no utilities have announced plans to construct 25 MW(e) or larger wind power plants in the foreseeable future, although some utilities may have unpublished plans (Bergesen 1994). Wind technology can be advanced with many small improvements, as well as larger ones such as development of lighter, stronger blade materials; improved gearing to capture a greater portion of useful wind velocities; improved understanding of wind patterns and siting configurations for wind turbines at a site; and improved electrical storage capabilities (SERI/TP-260-3674).

Wind energy is expected to require the use of approximately 61,000 ha (150,000 acres) or 610 square km (about 235 square miles) of land to generate 1000 MW(e) of power (see Table 8.1 for construction impacts and references). This large land requirement, even in dispersed sites, would eliminate any possibility of co-locating a wind energy facility with a retired nuclear plant, thereby pointing to the need for greenfield siting (siting on undeveloped land). The relatively low capacity factor of wind power means that it would operate less frequently at full power than nuclear, but the impacts associated with land use would still occur. The earth-moving that might be required to clear such a large amount of land would destroy much of the natural environment in affected areas (e.g., coastal, mountainous, or plains), where wind velocities are highest. Erosion and sedimentation, while controllable, would still occur and would adversely affect land and water resources. The visual impact of such extended land clearing would be quite

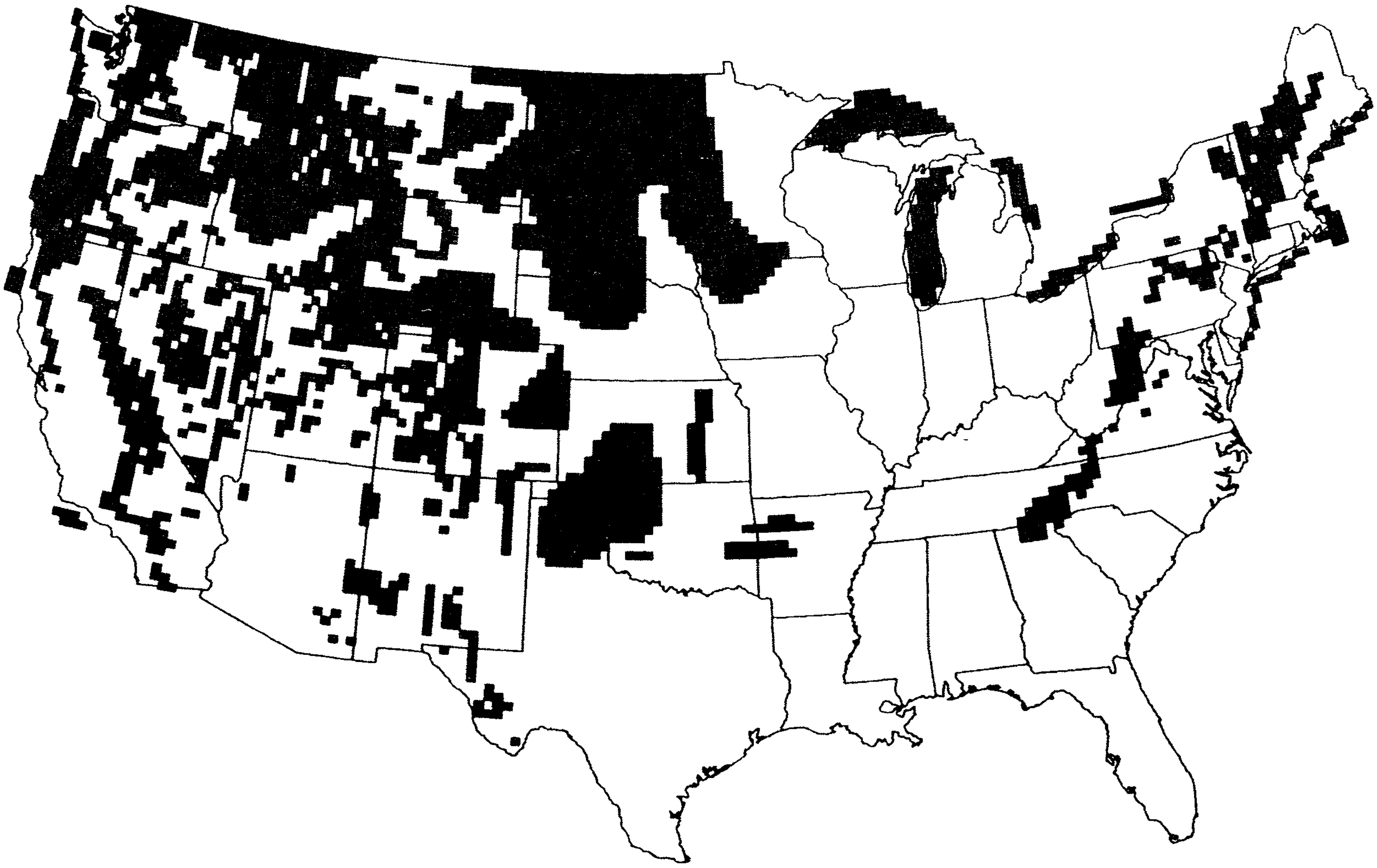

Figure 8.1 U.S. wind energy resources (contiguous states, winds 13 miles per hour or greater).
Source: Adapted from DOE/EIA-0561.

noticeable and would be a negative aesthetic consequence. Short-term air quality impacts from fugitive dust and equipment exhaust would occur with such extensive activities, and considerable vegetation debris could require disposal. Disturbance of such a large amount of land likely would reveal cultural resources that would require protection. Each of these site impacts would be magnified because of the new transmission lines that are almost always required for greenfield sites. Agricultural land could also be committed to the siting of wind energy facilities in some areas. Adverse impacts could still occur where land is taken out of production, but the acreage lost would likely be less than with natural environments.

The projected impacts of operating wind energy facilities are less than those expected from construction (see Table 8.2 for operational impacts and references). The same amount of land would still be committed to wind generation, but the machines would occupy less than 10 percent of it, freeing up most of the remainder for agricultural or some other compatible use. The aesthetic impact of several thousand wind turbines over a large area likely would strike many observers as obtrusive. The noise from such equipment likely would reinforce these negative opinions. Birds are likely to collide with the turbines, and wind energy developers should consider migration areas and nesting locations when sites for wind energy facilities are selected. In terms of positive environmental impacts, wind power plants would have little effect on water and air quality and would generate very little waste. Human health, except for a potential small number of occupational injuries, would not be affected by operations.

8.3.2 Photovoltaic Cells

PV cells, solid-state devices composed of a thin layer of semi-conductor material (usually single-crystal silicon), convert sunlight directly into electricity. Groups of cells that are mounted on a rigid plate and interconnected to form PV modules have a peak generating capacity of 50 W each (DOE/EH-0077). Usually, groups of modules are permanently attached to a frame and interconnected to form PV arrays or power systems. Power production is proportional to the amount of solar radiation received in a specific geographic area.

The most promising geographic area for the expansion of PV systems is the West; the Midwest and South have some potential (Figure 8.2).

PV power is produced intermittently because solar cells generate electricity only when sunlight is available. The National Association of Regulatory Utility Commissioners indicates an estimated capacity factor of 25 percent (Hamrin and Rader 1993). The largest utility PV system in the United States was built in 1984 on Carrisa Plain in central California by ARCO Solar at a site owned by Pacific Gas and Electric Company (Firor et al. 1993). Until it was dismantled in 1990, it generated 6.5 MW(e) of peak power. Thirty utilities were experimenting with small, grid-connected PV systems as of 1991 (Firor et al. 1993). Use of PV cells for baseload capacity requires very large energy storage devices, such as pumped hydro facilities, batteries, or compressed air chambers. Currently available energy storage devices are too expensive to store sufficient electricity to meet the baseload generating requirements. Thus, while the resource is plentiful, the reserves that

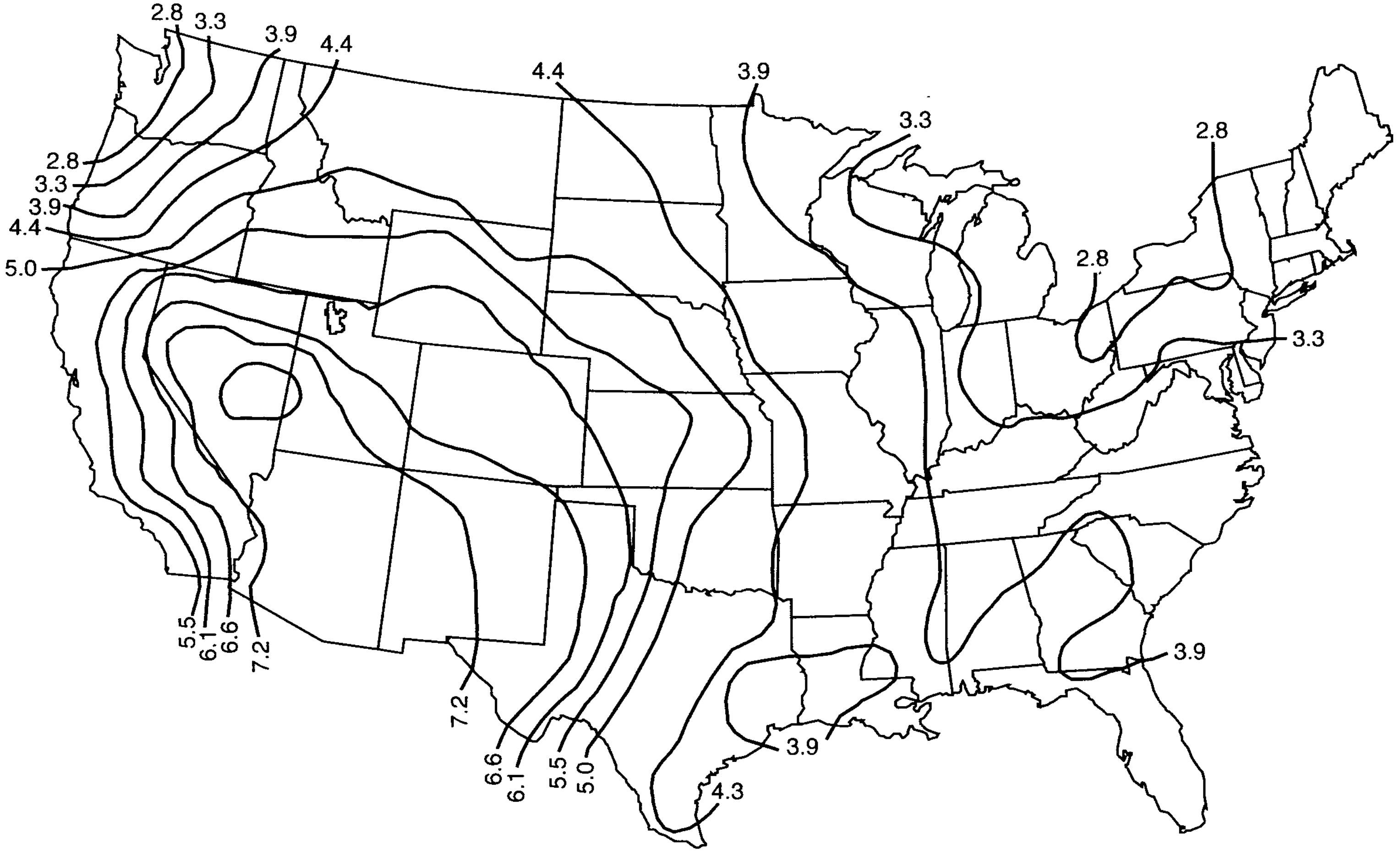

Figure 8.2 Solar resource availability: annual average daily direct normal solar radiation.
Source: Adapted from DOE/EIA-0561.

currently can be tapped economically for generating electricity in plants of appreciable size are limited.

The high cost of PV systems has been the primary impediment to their more extensive use. These high costs reflect the technical barriers that PV technology must overcome to be competitive. Improvements such as more effective concentrators, use of more easily produced thin-film PV cells rather than silicon cells, and lower module costs could play some part in reducing PV costs. Energy storage technology must become considerably less expensive to enable intermittent technologies like PV to provide reliable electricity. EIA projects that almost no additional PV generating capacity will be added to the electricity grid by 2010, its longest-term forecast (DOE/EIA-0561).

Construction impacts to several resources would be substantial from building a 1000-MW(e) PV facility either at a single site or at numerous smaller dispersed sites. The large land requirement would rule out co-locating a PV facility with an existing nuclear plant, which requires far less land. In addition to these new land requirements, additional land would be required for new transmission lines. No PV plant of this size currently exists, and impacts must be inferred from smaller PV facilities. It is estimated that at least 14,000 ha (35,000 acres) or about 130 km^2 (50 square miles), either at a single site or at multiple sites, would be needed in areas optimal for PV technology to be able to generate as much as 1000 MW(e) of power.Clearing and grading 14,000 ha (35,000 acres) would largely destroy the previous natural or agricultural environment for the life of the facility, with resulting potential impacts to any threatened and endangered species and to aesthetic qualities of the area. Such construction likely would create erosion and resulting stream sedimentation problems. Considerable vegetation debris probably would need to be disposed of as well, which could create short-term air quality problems if it were disposed of through open-air burning. In an area this large, construction impacts to cultural resources would be likely to occur. No work force projections are available for constructing a large PV facility. If prefabricated components and a modular construction approach were used, the work force would probably be smaller than for nonrenewable central generating stations. Such a work force would result in fewer socioeconomic impacts in the form of jobs and local purchases, but the severe impacts of large work forces affecting small communities probably could be avoided.

