EPA-450/3-81-009a

Metallic Mineral Processing Plants — Background Information for Proposed Standards

Volume 1: Chapters 1-9

Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

August 1982

This report has been reviewed by the Emission Standards and Engineering Division of the Office of Air Quality Planning and Standards, EPA, and approved for publication. Mention of trade names or commercial products is not intended to constitute endorsement or recommendation for use. Copies of this report are available through the Library Services Office (MD-35), U. S. Environmental Protection Agency, Research Triangle Park, N. C. 27711, or from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

PUBLICATION NO. EPA-450/3-81-009a

ENVIRONMENTAL PROTECTION AGENCY

Background Information
and Draft
Environmental Impact Statement
for Metallic Mineral
Processing Plants
Prepared by:

______________________________ ____________
(Date)

Don R. Goodwin
Director, Emission Standards and Engineering Division
U. S. Environmental Protection Agency
Research Triangle Park, NC 27711

1. The proposed standards of performance would limit emissions of particulate matter from new, modified, and reconstructed metallic mineral processing plants. Section 111 of the Clean Air Act (42 U.S.C 7411), as amended, directs the Administrator to establish standards of performance for any category of new stationary source of air pollution that ". . . causes or contributes significantly to air pollution which may reasonably be anticipated to endanger public health or welfare."

2. Copies of this document have been sent to the following Federal Departments: Labor, Health and Human Services, Defense, Transportation, Agriculture, Commerce, Interior, and Energy, as well as the National Science Foundation, the Council on Environmental Quality, State and Territorial Air Pollution Program Administrators, the Association of Local Air Pollution Control Officials, EPA Regional Administrators, and other interested parties.

3. The comment period for review of this document is 60 days. Mr. Gene Smith may be contacted regarding the date of the comment period.

4. For additional information contact:

   Mr. Gene Smith
   Standards Development Branch (MD-13)
   U.S. Environmental Protection Agency
   Research Triangle Park, NC 27711
   telephone: (919) 541-5624

5. Copies of this document may be obtained from:

   U. S. EPA Library (MD-35)
   Research Triangle Park, NC 27711

   National Technical Information Service
   5285 Port Royal Road
   Springfield, VA 22161

TABLE OF CONTENTS

Section | Page

Section		Page

LIST OF TABLES

LIST OF FIGURES

Figure No.		Page

1. SUMMARY

Standards of performance for new stationary sources are established under Section 111 of the Clean Air Act (42 U.S.C. 7411), as amended in 1977. Section 111 directs the Administrator of the EPA to establish standards of performance for any category of new stationary source of pollution that "...causes or contributes significantly to, air pollution that may reasonably be anticipated to endanger public health or welfare." These standards of performance apply to "new stationary sources" defined as "any stationary source, the construction, reconstruction, or modification of which is commenced after the publication of regulations (or, if earlier, proposed regulations)" and must reflect the degree of emission reduction achievable through application of the best demonstrated technological system of continuous emission reduction as determined by the Administrator.

This Background Information Document (BID) analyzes the impacts of standards development for the control of particulate emissions from the metallic mineral processing industry. Covered by this BID are operations that process ores of the following metals:

Aluminum	Silver
Copper	Titanium
Gold	Tungsten
Iron	Uranium
Lead	Zinc
Molybdenum	Zirconium

For purposes of analyzing the environmental, economic, and energy impacts, the process equipment at a metallic mineral processing plant has been grouped to form the following process units:

A. Crushing unit (primary, secondary, and tertiary) - which is defined as a crusher and its associated dumping station, grizzly, screens, coarse ore storage bins, and conveyor belt transfer points.

B. Ore storage unit - which is defined as an enclosed ore storage area and associated conveyor belt transfer points if the bins are isolated from the crushing unit.

C. Dryer unit - including the dryer and associated conveyor belt transfer points.

D. Product loadout unit - including all packaging, product bins, conveyor belt transfer points, and loadout mechanisms excluding ship loading facilities.

All new metallic mineral plants will contain some if not all of the process units listed above.

Many new metallic mineral plants are expected to recover byproduct metals or concentrates. Most metallic mineral processes such as crushing of ore, operate irrespective of the recovery of byproducts; however, final processing steps for byproducts or coproducts may involve only these byproducts. All processing units, whether associated with the primary products, byproducts alone, or combinations of these products, should be considered.