Adverse operating impacts of PV facilities are associated with the large land requirements. All of the 14,000 ha (35,000 acres) would be lost to other uses for the life of the plant because the land would be covered with PV arrays. Impacts associated with loss of wildlife habitat or agricultural lands would occur, and erosion could develop without proper controls. Water quality could be adversely affected from runoff from PV arrays and drainage unless site engineering included mitigative measures. Substantial visual impacts created from land clearing would be continued in a different form by the extensive PV arrays covering the landscape. The socioeconomic benefits flowing to host communities would be considerably less with PVs than from baseload nonrenewable generating technologies because work forces and plant expenditures would be much less. Tax revenues could be fairly substantial, however, if PV capital costs were comparable to nuclear and fossil plant costs and resulted in correspondingly high assessed values. Other impacts, including those to air quality, solid wastes, and human health, either would not occur or would be small.

8.3.3 Solar Thermal Power

Solar thermal conversion systems use reflective materials to concentrate sunlight to heat a fluid that runs a turbine. Both central-receiver and distributed-receiver systems have been used. The parabolic trough, an example of a distributed receiver system, is used in the only large-scale [354-MW(e)] commercial solar thermal power program in the United States, the Luz International facilities located at several sites in the Mojave Desert in California. The Luz facilities, which consist of nine thermal plants [one 13.8-MW(e) unit, six 30-MW(e) units, and two 80-MW(e) units], use natural gas as a backup fuel for generating steam on cloudy days and at night. The company filed for bankruptcy in 1991 because of lower fossil fuel prices and reduced incentives for renewable technologies (DeLaguil et al. 1993). DOE and a consortium of 12 other organizations are retrofitting Solar One, a 10-MW(e) central receiver pilot plant near Barstow, California. It is to come on-line in 1995, renamed Solar Two, and will use a molten-salt heat transfer medium instead of the original oil system to collect and store heat energy. Developers hope that commercial versions of this new Solar Two technology can operate at capacity factors of 60 percent and thus provide dispatchable rather than intermittent power. Based upon solar energy resources (Figure 8.2), the most promising region of the country for this technology is the West. Solar thermal systems have constraints similar to those of PV systems in that capital costs are higher than for nonrenewable resources, and solar thermal systems lack baseload capability unless combined with natural gas backup. The use of purely solar thermal systems for baseload capacity requires very large amounts of energy storage, such as pumped hydro facilities, compressed air chambers, or batteries. Capacity factors are estimated to be between 25 and 40 percent for future solar thermal plants (Hamrin and Rader 1993). Except for a few older units, most nuclear and baseload coal units generate between 200 and 1000 MW(e) of baseload power and have reached average capacity factors of 65 percent or better in recent years (OTA 1993a).

The construction impacts of building a solar thermal central generating station would stem from the amount of land required to generate 1000 MW(e) of electricity. About 6000 ha (14,000 acres) or 57 km^2 (22 square miles) of land would be cleared either at one site or at multiple locations, with the resulting destruction of whatever wildlife habitat or agricultural values the land provided. A greenfield site or sites, along with new transmission lines, probably would be required because few existing facilities would have sufficient land for such an endeavor. The visual impact of such clearing, even in desert landscapes where solar thermal technology is most competitive, would be regarded by many observers as an obvious negative aesthetic impact. Potential impacts to cultural resources could be considerable because of the large amount of land affected, and care would need to be taken to identify such resources before construction. Some erosion and sedimentation would likely occur during land clearance. Considerable short-term impacts to air quality would occur from dust and vehicle exhaust, and vegetation and other debris would require disposal, perhaps through on-site burning. As with PV technology, the size of the construction work force that would be needed is unknown, but it could be reduced through the use of prefabricated components and a modular construction approach. Adverse socioeconomic impacts could be reduced in this fashion.

The operating impacts of a large solar thermal facility also would revolve around land resources dedicated to the plant. No other uses would be compatible since the solar thermal collectors would take up most of the space. Construction-initiated adverse aesthetic impacts and habitat losses and any accompanying risks to threatened and endangered species would continue. There should be few operating impacts to air quality, human health, solid waste, and cultural resources. Water quality should not be affected unless water were used as a cooling agent in an arid environment where it is in short supply or water runoff from the collectors were uncontrolled and sedimentation damaged water bodies. Socioeconomic benefits should be small compared with those going to host communities of large nonrenewable generating stations. Work forces and local purchases would be small. However, the likely high cost—and high assessed value—of solar thermal facilities could lead to substantial property tax revenues.

8.3.4 Hydropower

Currently, the largest electricity contribution from renewable resources is from hydropower. In 1990, conventional hydroelectric plants generated 28 billion kWh of electricity or 83 percent of electricity generated by renewable technologies and about 9.5 percent of electricity generated by all technologies. Hydropower makes up 10 percent of this country's generating capacity. This percentage is expected to decline because new hydroelectric facilities have become difficult to site as a result of public concern over flooding, destruction of natural habitat, and destruction of natural river courses. Hydropower has an average capacity factor of 46 percent, placing it in the middle of the range for renewable technologies (DOE/EIA-0561). Of all renewable and nonrenewable energy resources, hydropower has the fewest resources at 986 quads per year, of which 157 quads are accessible at some cost and 58 quads, or about 6 percent, constitute reserves that are recoverable at current costs (DOE/EIA-0561). Figure 8.3 shows both developed and undeveloped hydropower generating capacity as of January 1992, according to the Federal Energy Regulatory Commission (DOE/EIA-0561).

Impediments to the development of hydropower capacity include environmental concerns and licensing requirements. New dam safety criteria also have affected development. Although it is unlikely that many hydroelectric dams will be constructed in the future, some measures can be taken to increase electrical generation. Older turbines and generators can be upgraded and refurbished. New equipment—such as variable-speed, constant-frequency generators—is being developed which would allow turbines to operate at higher efficiencies (SERI/TP-260-3674).

Although the amount varies, large-scale hydroelectric plants of 1000 MW(e) or greater require an average of almost 400,000 ha (1 million acres). Additional land would be required for transmission, as

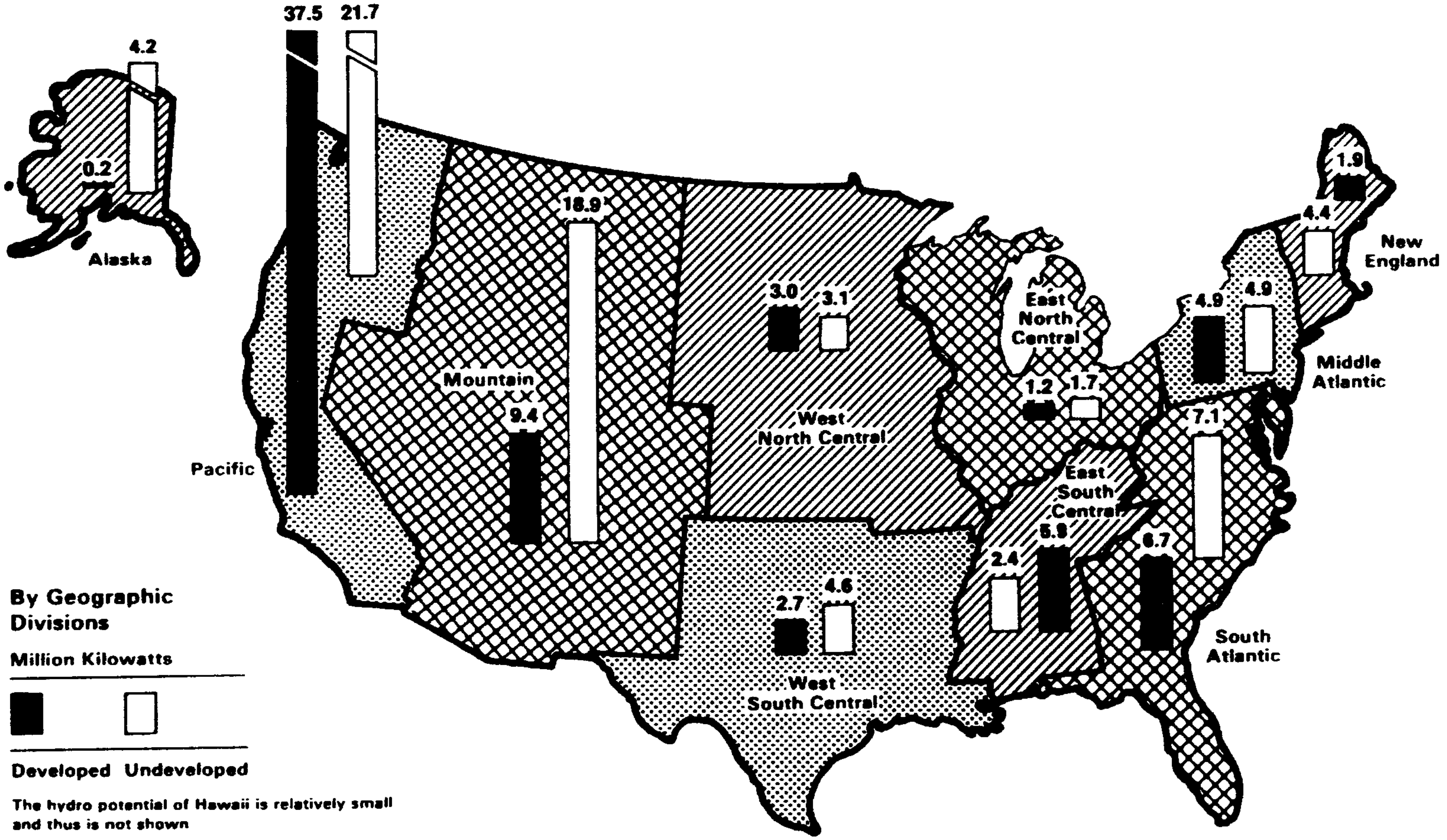

Figure 8.3 **U.S. conventional hydroelectric generating capacity, developed and undeveloped (gigawatts).** *Source:* Adapted from DOE/EIA-0561.

the sites likely would be new. Wildlife habitat would be lost for terrestrial and free-flowing aquatic biota, and additional habitat would be created for some aquatic species. Associated with the loss of land would be some erosion, sedimentation, dust, equipment exhaust, debris from land clearing, probable loss of cultural artifacts, and aesthetic impacts from land clearing and excavating. The construction work force would be fairly large, and socioeconomic impacts likely would be substantial, especially if the dam were constructed in a remote area where inmigrating workers would burden local public services.

Operating impacts from hydroelectric dams are associated predominantly with land and water resources. Land that once was lived on, farmed, ranched, forested, hunted, or mined would be submerged under water indefinitely. The original land uses would be replaced by electricity generation and recreation and, perhaps, residential and business developments that take advantage of the lake environment. Changes in water temperature, currents, and amount of sedimentation would produce a different aquatic environment above and below the dam. Alterations to terrestrial and aquatic habitats could change the risks to threatened and endangered species. Although the hydroelectric dam would create no air quality or solid waste impacts during operation and could serve as a protector of property and lives in preventing floods, lake recreation would likely bring with it a number of drownings and cause water pollution during the facility's operation.

8.3.5 Geothermal

Potentially recoverable geothermal resources are located in the upper 10 miles (16 km) of the earth's crust. These resources exist in the form of hot vapor (steam) or liquid (hydrothermal), geopressurized brines, or hot dry rock. Hydrothermal is the only resource used by current commercial technology. EIA estimates that about 1.5 million quads per year of geothermal resources exist in the United States; however, only about 22,800 quads are accessible and, of these, only approximately 250 quads per year can be economically developed today (DOE/EIA-0561). In 1990, geothermal resources contributed 0.32 quad of primary energy in the western United States. The net geothermal generating capacity in the United States is projected to grow from 15 billion kWh in 1990 to about 60 billion kWh in 2010. In comparison, one 1000-MW(e) nuclear plant operating at 60 percent capacity generates 5.26 billion kWh annually (DOE/EIA-0561). Geothermal has a high capacity factor of approximately 90 percent and can be used to provide reliable, baseload power. A geothermal electricity generating facility consists of a conversion well that brings the geothermal resources to the surface, the conversion system that produces useful energy from the resource, and the injection well that recycles cooled brine back to the underground reservoir (SERI/TP-260-3674).

As shown in Figure 8.4, geothermal plants may be located in the western United States, Alaska, and Hawaii where hydrothermal reservoirs are prevalent. The discrepancy between the vast amount of resource projected to be available (1.5 million quads per year) and projected usage is due primarily to technological problems. Although geothermal plants offer alternative baseload capacity to conventional fossil fuel and nuclear plants, widespread application of geothermal

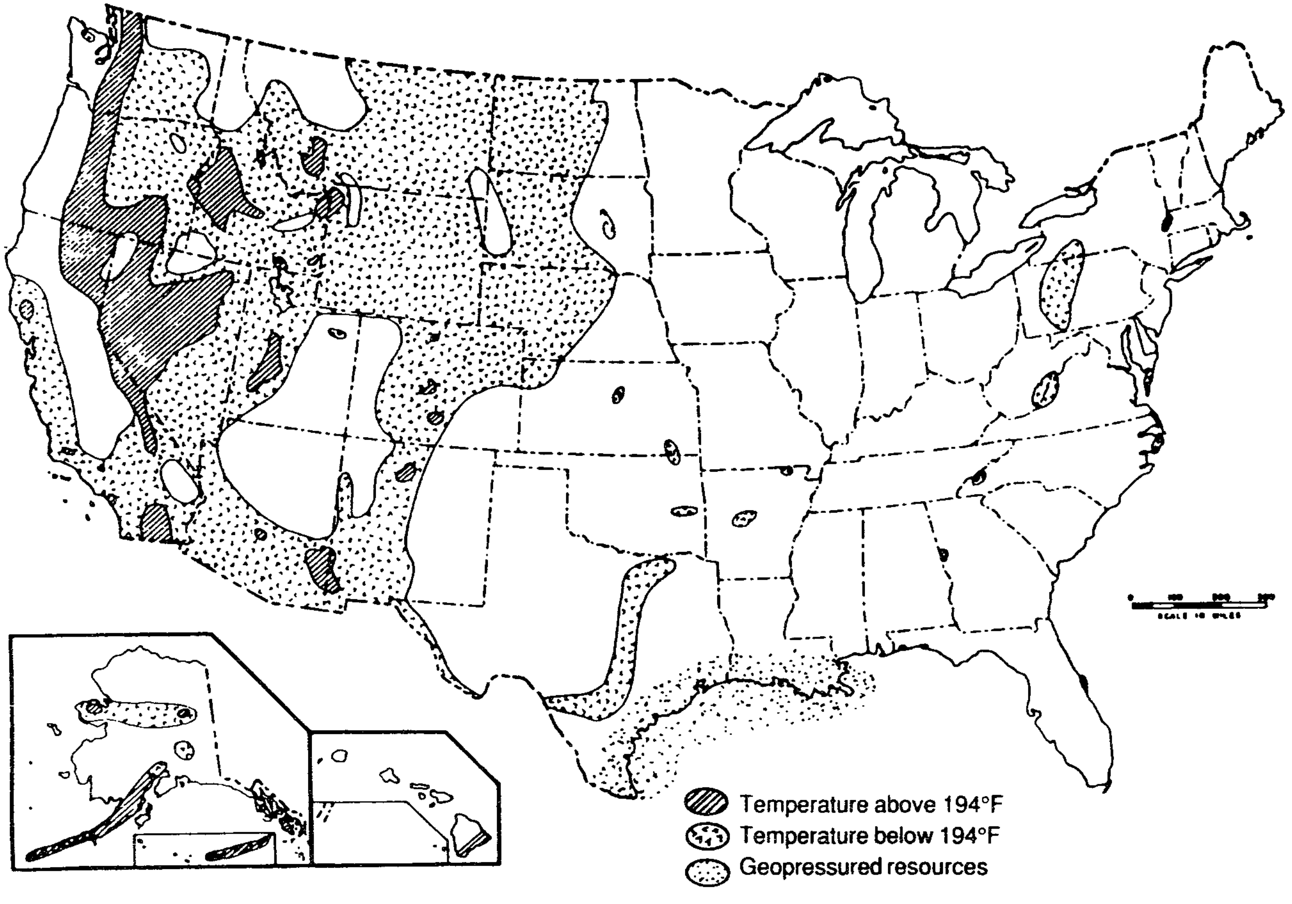

Figure 8.4 U.S. known and potential geothermal energy resources. *Source:* Adapted from DOE/EIA-0562.

energy is constrained by the geographic availability of the resource and the maturity of the technology. The maximum size of geothermal power plants, in their present state of development, is about 110 MW(e) per unit. Geothermal plants, however, could be sited as modular units that would allow for larger generating capacities.

Construction impacts of a geothermal facility would result primarily from disturbance of land to support the large number of geothermal wells and the power plant needed to produce electricity equivalent to that from a 1000-MW(e) plant. Excluding new transmission corridors, which would add to most impacts, an estimated 2800 ha (7000 acres) would be needed even though the generating facility or facilities would only occupy around 25 ha (60 acres). This amount of acreage having appropriate geothermal resources would require a greenfield site or sites, which would imply altering current land uses of farming, ranching, forest, or natural habitat. Clearing this land would damage or destroy much of the existing habitat for wildlife, as well as pose potential adverse consequences for cultural resources. Aesthetic impacts would include extensive vegetation removal and earth moving. Soil erosion and stream sedimentation likely would result in some degree from the early clearing operations. Fugitive dust and exhaust fumes from heavy equipment would reduce air quality temporarily. The moderate-sized work force would create some community impacts, particularly if affected communities were small and had little service infrastructure to accommodate workers who might move into a rural environment to build the plant. Operating impacts would involve those resources most closely associated with the land disturbed in constructing the geothermal facility. Some of the land originally cleared for construction of the geothermal facilities could probably be returned to previous uses, since it would not all have geothermal facilities located on it. Much acreage would still be lost for the life of the plant, however, and this loss could be complicated by subsidence caused by withdrawal of the geothermal fluid. Loss of habitat, impacts to threatened and endangered species, and visual impacts could be mitigated partially by returning much of the land to, or even leaving it in, its original condition. Surface water and groundwater quality could be impacted adversely if waste fluids from wells escaped into the ground water or surface streams or ponds. In addition various toxic gases such as ammonia, methane, and hydrogen sulfide and trace amounts of arsenic, borax, mercury, radon, and benzene would be released to the atmosphere. Noise impacts could be a problem for residents living on the edge of a geothermal site. Socioeconomic impacts should be positive with substantial tax revenues and a considerable number of jobs accruing to local taxing jurisdictions from a geothermal plant.

8.3.6 Wood Waste

The 2.4 quads per year of waste wood energy consumed in the United States generally is apportioned among the following sectors: industrial heat and power—1.6 quads (66 percent), residential space heating—0.8 quads (33 percent), and electric utilities—0.01 quads (1 percent). Industrial wood energy is used in a variety of process heat and cogeneration applications. Nearly half of that wood energy is used in boilers, a little over 40 percent in cogeneration (steam and electricity), and the remainder as process heat. Much of the electricity produced by the industrial sector is sold to utilities. These nonutility generators, along with independent power producers, generated about 31 billion kWh in 1990 from 6 GW(e) of installed wood- and wood-waste-fired capacity. By 2010, installed capacity is expected to increase to over 8 GW(e) and net generation to nearly 60 billion kWh (DOE/EIA-0561).

Wood waste is a sub-category of biomass energy. The category can include residues from forest clearcut and thinning operations, non-commercial tree species, harvests of forests for energy purposes, and wastes from forest product milling operations. The costs of these fuels are highly variable and very site-specific. Costs can be very low if the fuels are collected as part of commercial timber harvest operations or as residues from milling operations. Costs are higher if the biomass has to be collected and removed after forest harvest and thinning operations.

In addition to the costs of competing fuels, many factors affect the viability of wood waste power production. Among the factors influencing the costs of forest residues and wastes are the costs of collecting (harvesting), hauling, storing, and handling feedstocks; fuel characteristics (quality, reliability and variability of supply); levels of economic activity that affect waste generation; technological change in waste generation processes and development of competing uses (e.g., wafer board); and environmental considerations and restrictions as influenced by public perceptions, access, and environmental factors. Because mill wastes are concentrated, uniform, and often of high quality, they are highly desirable for non-energy uses and products. They are becoming fully utilized by forest products and pulp/paper industries, and there is limited availability for energy uses.

Nearly all of the wood-energy–using electricity generation facilities in the United States use steam turbine conversion technology. The technology is relatively simple to operate and it can accept a wide variety of biomass fuels. However, at the scale appropriate for biomass, the technology is expensive and inefficient. Therefore, the technology is relegated to applications where there is a readily available supply of low-, zero-, or negative-cost delivered feedstocks.

The low efficiency of wood-fired power plants, relative to modern coal-fired plants, is due in part to the use of more moderate steam conditions. Biomass steam-turbine plants use lower pressures and temperatures because of the strong scale-dependence of the unit capital cost (dollars per kilowatt). Building biomass plants at modest scales [<50 MW(e)] makes economic sense when conversion facilities have a nearby, reliable supply of low-cost wood wastes and residues. Conversion efficiencies of wood-fired power plants that are being built today are in the 20–25 percent net efficiency range (DOE/CH100093-152). These facilities usually provide baseload power and operate with capacity factors of around 70–80 percent.

Removal of logging slash and forest thinnings may be environmentally significant, particularly when 160,000 to 320,000 ha (400,000 to 800,000 acres) could be affected to support a large wood waste plant. Forest residues left on-site help to create habitat for animals and provide nutrients to forest soil. The presence of forest slash and thinnings can also serve to lessen soil erosion and its concomitant impacts. Forest residues are therefore important to ecosystems, and they must be carefully guarded from overuse (OTA 1993b).

Plant construction impacts should not be significant if the plants are properly sited and designed (ECO Northwest et al. 1986). The overall level of construction impact should be approximately the same as that for a coal-fired plant, although wood-waste-fired facilities will be built at smaller scales. Like coal-fired plants, wood-waste plants require large areas for fuel storage and processing and involve the same type of combustion equipment.

Emissions during plant operations are CO, oxides of nitrogen, SO_x, PM, and CO_2. Relative to coal and other primary fossil-fuel sources of electricity, wood-fired electricity generation has very low levels of SO_x emissions because wood contains very little sulfur. There are also reduced emissions of oxides of nitrogen. The major emissions from wood-fired generation involve the release of particulate matter. However, these emissions are controlled effectively with existing technology. Emissions to land and water resources are associated with soil disturbance and runoff and the disposal of ash. However, ash disposal is not a major concern from wood combustion and the ash may be beneficial as a fertilizer and soil conditioner provided the pH is not excessively high.

8.3.7 Municipal Solid Waste

MSW differs from other biomass energy sources because utilization is primarily a waste management decision, and increased use of MSW is likely to be driven by costs of disposal (i.e., higher tipping fees and reduced landfill space) rather than by energy considerations. Currently, about 15 percent of the MSW produced in this country is burned to produce heat and power. In 1990, MSW was used to generate 10 billion kWh from 2 GW(e) of installed capacity (DOE/EIA-0561). Electricity generation from MSW is projected to grow to 54 billion kWh by 2010 with 11 GW(e) of installed capacity (DOE/EIA-0561).

Population and economic growth, reduced availability of landfill space, and increasing tipping fees are creating strong incentives to reduce the size of the waste stream, change its composition, and find alternative uses, such as energy. However, numerous obstacles and factors may limit the growth in MSW power generation. Chief among them are environmental regulations and public opposition to siting MSW facilities. Others include voluntary recycling, state laws mandating reductions in the MSW going to landfills, efforts to limit packaging, prohibitions against yard wastes and construction and demolition wastes in landfills, and changes in the heat content of MSW given the fate of plastics and wood in waste streams.

MSW conversion facilities use basically the same steam-turbine technology found at wood waste facilities. However, installed capital costs are much greater because of the need for specialized MSW handling and waste separation equipment and stricter environmental emissions controls. MSW facilities typically have high capacity factors (85–90 percent) and provide baseload power.

MSW combustion is a waste disposal option for communities that lack landfill space. Since MSW must be collected regardless of whether it is used for power production, impacts associated with collection and transport are not considered here. The environmental impacts that are relevant are those associated with combustion compared with the actual landfilling of the wastes. Among the more important environmental tradeoffs are decreased landfill requirements and possible improvements in groundwater quality (leachate minimization) versus decreased air quality from MSW combustion (ECO Northwest 1986).

MSW-fired facilities are usually sited and constructed in industrial areas; the overall construction impact is not likely to be significant if plants are sited and built properly (ECO Northwest et al. 1986). Construction impacts are similar to those of coal-fired power plants in terms of the acreage disturbed.

Emissions from MSW combustion facilities include particulates, oxides of nitrogen, acid gases, metals, and organic compounds. These are potentially serious emissions; however, MSW facilities are required to operate with much stricter controls than biomass facilities burning wood and wood wastes. Odors are also a potential impact from MSW combustion. MSW facilities face much public opposition, and siting can be especially problematic.

8.3.8 Energy Crops

Expanding biomass-fired power generation capabilities beyond the size of the waste resource base requires the use of dedicated feedstocks or energy crops (Wright 1994; Hohenstein and Wright 1994). Energy crops appropriate for combustion and power production include short-rotation woody crops (e.g., poplar) and perennial herbaceous crops (e.g., switchgrass). Woody crops typically consist of plantations of closely spaced trees that are harvested on a cutting cycle of 3–10 years. The trees are not managed intensively, requiring only weed control in the first 2–3 years of growth and some fertilization. Woody crops have been developed that produce yields two to three times greater than those achieved by traditional forest management. Growing herbaceous crops is similar to growing hay. They are managed similarly to hay; however, yields are much higher. As with other biomass energy feedstocks, projected energy costs are very site specific and depend greatly on realized yields.

Biomass power based on energy crops and current conversion technology generally is not currently competitive with fossil-fired alternatives in terms of generating costs. The competitiveness of generating electricity from energy crops can be improved by developing conversion technologies that offer higher efficiencies and lower unit capital costs at modest scales appropriate for biomass. One technology under development and testing that offers higher conversion efficiency is Whole Tree Energy (*WTE*®) technology (Lamarre 1994). WTE® is an innovative steam turbine technology that uses an integral fuel drying process. Waste heat, produced by the flue gas at 54°C (130°F), is used to dry wood stacked in a large, air-inflated building for 30 days before it is conveyed to a boiler and burned. Allowing the waste heat to dry the wet whole-tree fuel can result in net plant efficiencies comparable to those of a modern coal-fired plant (35 percent). WTE™ also reduces wood harvesting and handling costs as well as the need for equipment such as hammer mills, screens, and chippers that is used for reducing the size of the wood feedstock.