1.1 REGULATORY ALTERNATIVES

In developing the regulatory alternatives, worst-case uncontrolled emission characteristics (particulate loading and particle size) were assumed for all process units at all model plants. Measurements at inlets to scrubbers and baghouses tested during this project indicate that many process units will not have these worst-case characteristics; however, to ensure that the recommended standard can be met in all cases, the worst-case particulate loading and particle size assumptions have been retained. Furthermore, high-moisture conditions for all process units in each regulatory alternative have been incorporated although such high-moisture cases are expected to be limited to some dryers and a few of the crushers that process ore from underground mines. Again, because it is possible that such conditions could occur, and because we cannot accurately predict the frequency of such conditions in the metallic minerals processing industries, these conditions have been assumed for all models for the purposes of analysis. Therefore, the estimated environmental, economic, and energy impacts are somewhat overstated; however, these overstatements are consistent in their bases for all regulatory alternatives.

The following regulatory alternatives were selected for analysis:

1. Regulatory Alternative 1 requires no additional standards. This alternative assumes the use of low energy (1.5-kPa (6-inch water gauge) pressure drop) wet scrubbers to meet emission levels required by State Implementation Plans (SIP). This alternative would result in no further reduction in emissions at new plants by 1985.

Test data indicate that current controlled emission rates at existing facilities are often significantly less than those required by SIP regulations and these lower emission levels are used as the baseline control level. Fractional efficiency curves for a 6-inch pressure drop dynamic wet scrubber indicate that under worst-case conditions the achievable emission level would be about 0.35 g/dscm (0.15 gr/dscf).

2. Regulatory Alternative 2 assumes the use of a medium energy (3.75-kPa (15-inch water gauge) pressure drop) wet scrubber and would result in an emission reduction of 60 percent over Alternative 1. Performance evaluations using a programmed scrubber model indicate that the 15-inch pressure drop scrubber is capable of reducing the worst-case uncontrolled emissions level to 0.14 g/dscm (0.06 gr/dscf).

3. Regulatory Alternative 3 assumes the use of either a high energy (7.5-kPa (30-inch pressure drop)) wet scrubber or a baghouse and would result in an emission reduction of 87 percent over Alternative 1. Source test data indicate that a baghouse will reduce the worst-case uncontrolled emissions to a controlled level less than 0.05 g/dscm (0.02 gr/dscf).

Because of high moisture conditions, standard baghouses may not be applicable to all emission points. In these cases, insulated and heated baghouses or wet scrubbers may be preferred. Comparative control efficiency evaluations using a programmed scrubber model indicate that a 30-inch pressure drop venturi scrubber would achieve an emission limit of 0.05 g/dscm (0.02 gr/dscf) under worst-case conditions. High moisture conditions are expected only for some dryers and a few of the crushers that crush ore from underground mines.

Emphasis on worst-case conditions and the design of control equipment to handle worst case conditions should not be interpreted as a recommendation or a requirement that certain types of equipment would be necessary to meet a specific emission level under all conditions found in the metallic mineral industries. The selection of control equipment for an actual emissions source requires consideration of the characteristics of only that source. Rather, the discussions of worst-case conditions are based on two premises. First, if an emission level can be demonstrated as achievable under worst-case conditions, then it is achievable under all conditions found in the industry. Second, if the cost of achieving an emission level is based on the cost of control equipment designed to meet that emission limit under worst-case conditions, then the actual cost of control equipment designed to meet the emission level under less than worst-case conditions should be less.

1.2 ENVIRONMENTAL IMPACT AND ENERGY IMPACTS

The beneficial and adverse environmental impacts associated wth the three regulatory alternatives are presented in this section (see Table 1-1). These impacts are outlined in Chapter 7 and are based on an estimated 25 new plants for the industry to be built prior to 1985.

Regulatory Alternative 1 would have no additional impact on the industry or its emissions. This alternative requires no additional control measures other than those now being implemented under the applicable SIP regulations. It is anticipated that if no further standards are promulgated, new plants would continue to apply control techniques upon which Regulatory Alternative 1 is based.

Regulatory Alternative 2 has the potential of reducing annual particulate emissions from the industry to 8,200 Mg (9,000 tons) for 1985. This reduction is accompanied by a negligible water impact because it would cause less than a 1 percent increase in water discharged compared with a metallic mineral processing plant with baseline control levels. Additional energy requirements resulting from Alternative 2 are minor

Table 1-1. ASSESSMENT OF ENVIRONMENTAL, ENERGY, AND ECONOMIC IMPACTS FOR EACH REGULATORY ALTERNATIVE CONSIDERED FOR NEW METALLIC MINERAL PROCESSING PLANTS[a]

Administrative alternative	Air impact	Water impact	Solid waste impact	Energy impact	Noise impact	Economic impact
Regulatory Alternative 1	0	0	0	0	0	0
Regulatory Alternative 2	+2**	-1**	-1	-1**	-1	-2
Regulatory Alternative 3(a)[1]	+3**	0[3]	-1	+1**	-1	-2
Regulatory Alternative 3(b)[2]	+3**	-1**	-1	-2**	-1	-2

[a]KEY:
+ Beneficial impact
- Adverse impact
0 No impact
1 Negligible impact
2 Small impact
3 Moderate impact
4 Large impact
5 Very large impact
* Short term impact
** Long term impact
*** Irreversible impact

[1]Based on the use of a 6-inch pressure drop baghouse.
[2]Based on the use of a 30-inch pressure drop wet scrubber.
[3]Alternative 3(a) is a dry process and as such produces no liquid waste.

and range from a 0.01 percent increase for alumina plants to a 1.6 percent for titanium/zirconium plants.

Regulatory Alternative 3 has the potential of reducing the industry's annual particulate emissions in 1985 by a total of 11,800 mg (13,000 tons) regardless of which control option is adopted. Because a baghouse is a dry collection process, this control option will have no water impact. The water impact from the use of high energy scrubbers to meet this alternative is comparable with the impact from Regulatory Alternative 2 and is insignificant.

The incremental increase in energy use will be the greatest for Regulatory Alternative 3 using a 30-inch pressure drop wet scrubber. This increase ranges from 0.04 percent for aluminum plants to 7 percent for titanium/zirconium plants. These energy impacts are based on a comparison of the energy usage of 30-inch pressure drop scrubbers with the energy consumption of the entire mineral processing operation (including mining and beneficiation operations with the exception of pelletizing and calcining operations) with baseline control. These impacts are worst-case projections from the standpoint of control equipment energy use because it is extremely unlikely that any plants will use only 30-inch pressure drop scrubbers. Rather, it is likely that most installations will include baghouses for unit processes without moisture concerns and wet scrubbers (often with less than 30-inch pressure drop) for unit processes with moisture concerns. The use of baghouses may decrease energy use compared with the requirements of low energy scrubbers. This positive impact results from the use of more efficient fans in a baghouse for a given air flow rate as well as the fact that baghouses do not need pumps to handle scrubber liquids. Solid-waste impacts under Regulatory Alternative 3 will be comparable with the impacts from Regulatory Alternative 2 and are insignificant in comparison with the tailings from the beneficiation processes.

Because the particulate matter emitted from lead ore processors would be expected to contain various amounts of lead, an additional concern for lead ore processors is the maintenance of the National Ambient Air Quality Standard (NAAQS) for lead in the vicinity of these plants. In the absence of any New Source Performance Standard (NSPS) for metallic mineral plants, new lead ore processing facilities may be required to meet more stringent emission levels than indicated by typical State standards for generic particulate matter. The reduction in particulate matter due to the implementation of an NSPS applicable to lead ore processing plant may be less than indicated in this document because of a higher level of baseline control required to meet the lead NAAQS.

Although not expected under most conditions, it could be possible that, with certain configurations and sitings of new lead ore processing facilities, a facility could meet the requirements of an NSPS for metallic mineral processing plants and yet cause a violation of the NAAQS for lead in the vicinity of this plant. In this case, a lead ore processing plant could be required to apply more effective control systems than would be necessary to meet an NSPS for metallic mineral processing plants.

1.3 ECONOMIC IMPACT

An economic impact assessment is reported in Section 9.2 for Regulatory Alternative 3 using the annualized cost for high energy wet scrubbers. This control option has the potential for the largest economic impact of any of the alternatives or control options being considered. Two parameters are considered by this economic analysis as a means of quantifying the potential impact. These parameters are the percentage increase in the price of the finished product and the percentage increase in capital expenditures that would be attributable to the use of high energy wet scrubbers. The range of price increases for the industry is from <0.1 percent for the product of aluminum plants to 1.7 percent for the product of small copper plants. The increase for small copper plants is a worst-case impact because the likely recovery of byproduct metals was not included in the profitability of these operations. The installation of control equipment to meet the emission levels of Regulatory Alternative 3 will cause an increase in the capital requirements for new plants ranging from less than 0.1 percent for alumina (bauxite) plants to 1 percent for a small (23 megagram (25 ton) per hour) tungsten plant. Thus, none of the metallic mineral processing operations covered by this BID will experience a significant economic impact.

Because of the NAAQS for lead, lead ore processing plants may be required to apply more effective (and, presumably, more expensive) control systems than would be required by the State Implementation Plans (SIP's) for attaining the NAAQS for generic particulate matter. Thus, the actual incremental costs (that is the costs above baseline control) incurred by lead ore processing plants in meeting an NSPS for metallic mineral processing plants could be less than those presented in this document.