According to some experts, the most promising technologies for wood-fired power generation lie in the development of gas turbine cycles (Williams and Larson 1993). Gas turbines (or Brayton cycles) have already been developed for natural gas and clean liquid fuels. A key advantage of gas turbine technology is the potential for substantially reduced capital costs, which are relatively insensitive to scale, higher conversion efficiencies (upwards of 45 percent), and greater modularity. Adapting the technology for biomass (i.e., biomass-gasifier/gas turbine—BIG/GT) would require the use of a gasifier to thermochemically convert wood to a gas. The resultant gas would then be cooled and cleaned before being burned in a gas turbine. There are a number of technology choices for both gasification and power generation, ranging from simple cycle gas turbines to gasifier combined cycles and gasifier intercooled steam-injected cycles.

The net environmental impacts of growing energy crops depend on the type of land they occupy and the uses they displace. Energy crops are currently being targeted as alternatives to conventional agriculture. With surpluses in cropland projected, energy crops are seen as a potentially important alternative crop to conventional agriculture. The displacement of certain agricultural row crops (e.g., corn and soybeans) with trees might result in a positive net change in environmental impacts, especially on erosive sites. The production of wood in managed plantations would be much less erosive than row crop production, and the amounts of fertilizers and pesticides used would be much smaller. The conversion of pasture land to tree production might increase soil erosion as trees were being established. However, runoff containing nutrients from animal wastes would not be present. Perhaps the strongest environmental argument for energy crops is the potential to reduce net greenhouse gas emissions by providing a substitute baseload generation source for fossil fuels (Wright 1994).

Plant construction and operating impacts would be identical to those associated with wood-waste-fired facilities.

8.3.9 Coal

Coal-fired steam electric plants provide the bulk of electric generating capacity in the United States, accounting for about 56 percent of the electric utility industry's net generation and 43 percent of its capacity in 1992 [(DOE/EIA-0383(94)]. EIA projects slight changes in these percentages to 58 percent and 42 percent, respectively, by 2010. Conventional coal-fired plants generally include two or more generating units and have total capacities ranging from 100 MW(e) to more than 2000 MW(e). Domestic coal resources are estimated at over 87,000 quads of energy, of which about 38,000 quads constitute accessible resources and 5,300 quads are reserves that can be cost-effectively recovered today. Total U.S. coal consumption in 1990 was about 19 quads, which leads to the conclusion that coal is likely to continue to be a reliable energy source well into the future (DOE/EIA-0561), assuming environmental constraints do not cause a gradual substitution of other fuels.

DOE has encouraged the increased use of coal by electric utilities through its cost sharing of clean coal projects to develop and demonstrate advanced technologies that reduce atmospheric emissions of coal combustion pollutants and improve the environmental acceptability of coal. A description of 22 generic clean coal technologies considered by DOE in the Clean Coal Technology Program, which is being terminated, is provided in DOE/EIS-0146.

A window of opportunity for clean coal technologies may occur in the late 1990s as a result of the aging of currently operating coal-fired power plants and passage of the Clean Air Act Amendments of 1990 (CAAA) and Energy Policy Act of 1992 (EPACT). Utilities will be considering the option of constructing replacement plants, extending the life of existing coal-fired plants, purchasing additional pollution allowances, or even buying electricity from other sources. Repowering is an important alternative that is discussed in Section 8.3.13. It is quite cost effective, increases plant capacity, and offers various financial and institutional benefits under the CAAA and EPACT that enhance a utility's competitiveness (Norton and Gottlieb 1993). With repowering, a utility replaces an obsolete steam generator with an advanced coal technology, such as an atmospheric fluidized-bed boiler or an integrated coal-gasification/combined-cycle (Bretz 1994). To date, utilities have responded to CAAA's SO_2 emissions goals by adding scrubbers and burning a higher proportion of Western low-sulfur coal rather than purchasing pollution allowances, thereby resulting in lower SO_2 emissions (Bohi 1994). DOE also forecasts that by the year 2010, advanced coal technologies—if successfully applied—could have the capability to reduce national CO_2 emissions by 5 to 12 percent (DOE/EIS-0146).

The United States has abundant low-cost coal reserves, and the price of coal for electric generation is likely to increase at a relatively slow rate. Even with recent environmental legislation, new coal capacity is expected to be an affordable technology for reliable, near-term development and for potential use as a replacement technology for retired nuclear power plants.

The environmental impacts of constructing a typical coal-fired steam plant are well known because coal is the most prevalent type of central generating technology in the United States. The impacts of constructing a 1000-MW(e) coal plant at a greenfield site can be substantial, particularly if it is sited in a rural area with considerable natural habitat. An estimated 700 ha (1700 acres) would be needed, and this could amount to the loss of about 8 km^2 (3 square miles) of natural habitat and/or agricultural land for the plant site alone, excluding that required for mining and other fuel cycle impacts. Ecological impacts could be large, and important cultural sites could be encountered, particularly near rivers. With this much land being cleared, some erosion and sedimentation would be expected. Considerable fugitive dust emissions would affect air quality temporarily, and the quantity of construction debris also would be substantial. Aesthetic impacts from such a large construction effort in a rural area could be substantial. Socioeconomic impacts at a rural site would be larger than at an urban site because more of the 1200–2500 peak work force would need to move to the area to work. Such impacts are worst at very remote sites where accommodations may be nonexistent and the large majority of workers must move to work on the plant. Transmission line impacts would add to virtually all these impacts. Siting a new coal-fired plant where a nuclear plant is located would reduce many construction impacts, thereby reducing the initial damage to the environment and eliminating the need for new transmission lines. Such co-locating would depend on factors such as location of load centers, environmental restrictions, and site characteristics.

Operating impacts of new coal plants would be substantial for several resources. Concerns over adverse human health effects from coal combustion have led to important federal legislation in recent years, such as the CAAA. Although the situation appears to be improving, health concerns remain. Air quality would be impacted by the release of CO_2, regulated pollutants, and radionuclides. Public health risks such as cancer and emphysema are considered likely results. CO_2 has been identified as a leading cause of global warming. SO_2 and oxides of nitrogen have been identified with acid rain. Substantial solid waste, especially fly ash and scrubber sludge, would be produced and would require constant management. Losses to aquatic biota would occur through impingement and entrainment and discharge of cooling water to natural water bodies. Socioeconomic benefits can be considerable for surrounding communities in the form of several hundred jobs, substantial tax revenues, and plant spending.

An estimated 8,900 ha (22,000 acres) for mining the coal and disposing of the waste could be committed to supporting a coal plant during its operational life. Air quality impacts from fugitive dust, water quality impacts from acidic runoff, and aesthetic and cultural resources impacts are all potential adverse consequences of coal mining. Socioeconomic benefits from several hundred mining jobs and tax revenues would also accompany the coal mining.

8.3.10 Natural Gas

Natural gas supplied 9.4 percent of this country's net electric utility generation in 1992 and is projected to supply 11.4 percent of electricity in 2010 [DOE/EIA-0383(94)]. Domestic natural gas resources are estimated at 1,700 quads, of which approximately 900 quads are accessible resources and about 230 quads are reserves that currently can be recovered cost-effectively (DOE/EIA-0561). Most of the supply in the continental United States is located in Texas, Louisiana, Oklahoma, New Mexico, and Kansas, locations favored for gas-fired plants because of relatively low gas prices. Although natural gas reserves are fairly large, much of the resource is located in remote areas that are not served by a pipeline infrastructure connected to high-demand centers.

The natural gas fuel cycle consists of exploration/extraction (drilling and production), processing, transportation by pipelines, end use, and waste management. Utilities receive gas at power plants through pipelines on a continuous basis.

Natural gas is used in three technologies: conventional steam, gas-turbine, and combined-cycle. In conventional steam plants, the traditional gas-fired technology, natural gas is burned to produce steam. The process is very similar to that used for coal and oil technologies. Because natural gas can be used more efficiently in gas-turbine and combined-cycle facilities than in a conventional steam plant, the latter technology is no longer being used for new generating stations. In gas-turbine plants, gas (or distillate oil) is burned to produce an exhaust gas that drives the turbine. Combined-cycle plants, which are particularly efficient and are used as intermediate and baseload facilities, combine the gas-turbine technology with a heat recovery system that powers a steam cycle [DOE/EIA-0383(94)]. These combined-cycle systems represent the large majority of the total number of plants currently under construction or planned in the United States. Most of the plants are small and have proved to be popular with nonutility generators (Bergesen 1994). Those using combined-cycle technology can qualify as Public Utility Regulatory Policies Act of 1978 (PURPA) plants if they are no larger than 80 MW(e) and operate as cogenerators.

Most environmental impacts of constructing natural-gas–fired plants should be approximately the same for steam, gas-turbine and combined-cycle plants. These impacts, in turn, generally will be similar to those of other large central generating stations. Land-use requirements for gas-fired plants are small at 45 ha (110 acres) for a 1000-MW(e) plant; thus land-dependent ecological, aesthetic, erosion, and cultural impacts should be small unless site-specific factors should indicate a particular sensitivity for some environmental resource. Siting at a greenfield location would require new transmission lines and increased land-related impacts, whereas co-locating the gas-fired plant with the retired nuclear plant would help reduce land-related impacts. Socioeconomic impacts should not be very noticeable because the highest peak work force of 1200 for steam plants is small for a central generating technology, and gas-fired plants are not usually sited in remote areas where community impacts would be most adverse. Also, gas-fired plants, particularly combined cycle and gas turbine, take much less time to construct than other plants.

The environmental impacts of operating gas-fired plants are generally less than those of other fossil fuel technologies of equal capacity. Consumptive water use is about the same for steam plants as for other technologies. There are potential impacts to aquatic biota through impingement and entrainment and increased water temperatures in receiving water bodies. Water consumption is likely to be less for gas-turbine plants. Generally, air quality impacts for all natural gas technologies are less than for other fossil technologies because fewer pollutants are emitted and SO_2, a contributor to acid precipitation, is not emitted at all. Solid waste should be minimal. The work force of 150 workers would be the lowest of any nonrenewable technology, as would local purchases and local tax revenues. Approximately 1500 ha (3600 acres) of additional land would be required for wells, collection stations, and pipelines to bring the natural gas to the generating facility. Impacts would be typical of those associated with land clearance. Operational impacts should not be severe because most of the land would not be disturbed further once facilities were sited.

8.3.11 Oil

Oil-fired power production was 3.2 percent of the country's total net electricity generation in 1992 and is projected to decline to 2.3 percent by 2010 [DOE/EIA-0383(94)]. Domestic petroleum resources are estimated by the EIA at about 2,800 quads, of which about 1,100 quads are accessible at some price, and about 160 are recoverable at current costs (DOE/EIA-0561). In the 12-year period for which EIA has reported annual oil and gas reserves (1977 through 1988), year-end crude oil reserves decreased by 19.9 percent ([DOE/EIA-0216(88)].

The oil fuel cycle system involves exploration/extraction, processing, transportation, end use, and waste management. The production of electricity from oil combustion is accomplished by the same process used for coal and natural gas. Oil-fired plants provide peak, intermediate, and baseload capacity.

The economics, apart from fuel price, of oil-fired power generation are similar to those of natural gas-fired power generation. Distillate oil can be used to run gas turbines in a combined-cycle system; however, the cost of distillate oil usually makes this combined-cycle system much less competitive where gas is available. Oil-fired power generation has experienced a significant decline since the early 1970s. Increases in world oil prices have forced utilities to use less expensive fuels; however, oil-fired power generation is still important in certain regions of the United States.

Constructing a 1000-MW(e) oil-fired power plant would have the same environmental impacts as constructing other large central generating power stations. Relatively small land requirements of an estimated 50 ha (120 acres), however, would be expected to reduce other resource impacts that tend to follow land-use impacts: ecological, aesthetic, air quality, water quality, and cultural. As land-use requirements decrease, erosion, loss of habitat, and negative aesthetic impacts decrease as well, although very site-specific considerations occasionally enter the picture. Expected socioeconomic impacts should not be high because of the moderate size work force of 1700, and oil-fired plants typically are not sited in remote areas or otherwise away from larger communities that are on pipelines or near where the oil is refined, consumed, or imported. Transmission lines for a greenfield site likely would increase land-dependent impacts in approximate proportion to the transmission/generation acreage. Land-use related impacts could be reduced if the oil-fired plant were colocated with the retired nuclear plant.

Environmental impacts of operating oil-fired power plants are similar to those from comparably sized coal-fired plants. Since they typically use the same cooling systems, water use and related impacts to water quality and aquatic biota would be similar. Air emissions, too, would be typical of coal plants; regulated pollutants, CO_2, and small amounts of radionuclides would be emitted, although in lesser quantities than from an equivalent-size coal-fired plant. Moderate amounts of scrubber sludge would require disposal. Attendant impacts would include acid precipitation, global warming, and some increased risk of health problems, such as emphysema, cancer, and other illnesses associated with combustion of fossil fuels. Employment, tax revenues, and local purchases would be positive socioeconomic impacts for some local communities. Approximately 650 ha (1600 acres) of additional land would be needed for oil wells and support facilities that would provide the generating plant with fuel. Impacts would likely be similar to those of other land clearing activities. Operational impacts should not be severe because, as with gas, the land generally would not be disturbed once the wells were producing.

8.3.12 Advanced Light-Water Reactor

Section 2.1 describes a typical nuclear power plant and its operation. In 1992, nuclear power provided 22 percent of total United States net electric utility generation, a figure that is expected to decline to 18.8 percent by 2010. Nuclear power represented 14.3 percent of this country's 1992 electric utility generation capacity and is projected to decline to 12.2 percent by 2010 [DOE/EIA-0383(94)].

Current American research focuses on the advanced LWR as a viable replacement for existing nuclear plants. Advanced LWR technology differs from current LWR technologies primarily in component design, including passive safety features that reduce the probability of severe accidents (NUREG-1362). Advanced LWRs would require slightly more fuel than current designs, resulting in slight increases in spent fuel generation and lower overall plant efficiencies. Future plants using the advanced LWR technology are expected to require smaller sites and shorter construction periods than current nuclear plants (NUREG-1362). They may also involve smaller, modular plants. The long hiatus in nuclear plant starts is not expected to end soon, however, even with advanced LWR technology, and the EIA projects that no new nuclear plants will be added by 2010 [DOE/EIA-0383(94)].

The environmental impacts of constructing an advanced LWR nuclear plant are expected to be equivalent to the impacts of building any large energy facility. Impacts could be moderated somewhat if the plant were built at a current nuclear plant site rather than at a greenfield site because the prevailing land use would be compatible at the former site. Thus, building a plant on a greenfield site would produce more severe impacts.

Advanced LWRs require perhaps 200 to 400 ha (500 to 1000 acres) excluding transmission lines, which could add hundreds to thousands of ha depending upon the distance of the plant from connecting transmission lines or load centers. Destruction of wildlife habitat would occur, and threatened and endangered species would require special consideration to avoid adverse impacts. Erosion, sedimentation, fugitive dust, aesthetic intrusions, and disturbance to cultural artifacts would tend to be proportional to the amount of land disturbed, but site-specific considerations can enter the picture. Socioeconomic impacts from building a large, complex technology would be substantial. With a relatively large but currently unquantified peak construction work force, employment and local spending would benefit. Public services could be adversely affected if those services were operating at capacity previous to plant construction or if a relatively undeveloped remote community were impacted by a large number of inmigrating, temporary workers.

The environmental impacts of operating advanced LWRs would be similar to those of operating current nuclear plants except that slightly more radioactive waste would be generated and the potential for accidents should be reduced somewhat. The newer technology would have built-in safety features that would shut down the plant automatically and use natural forces to greatly reduce the possibilities that severe accidents could occur. Socioeconomic benefits for local communities normally associated with large energy facilities, including substantial employment, tax revenues, and local purchases, would also result from siting of an advanced LWR. Approximately 400 additional ha (1000 acres) would be committed to uranium mining and processing during the life of the advanced LWR. Impacts should be similar to those of other clearing and land-use operations associated with uranium mines and mills and would involve some adverse air and water quality impacts and health risks.

8.3.13 Delayed Retirement of Existing Non-Nuclear Plants

Another potential alternative to license renewal would be to continue to generate electricity from non-nuclear plants beyond the original date at which they were scheduled to shut down permanently. This alternative would have the effect mainly of substituting coal, gas, oil, or hydropower plants for nuclear facilities.

In recent years electric utilities have given considerable attention to the issue of repowering non-nuclear generating facilities. Repowering is the primary process by which utilities extend the life of their generating plants. It is comparable to refurbishing a nuclear plant. Since the average age of all types of fossil units is over 30 years, utilities have been exploring repowering older fossil units as a way of avoiding even larger capital outlays for new plants (Bretz 1994). As of March 1994, about 30 units with a total capacity of 3000 MW(e) had been proposed for repowering. Assuming regulatory environmental compliance and a successful application of lessons learned from federal clean coal technology demonstrations, DOE estimates that up to 248 GW(e) of generating capacity could be repowered or retrofitted with clean coal technologies by the year 2010 (DOE/EIS-0146). In 1991 DOE estimated that 2500 coal-fired plants were 30 years old or older (making them candidates for repowering) and that this total would rise to 3500 to 3700 in 1998. From a utility's perspective, not only might repowering be cost-effective; but also environmental goals, particularly improved air quality, could be easier to accomplish since improved, less polluting technologies would be installed during repowering.

Repowering involves a major rehabilitation of a generating facility and focuses on replacing the steam generator with an improved steam generating technology. Replacement technologies currently regarded as the most attractive candidates include (1) gas-turbine/generator and heat recovery steam generator, (2) atmospheric fluidized-bed boiler, (3) integrated coal-gasification/combined cycle, and (4) pressurized fluidized-bed combustor/combined cycle. The first candidate, the most favored by utilities to date, is a natural gas technology and the last three are coal-fired technologies (Bretz 1994). The technologies could be sited anywhere in the country where fossil plants are located. Repowering efforts currently under way may produce increases in plant output of 20 percent or more, an improvement that amounts to a substantial increase in generating capacity.

Delaying the retirement of older fossil fuel plants (30 years old) would normally require that such plants be repowered if they are to operate long enough for them to be considered feasible alternatives to relicensed nuclear plants. Because repowering technologies are just being implemented, information about actual environmental impacts is only now becoming available.

The construction required to repower a coal or gas-fired plant would be substantial because much of the plant would be improved. For a large coal plant, the effort would be of the same general magnitude as that required to refurbish a nuclear plant. Gas-fired plants are less complex and would involve less work than coal plants. Little land would be affected that had not already been cleared and built upon in the initial plant construction. Consequently, ecological and cultural impacts would be negligible during repowering, as would impacts to air and water. Socioeconomic impacts would occur but would be smaller than during the original construction of the coal or gas-fired plants.

Major reductions in a plant's airborne emissions should be realized as the most important impact. DOE/EIS-0146 states, "Repowering opens the door to a future of sustained deep reductions in nationwide emissions of SO_2, one of the chief pollutants thought to contribute to acid rainfall" (p. 2-10). SO_2 reductions by conventional coal-fired plants would vary from 90 to 99 percent depending upon the specific technology. Similarly, oxides of nitrogen, one of the emissions associated with global warming, would be reduced between 60 and 92 percent from current emissions from conventional coal-fired plants. On the other hand, solid waste would be increased as the new technologies reduced air pollution by converting what would normally be an air pollutant into solid wastes (DOE/EIS-0146). Recent experience with repowered plants starting to come on line confirms SO_2 and oxides of nitrogen reductions of at least 90 percent in these technologies (Bretz 1994). Gas turbine/generators without heat recovery steam generators are expected to reduce oxides of nitrogen emissions by more than 90 percent. Land use, cultural resources, and socioeconomic resources should not be affected by repowering.

8.3.14 Conservation

A wide variety of conservation technologies could be considered as alternatives to generating electricity at current nuclear plants. These technologies could include hardware, such as more efficient motors in consumer appliances, commercial establishments, or manufacturing processes; more energy-efficient light bulbs; and improved heating, ventilation, and air conditioning systems. Also, structures could be weatherized with better insulation, weather stripping, and storm windows. These measures generally come under the heading of DSM, which is a collection of diverse measures to reduce customers' electricity consumption without adversely affecting service. Other conservation measures a utility could take would be to install more efficient equipment as it retrofits its power plants and improves distribution and transmission technologies. An average of 6.2 percent of an American utility's power is lost before reaching customers (Kelly and Weinberg 1993).

Conservation technologies and measures have proved to be popular with some utilities, public utility commissions and members of the public, who see them as a way of providing economical service while avoiding construction of more electric generating facilities. Increased competition within the utility industry and pressure from public utility commissions and public interest groups have forced utilities to consider conservation technologies as essentially new resources in the utility's portfolio of capabilities and invest in them as they would new generating sources. On a national scale (based on EIA electricity growth projections in DOE's National Energy Strategy and Electric Power Research Institute estimates of DSM savings in 1990), Hirst (1991) calculates that almost half of electricity demand growth from 1990 to 2010 could be eliminated with an "ambitious" DSM program. This growth would eliminate the need for an estimated 430 500-MW(e) power plants or an equivalent 215 1000-MW(e) nuclear plants (Hirst 1991). A study of three New York utilities found that DSM programs could produce energy savings equalling 10–20 percent of each utility's projected demand in the years 2000 and 2008 (Nagel 1993).

Treating energy conservation measures as resource options received a major stimulus in the form of the EPACT, which amended the Public Utility Regulatory Policies Act of 1978 to require each utility to employ up-to-date integrated resource planning as a forecasting tool in cooperation with state regulators and the public. Under Sec. 111 (d)(19), integrated resource planning is defined as "a planning and selection process for new energy resources that evaluates the full ranges of alternatives, including new generating capacity, power purchases, energy conservation and efficiency, cogeneration and district heating and cooling applications, and renewable energy resources, in order to provide adequate and reliable service to its electric customers at the lowest system cost." A major barrier to implementing conservation technologies was the degree to which utilities could recover their costs and earn a profit while reducing growth in electric sales as opposed to selling more power. This barrier was removed under EPACT by ensuring that conservation investments were at least as profitable to utilities as investments in energy generation facilities [Sec. 111(a)(8)].

Environmental impacts of electrical energy conservation programs are not well understood. The Pace report (1991) that surveyed literature assessing indoor air quality impacts of conservation programs, and a 1991 national conference with multiple government, utility, and environmental sponsors that investigated the environmental impacts of utility DSM programs (DSM and the Global Environment) are two noteworthy efforts to address such impacts. Environmental impacts of electrical energy conservation programs should fall into three categories: those resulting from energy demand reduction measures, those resulting from energy supply reduction measures, and those caused by fuel cycle activities.

Energy demand reduction measures are specific procedures or technologies that are undertaken to reduce energy demand. Indoor air quality is considered to be the potential impact of greatest concern from demand reduction technologies. Radon, formaldehyde, and combustion products from cigarette smoking and furnaces are the substances that appear to be the sources of most problems. Another area of concern is mercury used in fluorescent lights and polychlorinated biphenyls (PCBs) used in fluorescent light ballasts.

Pace's (1991) examination of the indoor air quality issue reached the general conclusion that, "there are no significant environmental impacts of DSM." Pace went on to argue that "weatherization programs by themselves are not a primary cause of indoor air pollution problems. Where problems do exist, mitigation measures are available." Pace also notes, however, that the U.S. Environmental Protection Agency warns that indoor air quality can be impaired if energy conservation measures override health considerations. The report also pointed out that a Bonneville Power Administration radon study found that radon was a serious concern in new home construction if mitigation measures were not built in. Cancer cases from radon were estimated to be 335 per 100,000 for baseline homes but as high as 767 cases per 100,000 for new homes with advanced infiltration control but no exhaust or mechanical ventilation.

Current research, according to Pace (1991), indicates that indoor air quality is highly site specific, and the levels of contamination existing before weatherization appear to be a major factor in determining post-weatherization pollution levels. In addition, research indicates that mitigation measures are available to correct problems. It should be noted that no studies have been completed to quantify pollutants associated with weatherization, and more research is called for.

As conservation technologies are implemented and growth in electricity demand is reduced, utilities should expect to build fewer power plants. Cost savings to electric utilities nationwide could be substantial. Hirst (1991) estimates that an ambitious 20 percent conservation-inspired reduction in total demand by 2010 could produce savings in fuel and capital of $370 billion and could reduce utility bills by $61 billion at a total cost to the utilities of $165 billion. Studies for specific utilities have identified savings either in terms of money saved or emissions eliminated. Although a utility might prefer to close a fossil-fired plant that is particularly costly or dirty to operate rather than close a nuclear power plant, the GEIS assumes that conservation technologies produce enough energy savings to permit the closing of a nuclear plant. Should a nuclear plant be closed, the environmental gain, in terms of avoided environmental impacts, would be those discussed in Section 8.3.

The third category of environmental impact of electrical energy conservation programs is the resource recovery, processing, and manufacturing stages associated with producing conservation equipment or material, as well as impacts of disposing of the equipment or material. At this time little assessment has been undertaken of these stages. Resources used in producing conservation technologies are common to many manufacturing processes, and large amounts of resources would not be required. Disposal should involve normal procedures, and some benefits are likely over the long term as troublesome components of current technologies, such as PCBs and chlorofluorocarbons (CFCs) that require special handling, ultimately are eliminated from the waste stream and replaced by more benign components. The amounts of mercury and PCBs in lighting are considered to be small enough and disposal methods sufficiently effective that no adverse health effects should be experienced. Acceleration of CFC releases could occur as some appliances are disposed of earlier than anticipated, but this increase should abate as CFC replacements come on the market.

8.3.15 Imported Electrical Power

Although it is not a technology as such, imported electrical power from Canada or Mexico could constitute an alternative to renewing a nuclear plant's license. Electricity trading has existed between the United States and both countries for many years, and numerous transmission ties exist, particularly with Canada, to facilitate easy exchanges of power. The North American Electric Reliability Council (NERC) was established in 1968 to enhance electricity reliability between the United States and Canada and a small portion of northern Baja California in Mexico. Today this system operates essentially as a single power grid, albeit with limited power exchanges and varying prices (NERC 1993b).

Electricity trading between the United States and Mexico has been quite small, amounting in 1990 to about 2 billion kWh of power imported by the United States (Texas) and about 600 million kWh of power exported to Mexico [DOE/EIA-0531(90)]. [The annual electric generation of a 1000-MW(e) power plant operating at 60 percent capacity is 5.26 billion kWh; thus, 1990 imports from Mexico amounted to the equivalent of about 40 percent of a 1000-MW(e) plant.]

Electricity trading between the United States and Canada is considerably larger and involves exchanges along almost the entire boundary separating the countries. In 1990 American utilities purchased approximately 22.5 billion kWh of electricity [the equivalent of four 1000-MW(e) plants] and sold about 20.5 billion kWh to Canada. These figures exclude power that is exchanged at no cost between utilities in which power moves freely across the border in one direction and is replaced with an equal amount of power moving free of charge in the other direction [DOE/EIA-0531(90)]. In 1990 the largest provincial exporter of power to the United States was British Columbia, which accounted for about 30 percent of the total. The largest provincial importer of power was Ontario, which accounted for almost two-thirds of the total Canadian imports from the United States.

Environmental impacts of importing electrical power to the United States in place of relicensing American nuclear plants should be similar to impacts of operating a mix of coal, hydropower, and nuclear power plants and the associated transmission lines in the United States. Projected capacity margins—essentially the amount of existing and planned generating capacity available for planned maintenance, unplanned electrical outages, and unforeseen growth in demand—are similar in both the United States and Canada, from which most imported power originates. U.S. capacity margins are projected at 20.6 percent of capacity in 1994 and 17.6 percent of capacity in 2002. Canada's capacity margins are projected to be 20.7 percent in 1994 and 16.3 percent in 2002 (NERC 1993a).

Canada's mix of generating technologies is considerably different from that of the United States, with hydroelectric power constituting over half of its capacity and coal constituting a distant second at about 20 percent. Nuclear power accounts for about 16 percent of Canadian capacity, or about the same as in the United States. Oil and gas combined make up only 10 percent of Canadian capacity, or slightly more than one-third the amount they account for in the United States. This mix of generating technologies is not expected to change appreciably through 2002 (NERC 1993a). Electrical power that is exported to the United States could originate almost anywhere in Canada, because the U.S.-Canadian system is essentially a grid in which power can be transmitted to any location from any location. Since transmission is not free and line losses do occur, however, distance is a factor in determining transmission costs and thus feasibility.

Given the generating mix of Canadian power plants, one would expect that hydroelectric dams would be a principal source of exported power to the United States. This point is particularly true when new dam development on the James Bay in northern Quebec is factored into Canadian capacity. Coal and nuclear plants would provide approximately equal amounts of power that would not total the hydropower contribution to exported power. Thus, if environmental impacts of power imported by the United States are distributed among Canadian power plants according to their percentage of the total, environmental impacts of hydroelectric dams (Section 8.2.5) would be the most prevalent types expected. Hydroelectric development in James Bay has been an important environmental dispute in Canada for quite some time, particularly in its impacts on native groups concerned with hunting, fishing, and gathering activities. Impacts of coal and nuclear plants would be expected to follow similar courses as in the United States, which are described in Sections 8.2.9 and 8.2.12, respectively.

Because Canada is engaged in substantial conservation efforts and has adequate generating capacity, it appears unlikely that a major power plant construction effort would have to be undertaken to meet expected American needs in the next 20 years. Similarly, transmission lines are in place within and between the two countries, and any construction of new lines should be a modest effort at best.

8.4 TERMINATION OF NUCLEAR POWER PLANT OPERATIONS AND DECOMMISSIONING

A nuclear power plant that ceases operations and closes permanently must go through a lengthy decommissioning process. In the process certain activities will occur that will have environmental consequences. This section summarizes the impacts of cessation of operations and beginning of decommissioning. The effect of the shutdown of operations is expected to be the same as that of a major scheduled outage, although the effect would be permanent and the loss of employment, local purchases, and most tax revenues would be permanent. All nonradioactive emissions (both airborne and liquid) would cease, as would cooling system impacts, transportation of radioactive materials, and major economic activities. Decommissioning would involve the removal of nuclear components from service and the reduction of residual radioactivity to a level that would allow the eventual release of the property for unrestricted use. Decommissioning does not mean that the plant would be demolished and the site returned to an essentially greenfield status. Rather, decommissioning requires that a nuclear facility be secured in nonoperational storage for a specified period before the next step: dismantlement. The decommissioning methods and their environmental impacts are summarized in Chapter 7. A more detailed evaluation of decommissioning requirements is provided in NUREG-0586.

8.4.1 Land Use

Neither terminating operations nor decommissioning is expected to have any immediate impacts on land use at a plant site, which would generally encompass 80–200 ha (200–500 acres). Because the ultimate objective of decommissioning is to release a site for unrestricted use, the activities that would occur at a site after the eventual completion of decommissioning and dismantlement of the plant would determine the subsequent land-use impacts. For example, it might be feasible to co-locate another power plant on a retired nuclear plant site provided safety requirements could be met and the site were large enough.

8.4.2 Air Quality

Only temporary, localized ambient air quality impacts result from nuclear plant operations. These impacts are not related to power production but instead, to motor vehicle use by plant personnel. Decommissioning activities involving vehicles and gasoline-powered equipment would extend these impacts for a few years past the termination of operations until a plant was in a secure storage configuration (Section 7.3.3). Once storage was in progress and nonsecurity-related activities ceased, these minor air quality impacts would end.

8.4.3 Water Resources

The impacts of nuclear power plant operation on water resources result from consumptive uses (e.g., evaporation associated with the condenser cooling system) and the discharge of chemicals and heat, which affect water quality and biota present in receiving water bodies (Sections 4.2.1 and 4.2.2). These impacts would cease with termination of plant operations. Although liquid releases during decommissioning could result in similar impacts to water quality, they are expected to be temporary and minimal (Section 7.3.4). Standard construction management practices and measures would be taken to minimize worker and public radiation exposure and to protect water quality.

8.4.4 Ecology

When a nuclear plant cooling system ceases operation, an improvement in water quality of the affected water body would be expected to occur; impingement and entrainment effects on aquatic organisms would cease; and drift deposition, icing, and fogging associated with cooling tower operation (if cooling towers are used) would cease. Generally, termination of entrainment and impingement would have positive effects. However, because of compensatory mechanisms that have occurred during the many years of plant operations, the change in aquatic organism populations could be negligible at many sites. Within the cooling water effluent-mixing zone, an aquatic community acclimated to warmer temperatures and biocides will have developed. Some exogenous aquatic organisms may have become established in the zone because of the warmer environment, and these organisms likely would be adversely affected as the water temperature cooled and the original conditions were restored to the water body. Recovery of a community to the normal background composition is a process of variable duration depending on the mobility of the organisms, sources of colonists, rate of growth and maturation of the species, and other factors. In medium-size rivers, most aquatic communities recover within a period of several months, but some groups, such as mollusks, may take more than 2 years to recover (Cairns 1971).

The impacts to a cooling pond that result from plant shutdown depend on whether the pond continues to exist. If cooling ponds were maintained during plant operation by pumping water from another water body, the ponds would revert to a terrestrial system after pumping stopped. Even if ponds are maintained by natural flow, water would probably no longer be impounded. If the ponds continued to exist, the nuclear plant's effects on the ponds described in Section 4.4 would cease. Cooling ponds often remain ice-free during the winter, thereby providing artificial habitat for wildlife. Loss of the heated effluent would change the composition and dynamics of the pond community until it resembled other ponds in the region not used for cooling. This effect is likely to be significant only at Turkey Point (Florida), where the cooling canals serve as habitat for the endangered American crocodile (*Crocodylus acutus*). Changing the temperature in the canal system might adversely affect the crocodile population through loss of that habitat (Gaby et al. 1985, Mazzotti et al.).

Many transmission lines associated with a nuclear power plant would be expected to remain in service even if the plant were shut down. Those lines that are deactivated or removed would no longer produce electromagnetic fields or discharge ozone (Section 4.5). Some rights-of-way would no longer be maintained; therefore, herbicide effects would cease, and forest vegetation and wildlife eventually would predominate in previously cleared portions of corridors (Sections 4.5.3, 4.5.5, and 4.5.6). If lines were removed, they would no longer be collision hazards for birds and would no longer provide perches or nesting sites (Section 4.5.6).

Minimal land disturbance is expected during decommissioning; therefore, no direct impacts to terrestrial biota are expected (Section 7.3.5). Also, measures to protect water quality would prevent toxic effects to aquatic organisms from aqueous effluents.

8.4.5 Radiological Impacts

Radiological impacts to the public from routine existing nuclear plant operations are minimal (Section 4.6). Impacts would be reduced to even lower levels by terminating operations and would be eliminated altogether at the completion of decommissioning. Population radiation doses from decommissioning (from transport of radioactive wastes) would be no greater than 21 person-rem (Section 7.3.1). (A discussion of the Standard International units used in measuring radioactivity and radiation dose is given in Appendix E, Section E.A.3.) Occupational doses would be between 300 and about 1900 person-rem, depending on the decommissioning method (NUREG-0586) (Section 7.3.1). Most of the occupational dose would occur during handling of radioactive materials, and the health risks associated with these dose commitments are within regulatory levels.

8.4.6 Waste Management

Terminating power plant operations eventually would eliminate generation of spent fuel and low-level radioactive waste (LLW). However, decommissioning would require the disposal of up to 19,000 m^3 (670,000 ft^3) of LLW (see Table 7.5), about 30 percent of the amount of LLW generated during the preceding 40 years of operation. Over 90 percent of the LLW would consist of nuclides with short half-life periods that decay to nonhazardous levels within about 100 years. These can be safely disposed of near the earth's surface (Section 7.3.2). At the conclusion of plant operations, no further LLW would be generated.

8.4.7 Socioeconomics

Termination of plant operations and decommissioning could have significant impacts on the economic structure and tax base of communities surrounding the plant. The magnitude of these impacts would be site-specific, depending on the proportion of total local employment, income, and local revenues provided by the plant. Direct employment at a 1000-MW(e) nuclear plant can easily total 700 people, and indirect jobs in the community can total several hundred more. Rural areas with small populations and a narrow economic base would be most impacted by termination of operations. Some jurisdictions may obtain several million dollars in annual tax revenues from plants. If these revenues constitute a substantial portion of the jurisdiction's revenues, the jurisdiction could have difficulty supporting its preclosure level of public services. Similarly, where plant-related employment is a large portion of total local employment, plant shutdown would result in a significant loss of jobs and income. In rural areas, where replacement jobs are not readily available, a loss of so many direct and indirect jobs could result in the out-migration of former plant employees, leading to population decline. In turn, this population decline could result in increased housing vacancies, decreased property values, diminished ability of the community to maintain existing levels of public services, and possibly some gradual changes in area land-use patterns.

Decommissioning would help mitigate temporarily some of the community-wide adverse effects of terminating operations even if the decommissioning work force were smaller than the operations work force and involved different personnel (Section 7.3.7). If the decommissioning work force were substantially larger than the operational work force in a rural area, the net increase could produce some of the problems of rapid economic growth, followed by the adverse effects of terminating plant operations. In effect, decommissioning activities would perpetuate for several years much of the employment and local spending benefits associated with nuclear plant operations. These benefits would cease with the end of decommissioning.

8.4.8 Aesthetics Resources

The primary positive aesthetic impact associated with decommissioning would be elimination of steam plumes from mechanical or natural-draft cooling towers wherever they are used. Other impacts that could be viewed by many people as positive would result from reduced human activities at the site. Since decommissioning would not necessarily lead to dismantlement, aesthetic impacts associated with plant appearance (in particular, large, natural draft cooling towers) might not change except where uncontaminated facilities would be removed. Visual improvements from removal of transmission lines and corridors would occur in those locations where no new plants were built as replacements for decommissioned nuclear plants.

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9. CONCLUSIONS

Table 9.1 summarizes the findings of the GEIS. Ninety-two environmental impacts were analyzed. Most of these were found to be Category 1 issues, which means that the impacts are of small significance at all plants and that no mitigation beyond that already employed at the plants is warranted. Category 2 issues are those for which the significance of the impacts or the appropriateness of mitigation must be determined on a site-specific basis. Because some plants have distinctly different impacts than others, not all conclusions apply to all plants. For this reason, some environmental impacts have Category 1 conclusions for some groups of plants and Category 2 conclusions for other groups of plants. Category definitions are presented in Chapter 1 and in the footnotes to Table 9.1. There remains scientific dispute about the effects of electromagnetic fields from power lines on human health. Consequently, the EIS reaches no conclusion about the significance of that impact. Also, environmental justice was not addressed in this document because guidance on that issue was not available in time to address it in this document.

Table 9.1 Summary of findings on NEPA issues for license renewal of nuclear power plants

Issue	Sections	Category[a]	Findings[b]
		Surface Water Quality, Hydrology, and Use (for all plants)	
Impacts of refurbishment on surface water quality	3.4.1	1	SMALL. Impacts are expected to be negligible during refurbishment because best management practices are expected to be employed to control soil erosion and spills.
Impacts of refurbishment on surface water use	3.4.1	1	SMALL. Water use during refurbishment will not increase appreciably or will be reduced during plant outage.
Altered current patterns at intake and discharge structures	4.2.1.2.1 4.3.2.2 4.4.2	1	SMALL. Altered current patterns have not been found to be a problem at operating nuclear power plants and are not expected to be a problem during the license renewal term.
Altered salinity gradients	4.2.1.2.2 4.4.2	1	SMALL. Salinity gradients have not been found to be a problem at operating nuclear power plants and are not expected to be a problem during the license renewal term.
Altered thermal stratification of lakes	4.2.1.2.3 4.4.2.2	1	SMALL. Generally, lake stratification has not been found to be a problem at operating nuclear power plants and is not expected to be a problem during the license renewal term.
Temperature effects on sediment transport capacity	4.2.1.2.3 4.4.2.2	1	SMALL. These effects have not been found to be a problem at operating nuclear power plants and are not expected to be a problem during the license renewal term.
Scouring caused by discharged cooling water	4.2.1.2.3 4.4.2.2	1	SMALL. Scouring has not been found to be a problem at most operating nuclear power plants and has caused only localized effects at a few plants. It is not expected to be a problem during the license renewal term.
Eutrophication	4.2.1.2.3 4.4.2.2	1	SMALL. Eutrophication has not been found to be a problem at operating nuclear power plants and is not expected to be a problem during the license renewal term.

Footnotes at end of table

Table 9.1 Continued

Issue	Sections	Category[a]	Findings[b]
Discharge of chlorine or other biocides	4.2.1.2.4 4.4.2.2	1	SMALL. Effects are not a concern among regulatory and resource agencies and are not expected to be a problem during the license renewal term.
Discharge of sanitary wastes and minor chemical spills	4.2.1.2.4 4.4.2.2	1	SMALL. Effects are readily controlled through NPDES permit and periodic modifications, if needed, and are not expected to be a problem during the license renewal term.
Discharge of metals in waste water	4.2.1.2.4 4.3.2.2 4.4.2.2	1	SMALL. These discharges have not been found to be a problem at operating nuclear power plants with cooling-tower-based heat dissipation systems and have been satisfactorily mitigated at other plants. They are not expected to be a problem during the license renewal term.
Water use conflicts (plants with once-through cooling systems)	4.2.1.3	1	SMALL. These conflicts have not been found to be a problem at operating nuclear power plants with once-through heat dissipation systems.
Water use conflicts (plants with cooling towers and cooling ponds using make-up water from a small river with low flow)	4.3.2.1 4.4.2.1	2	SMALL OR MODERATE. The issue has been a concern at nuclear power plants with cooling ponds and at plants with cooling towers. Impacts on instream and riparian communities near these plants could be of moderate significance in some situations.
		Aquatic Ecology (for all plants)	
Refurbishment	3.5	1	SMALL. During plant shutdown and refurbishment there will be negligible effects on aquatic biota because of a reduction of entrainment and impingement of organisms or a reduced release of chemicals.
Accumulation of contaminants in sediments or biota	4.2.1.2.4 4.3.3 4.4.3 4.4.2.2	1	SMALL. Accumulation of contaminants has been a concern at a few nuclear power plants but has been satisfactorily mitigated by replacing copper alloy condenser tubes with condenser tubes of another metal. It is not expected to be a problem during the license renewal term.

Footnotes at end of table

Table 9.1 Continued

Issue	Sections	Category[a]	Findings[b]
Entrainment of phytoplankton and zooplankton	4.2.2.1.1 4.3.3 4.4.3	1	SMALL. Entrainment of phytoplankton and zooplankton has not been found to be a problem at operating nuclear power plants and is not expected to be a problem during the license renewal term.
Cold shock	4.2.2.1.5 4.3.3 4.4.3	1	SMALL. Cold shock has been satisfactorily mitigated at operating nuclear plants with once-through cooling systems, has not endangered fish populations or been found to be a problem at operating nuclear power plants with cooling towers or cooling ponds, and is not expected to be a problem during the license renewal term.
Thermal plume barrier to migrating fish	4.2.2.1.6 4.4.3	1	SMALL. Thermal plumes have not been found to be a problem at operating nuclear power plants and is not expected to be a problem during the license renewal term.
Distribution of aquatic organisms	4.2.2.1.6 4.4.3	1	SMALL. Thermal discharges may have localized effects but are not expected to affect the larger geographical distribution of aquatic organisms.
Premature emergence of aquatic insects	4.2.2.1.7 4.4.3	1	SMALL. Premature emergence has been found to be a localized effect at some operating nuclear power plants but has not been a problem and is not expected to be a problem during the license renewal term.
Gas supersaturation (gas bubble disease)	4.2.2.1.8 4.4.3	1	SMALL. Gas supersaturation was a concern at a small number of operating nuclear power plants with once-through cooling systems but has been satisfactorily mitigated. It has not been found to be a problem at operating nuclear power plants with cooling towers or cooling ponds and is not expected to be a problem during the license renewal term.
Low dissolved oxygen in the discharge	4.2.2.1.9 4.3.3 4.4.3	1	SMALL. Low dissolved oxygen has been a concern at one nuclear power plant with a once-through cooling system but has been effectively mitigated. It has not been found to be a problem at operating nuclear power plants with cooling towers or cooling ponds and is not expected to be a problem during the license renewal term.

Footnotes at end of table

Table 9.1 Continued

Issue	Sections	Category[a]	Findings[b]
Losses from predation, parasitism, and disease among organisms exposed to sublethal stresses	4.2.2.1.10 4.4.3	1	SMALL. These types of losses have not been found to be a problem at operating nuclear power plants and are not expected to be a problem during the license renewal term.
Stimulation of nuisance organisms (e.g., shipworms)	4.2.2.1.11 4.4.3	1	SMALL. Stimulation of nuisance organisms has been satisfactorily mitigated at the single nuclear power plant with a once-through cooling system where previously it was a problem. It has not been found to be a problem at operating nuclear power plants with cooling towers or cooling ponds and is not expected to be a problem during the license renewal term.
Aquatic Ecology (for plants with once-through and cooling pond heat dissipation systems)			
Entrainment of fish and shellfish in early life stages	4.2.2.1.2 4.4.3	2	SMALL, MODERATE, OR LARGE. The impacts of entrainment are small at many plants but may be moderate or large at a few plants with once-through and cooling-pond cooling systems. Further, ongoing efforts to restore fish populations may increase the numbers of fish susceptible to intake effects during the license renewal period, so that entrainment studies conducted in support of the original license may no longer be valid.
Impingement of fish and shellfish	4.2.2.1.3 4.4.3	2	SMALL, MODERATE, OR LARGE. The impacts of impingement are small at many plants but may be moderate or even large at a few plants with once-through and cooling pond cooling systems.
Heat shock	4.2.2.1.4 4.4.3	2	SMALL, MODERATE, OR LARGE. Because of continuing concerns about heat shock and the possible need to modify thermal discharges in response to changing environmental conditions, the impacts may be of moderate or large significance at some plants.

Footnotes at end of table

Table 9.1 Continued

Issue	Sections	Category[a]	Findings[b]
		Aquatic Ecology (continued) **(for plants with cooling-tower-based heat dissipation systems)**	
Entrainment of fish and shellfish in early life stages	4.3.3	1	SMALL. Entrainment of fish has not been found to be a problem at operating nuclear power plants with this type of cooling system and is not expected to be a problem during the license renewal term.
Impingement of fish and shellfish	4.3.3	1	SMALL. The impingement has not been found to be a problem at operating nuclear power plants with this type of cooling system and is not expected to be a problem during the license renewal term.
Heat shock	4.3.3	1	SMALL. Heat shock has not been found to be a problem at operating nuclear power plants with this type of cooling system and is not expected to be a problem during the license renewal term.
		Groundwater Use and Quality	
Impacts of refurbishment on groundwater use and quality	3.4.2	1	SMALL. Extensive dewatering during the original construction on some sites will not be repeated during refurbishment on any sites. Any plant wastes produced during refurbishment will be handled in the same manner as in current operating practices and are not expected to be a problem during the license renewal term.
Groundwater use conflicts (potable and service water; plants that use <100 gpm)	4.8.1.1 4.8.1.2	1	SMALL. Plants using less than 100 gpm are not expected to cause any groundwater use conflicts.
Groundwater use conflicts (potable and service water, and dewatering; plants that use > 100 gpm)	4.8.1.1 4.8.1.2	2	SMALL, MODERATE, OR LARGE. Plants that use more than 100 gpm may cause groundwater use conflicts with nearby groundwater users.

Footnotes at end of table

Table 9.1 Continued

Issue	Sections	Category[a]	Findings[b]
Groundwater use conflicts (plants using cooling towers withdrawing make-up water from a small river)	4.8.1.3	2	SMALL, MODERATE, OR LARGE. Water use conflicts may result from surface water withdrawals from small water bodies during low flow conditions which may affect aquifer recharge, especially if other groundwater or upstream surface water users come on line before the time of license renewal.
Groundwater use conflicts (Ranney wells)	4.8.1.4	2	SMALL, MODERATE, OR LARGE. Ranney wells can result in potential groundwater depression beyond the site boundary. Impacts of large groundwater withdrawal for cooling tower makeup at nuclear power plants using Ranney wells must be evaluated at the time of application for license renewal.
Groundwater quality degradation (Ranney wells)	4.8.2.2	1	SMALL. Groundwater quality at river sites may be degraded by induced infiltration of poor-quality river water into an aquifer that supplies large quantities of reactor cooling water. However, the lower quality infiltrating water would not preclude the current uses of groundwater and is not expected to be a problem during the license renewal term.
Groundwater quality degradation (saltwater intrusion)	4.8.2.1	1	SMALL. Nuclear power plants do not contribute significantly to saltwater intrusion.
Groundwater quality degradation (cooling ponds in salt marshes)	4.8.3	1	SMALL. Sites with closed-cycle cooling ponds may degrade groundwater quality. Because water in salt marshes is brackish, this is not a concern for plants located in salt marshes.
Groundwater quality degradation (cooling ponds at inland sites)	4.8.3	2	SMALL, MODERATE, OR LARGE. Sites with closed-cycle cooling ponds may degrade groundwater quality. For plants located inland, the quality of the groundwater in the vicinity of the ponds must be shown to be adequate to allow continuation of current uses.

Footnotes at end of table

Table 9.1 Continued

Issue	Sections	Category[a]	Findings[b]
Terrestrial Resources			
Refurbishment impacts	3.6	2	SMALL, MODERATE, OR LARGE. Refurbishment impacts are insignificant if no loss of important plant and animal habitat occurs. However, it cannot be known whether important plant and animal communities may be affected until the specific proposal is presented with the license renewal application.
Cooling tower impacts on crops and ornamental vegetation	4.3.4	1	SMALL. Impacts from salt drift, icing, fogging, or increased humidity associated with cooling tower operation have not been found to be a problem at operating nuclear power plants and are not expected to be a problem during the license renewal term.
Cooling tower impacts on native plants	4.3.5.1	1	SMALL. Impacts from salt drift, icing, fogging, or increased humidity associated with cooling tower operation have not been found to be a problem at operating nuclear power plants and are not expected to be a problem during the license renewal term.
Bird collisions with cooling towers	4.3.5.2	1	SMALL. These collisions have not been found to be a problem at operating nuclear power plants and are not expected to be a problem during the license renewal term.
Cooling pond impacts on terrestrial resources	4.4.4	1	SMALL. Impacts of cooling ponds on terrestrial ecological resources are considered to be of small significance at all sites.
Power line right-of-way management (cutting and herbicide application)	4.5.6.1	1	SMALL. The impacts of right-of-way maintenance on wildlife are expected to be of small significance at all sites.
Bird collision with power lines	4.5.6.2	1	SMALL. Impacts are expected to be of small significance at all sites.
Impacts of electromagnetic fields on flora and fauna (plants, agricultural crops, honeybees, wildlife, livestock)	4.5.6.3	1	SMALL. No significant impacts of electromagnetic fields on terrestrial flora and fauna have been identified. Such effects are not expected to be a problem during the license renewal term.

Footnotes at end of table

Table 9.1 Continued

Issue	Sections	Category[a]	Findings[b]
Floodplains and wetland on power line right of way	4.5.7	1	SMALL. Periodic vegetation control is necessary in forested wetlands underneath power lines and can be achieved with minimal damage to the wetland. No significant impact is expected at any nuclear power plant during the license renewal term.
Threatened or Endangered Species (for all plants)			
Threatened or endangered species	3.9 4.1	2	SMALL, MODERATE, OR LARGE. Generally, plant refurbishment and continued operation are not expected to adversely affect threatened or endangered species. However, consultation with appropriate agencies would be needed at the time of license renewal to determine whether threatened or endangered species are present and whether they would be adversely affected.
Air Quality			
Air quality during refurbishment (non-attainment and maintenance areas)	3.3	2	SMALL, MODERATE, OR LARGE. Air quality impacts from plant refurbishment associated with license renewal are expected to be small. However, vehicle exhaust emissions could be cause for concern at locations in or near nonattainment or maintenance areas. The significance of the potential impact cannot be determined without considering the compliance status of each site and the numbers of workers expected to be employed during the outage.
Air quality effects of transmission lines	4.5.2	1	SMALL. Production of ozone and oxides of nitrogen is insignificant and does not contribute measurably to ambient levels of these gases.
Land Use			
On-site land use	3.2	1	SMALL. Projected on-site land use changes would require a small fraction of any nuclear power plant site and would involve land that is controlled by the applicant.
Power line right-of-ways	4.5.3	1	SMALL. Ongoing uses of power line right-of-ways would continue with no change in restrictions. The effects of these restrictions are of small significance.

Footnotes at end of table

Table 9.1 Continued

Issue	Sections	Category[a]	Findings[b]
		Human Health	
Radiation exposures to the public during refurbishment	3.8.1	1	SMALL. During refurbishment, the gaseous effluents would result in doses that are similar to those from current operation. Applicable regulatory dose limits to the public are not expected to be exceeded.
Occupational radiation exposures during refurbishment	3.8.2	1	SMALL. Occupational doses from refurbishment are expected to be within the range of annual average collective doses experienced for pressurized-water reactors and boiling-water reactors. Occupational mortality risks from all causes including radiation is in the mid-range for industrial settings.
Microbiological organisms (occupational health)	4.3.6	1	SMALL. Occupational health impacts are expected to be controlled by continued application of accepted industrial hygiene practices to minimize worker exposures.
Microbiological organisms (public health) (plants using lakes or canals, or cooling towers or cooling ponds that discharge to a small river)	4.3.6	2	SMALL, MODERATE, OR LARGE. These organisms are not expected to be a problem at most operating plants except possibly at plants using cooling ponds, lakes, or canals that discharge to small rivers. Without site-specific data, it is not possible to predict the effects generically.
Noise	4.3.7	1	SMALL. Noise has not been found to be a problem at operating plants and is not expected to be a problem at any plant during the license renewal term.
Electromagnetic fields, acute effects (electric shock)	4.5.4.1	2	SMALL, MODERATE, OR LARGE. Electrical shock resulting from direct access to energized conductors or from induced charges in metallic structures have not been found to be a problem at most operating plants and are not expected to be a problem during the license renewal term. However, without review of each nuclear plant's transmission line conformance with National Electric Safety Code criteria, it is not possible to determine the significance of the electric shock potential.

Footnotes at end of table

Table 9.1 Continued

Issue	Sections	Category[a]	Findings[b]
Electromagnetic fields, chronic effects	4.5.4.2	NA[c]	UNCERTAIN. Biological and physical studies of 60-Hz electromagnetic fields have not found consistent evidence linking harmful effects with field exposures. However, because the state of the science is currently inadequate, no generic conclusion on human health impacts is possible.[c]
Radiation exposures to public (license renewal term)	4.6.2	1	SMALL. Radiation doses to the public will continue at current levels associated with normal operations.
Occupational radiation exposures (license renewal term)	4.6.3	1	SMALL. Projected maximum occupational doses during the license renewal term are within the range of doses recently experienced during normal operations and normal maintenance outages, and would be well below regulatory limits.
		Socioeconomics	
Housing impacts	3.7.2 4.7.1	2	SMALL, MODERATE, OR LARGE. Housing impacts are expected to be of small significance at plants located in a medium or high population area and not in an area where growth control measures that limit housing development are in effect. Moderate or large housing impacts of the work force associated with refurbishment may be associated with plants located in sparsely populated areas or in areas with growth control measures that limit housing development.
Public services: public safety, social services, and tourism and recreation	3.7.4 3.7.4.3 3.7.4.4 3.7.4.6 4.7.3 4.7.3.3 4.7.3.4 4.7.3.6	1	SMALL. Impacts to public safety, social services, and tourism and recreation are expected to be of small significance at all sites.

Footnotes at end of table

Table 9.1 Continued

Issue	Sections	Category[a]	Findings[b]
Public services: public utilities	3.7.4.5 4.7.3.5	2	SMALL OR MODERATE. An increased problem with water shortages at some sites may lead to impacts of moderate significance on public water supply availability.
Public services, education (refurbishment)	3.7.4.1	2	SMALL, MODERATE, OR LARGE. Most sites would experience impacts of small significance but larger impacts are possible depending on site- and project-specific factors.
Public services, education (license renewal term)	4.7.3.1	1	SMALL. Only impacts of small significance are expected.
Offsite land use (refurbishment)	3.7.5	2	SMALL OR MODERATE. Impacts may be of moderate significance at plants in low population areas.
Offsite land use (license renewal term)	4.7.4	2	SMALL, MODERATE, OR LARGE. Significant changes in land use may be associated with population and tax revenue changes resulting from license renewal.
Public services, transportation	3.7.4.2 4.7.3.2	2	SMALL, MODERATE, OR LARGE. Transportation impacts are generally expected to be of small significance. However, the increase in traffic associated with the additional workers and the local road and traffic control conditions may lead to impacts of moderate or large significance at some sites.
Historic and archaeological resources	3.7.7 4.7.7	2	SMALL, MODERATE, OR LARGE. Generally, plant refurbishment and continued operation are expected to have no more than small adverse impacts on historic and archaeological resources. However, the National Historic Preservation Act requires the Federal agency to consult with the State Historic Preservation Officer to determine whether there are properties present that require protection.

Footnotes at end of table

Table 9.1 Continued

Issue	Sections	Category[a]	Findings[b]
Aesthetic impacts (refurbishment)	3.7.8	1	SMALL. No significant impacts are expected during refurbishment.
Aesthetic impacts (license renewal term)	4.7.6	1	SMALL. No significant impacts are expected during the license renewal term.
Aesthetic impacts of transmission lines (license renewal term)	4.5.8	1	SMALL. No significant impacts are expected during the license renewal term.
Postulated Accidents			
Design basis accidents	5.3.2 5.5.1	1	SMALL. The NRC staff has concluded that the environmental impacts of design basis accidents are of small significance for all plants.
Severe accidents	5.3.3 5.3.3.2 5.3.3.3 5.3.3.4 5.3.3.5 5.4 5.5.2	2	SMALL. The probability weighted consequences of atmospheric releases, fallout onto open bodies of water, releases to ground water, and societal and economic impacts from severe accidents are small for all plants. However, alternatives to mitigate severe accidents must be considered for all plants that have not considered such alternatives.
Uranium Fuel Cycle and Waste Management			
Nonradiological waste		1	SMALL. No changes to generating systems are anticipated for license renewal. Facilities and procedures are in place to ensure continued proper handling and disposal at all plants.

Footnotes at end of table

Table 9.1 Continued

Issue	Sections	Category[a]	Findings[b]
Low-level waste storage and disposal		1	SMALL. The comprehensive regulatory controls that are in place and the low public doses being achieved at reactors ensure that the radiological impacts to the environment will remain small during the term of a renewed license. The maximum additional on-site land that may be required for low-level waste storage during the term of a renewed license and associated impacts will be small. Nonradiological impacts on air and water will be negligible. The radiological and nonradiological environmental impacts of long-term disposal of low-level waste from any individual plant at licensed sites are small. In addition, the Commission concludes that there is reasonable assurance that sufficient low-level waste disposal capacity will be made available when needed for facilities to be decommissioned consistent with NRC decommissioning requirements.
Mixed waste storage and disposal		1	SMALL. The comprehensive regulatory controls and the facilities and procedures that are in place ensure proper handling and storage, as well as negligible doses and exposure to toxic materials for the public and the environment at all plants. License renewal will not increase the small, continuing risk to human health and the environment posed by mixed waste at all plants. The radiological and nonradiological environmental impacts of long-term disposal of mixed waste from any individual plant at licensed sites are small. In addition, the Commission concludes that there is reasonable assurance that sufficient mixed waste disposal capacity will be made available when needed for facilities to be decommissioned consistent with NRC decommissioning requirements.
On-site spent fuel		1	SMALL. The expected increase in the volume of spent fuel from an additional 20 years of operation can be safely accommodated on site with small environmental effects through dry or pool storage at all plants if a permanent repository or monitored retrievable storage is not available.

Footnotes at end of table

Table 9.1 Continued

Issue	Sections	Category[a]	Findings[b]
Transportation		2	Table S-4 of 10 CFR 51 contains an assessment of impact parameters to be used in evaluating transportation effects in each case.
		Decommissioning	
Radiation doses	7.3.1 7.4	1	SMALL. Doses to the public will be well below applicable regulatory standards regardless of which decommissioning method is used. Occupational doses would increase no more than 1 man-rem caused by buildup of long-lived radionuclides during the license renewal term.
Waste management	7.3.2 7.4	1	SMALL. Decommissioning at the end of a 20-year license renewal period would generate no more solid wastes than at the end of the current license term. No increase in the quantities of Class C or greater than Class C wastes would be expected.
Air quality	7.3.3 7.4	1	SMALL. Air quality impacts of decommissioning are expected to be negligible either at the end of the current operating term or at the end of the license renewal term.
Water quality	7.3.4 7.4	1	SMALL. The potential for significant water quality impacts from erosion or spills is no greater whether decommissioning occurs after a 20-year license renewal period or after the original 40-year operation period, and measures are readily available to avoid such impacts.
Ecological resources	7.3.5 7.4		SMALL. Decommissioning after either the initial operating period or after a 20-year license renewal period is not expected to have any direct ecological impacts.
Socioeconomic impacts	7.3.7 7.4	1	SMALL. Decommissioning would have some short-term socioeconomic impacts. The impacts would not be increased by delaying decommissioning until the end of a 20-year relicense period, but they might be decreased by population and economic growth.

Footnotes at end of table

Table 9.1 Continued

Issue	Sections	Category[a]	Findings[b]
		Environmental Justice	
Environmental justice	NA[d]	NA[d]	NONE. The need for and content of an analysis of environmental justice will be addressed in plant-specific reviews.

[a]The numerical entries in this column are based on the following category definitions:
Category 1: For the issue, the analysis reported in the Generic Environmental Impact Statement has shown:

(1) The environmental impacts associated with the issue have been determined to apply either to all plants or, for some issues, to plants having a specific type of cooling system or other specified plant or site characteristics;

(2) A single significance level (i.e., small, moderate, or large) has been assigned to the impacts (except for collective off-site radiological impacts from the fuel cycle and from high-level waste and spent-fuel disposal); and

(3) Mitigation of adverse impacts associated with the issue has been considered in the analysis and it has been determined that additional plant-specific mitigation measures are likely not to be sufficiently beneficial to warrant implementation.

The generic analysis of the issue may be adopted in each plant-specific review.

Category 2: For the issue, the analysis reported in the Generic Environmental Impact Statement has shown that one or more of the criteria of Category 1 can not be met, and therefore additional plant-specific review is required.

[b]The impact findings in this column are based on the definitions of three significant levels. Unless the significance level is identified as beneficial, the impact is adverse, or in the case of "small," may be negligible. The definitions of significance follow:

SMALL—For the issue, environmental effects are not detectable or are so minor that they will neither destabilize nor noticeably alter any important attribute of the resource. For the purposes of assessing radiological impacts, the Commission has concluded that those impacts that do not exceed permissible levels in the Commission's regulations are considered small as the term is used in this table.
MODERATE—For the issue, environmental effects are sufficient to alter noticeably, but not to destabilize, important attributes of the resource.
LARGE—For the issue, environmental effects are clearly noticeable and are sufficient to destabilize important attributes of the resource.

For issues where probability is a key consideration (i.e. accident consequences), probability was a factor in determining significance.

[c]NA (not applicable). Scientific evidence on the chronic biological effects on humans from exposure to transmission line electric and magnetic fields is inconclusive. If the Commission finds that a consensus has been reached by appropriate Federal health agencies that there are adverse health effects, the Commission will require applicants to submit plant-specific reviews of these health effects.

[d]NA (not applicable). Environmental justice is not addressed in the GEIS because Executive Order 12898 issued on February 11, 1994, and implementation guidance were not available prior to completion of this report.

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THE GENERIC ENVIRONMENTAL IMPACT STATEMENT (GEIS) EXAMINES THE POSSIBLE ENVIRONMENTAL IMPACTS THAT COULD OCCUR AS A RESULT OF RENEWING LICENSES OF INDIVIDUAL NUCLEAR POWER PLANTS UNDER 10 CFR PART 54. THE GEIS, TO THE EXTENT POSSIBLE, ESTABLISHES THE BOUNDS AND SIGNIFICANCE OF THESE POTENTIAL IMPACTS. THE ANALYSES IN THE GEIS ENCOMPASS ALL OPERATING LIGHT-WATER POWER REACTORS. FOR EACH TYPE OF ENVIRONMENTAL IMPACT THE GEIS ATTEMPTS TO ESTABLISH GENERIC FINDINGS COVERING AS MANY PLANTS AS POSSIBLE. THIS GEIS HAS THREE PRINCIPAL OBJECTIVES: (1) TO PROVIDE AN UNDERSTANDING OF THE TYPES AND SEVERITY OF ENVIRONMENTAL IMPACTS THAT MAY OCCUR AS A RESULT OF LICENSE RENEWAL OF NUCLEAR POWER PLANTS UNDER 10 CFR PART 54, (2) TO INDENTIFY AND ASSESS THOSE IMPACTS THAT ARE EXPECTED TO BE GENERIC TO LICENSE RENEWAL, AND (3) TO SUPPORT A RULEMAKING (10 CFR PART 51) TO DEFINE THE NUMBER AND SCOPE OF ISSUES THAT NEED TO BE ADDRESSED BY THE APPLICANTS IN PLANT-BY-PLANT LICENSE RENEWAL PROCEEDINGS. TO ACCOMPLISH THESE OBJECTIVES, THE GEIS MAKES MAXIMUM USE OF ENVIRONMENTAL AND SAFETY DOCUMENTATION FROM ORIGINAL LICENSING PROCEEDINGS AND INFORMATION FROM STATE AND FEDERAL REGULATORY AGENCIES, THE NUCLEAR UTILITY INDUSTRY, THE OPEN LITERATURE, AND PROFESSIONAL CONTACTS.

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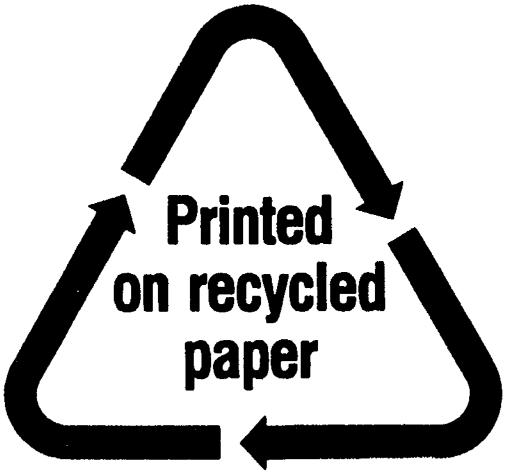
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