2. INTRODUCTION

2.1 BACKGROUND AND AUTHORITY FOR STANDARDS

Before standards of performance are proposed as a Federal regulation, air pollution control methods available to the affected industry and the associated costs of installing and maintaining the control equipment are examined in detail. Various levels of control based on different technologies and degrees of efficiency are expressed as regulatory alternatives. Each of these alternatives is studied by EPA as a prospective basis for a standard. The alternatives are investigated in terms of their impacts on the economics and well-being of the industry, the impacts on the national economy, and the impacts on the environment. This document summarizes the information obtained through these studies so that interested persons will be able to see the information considered by EPA in the development of the proposed standard.

Standards of performance for new stationary sources are established under Section 111 of the Clean Air Act (42 U.S.C. 7411) as amended, hereinafter referred to as the Act. Section 111 directs the Administrator to establish standards of performance for any category of new stationary source of air pollution which "causes, or contributes significantly to, air pollution which may reasonably be anticipated to endanger the public health or welfare."

The Act requires that standards of performance for stationary sources reflect "the degree of emission reduction achievable which (taking into consideration the cost of achieving such emission reduction, and any nonair quality health and environmental impact and energy requirements) the Administrator determines has been adequately demonstrated for that category of sources." The standards apply only to stationary sources whose construction or modification commences after regulations are proposed by publication in the Federal Register.

The 1977 amendments to the Act altered or added numerous provisions that apply to the process of establishing standards of performance.

1. EPA is required to list the categories of major stationary sources that have not already been listed and regulated under standards of performance. Regulations must be promulgated for these new categories on the following schedule:

a. 25 percent of the listed categories by August 7, 1980.

b. 75 percent of the listed categories by August 7, 1981.

c. 100 percent of the listed categories by August 7, 1982.

A governor of a State may apply to the Administrator to add a category not on the list or may apply to the Administrator to have a standard of performance revised.

2. EPA is required to review the standards of performance every 4 years and, if appropriate, revise them.

3. EPA is authorized to promulgate a standard based on design, equipment, work practice, or operational procedures when a standard based on emission levels is not feasible.

4. The term "standards of performance" is redefined, and a new term "technological system of continuous emission reduction" is defined. The new definitions clarify that the control system must be continuous and may include a low-polluting or nonpolluting process or operation.

5. The time between the proposal and promulgation of a standard under Section 111 of the Act may be extended to 6 months.

Standards of performance, by themselves, do not guarantee protection of health or welfare because they are not designed to achieve any specific air quality levels. Rather, they are designed to reflect the degree of emission limitation achievable through application of the best adequately demonstrated technological system of continuous emission reduction, taking into consideration the cost of achieving such emission reduction, any nonair-quality health and environmental impacts, and energy requirements.

Congress had several reasons for including these requirements. First, standards with a degree of uniformity are needed to avoid situations in which some States may attract industries by relaxing standards relative to other States. Second, stringent standards enhance the potential for long-term growth. Third, stringent standards may help achieve long-term cost savings by avoiding the need for more expensive retrofitting if pollution ceilings are reduced in the future. Fourth, certain types of standards for coal-burning sources can adversely affect the coal market by driving up the price of low-sulfur coal or effectively excluding certain coals from the reserve base because their untreated pollution potentials are high. Congress does not intend that new source performance standards contribute to these problems. Fifth, the standard-setting process should create incentives for improved technology.

Promulgation of standards of performance does not prevent State or local agencies from adopting more stringent emission limitations for the same sources. States are free under Section 116 of the Act to establish even more stringent emission limits than those established under Section 111 or those necessary to attain or maintain the National Ambient Air Quality Standards (NAAQS) under Section 110. Thus, new sources may in some cases be subject to limitations more stringent than standards of performance under Section 111, and prospective owners and operators of new sources should be aware of this possibility in planning for such facilities.

A similar situation may arise when a major emitting facility is to be constructed in a geographic area that falls under the provisions for prevention of significant deterioration of air quality in Part C of the Act. These provisions require, among other things, that major emitting facilities to be constructed in such areas be subject to best available control technology. The term "best available control technology" (BACT), as defined in the Act, means:

> an emission limitation based on the maximum degree of reduction of each pollutant subject to regulation under this Act emitted from, or which results from, any major emitting facility, which the permitting authority, on a case-by-case basis, taking into account energy, environmental, and economic impacts and other costs, determines is achievable for such facility through application of production processes and available methods, systems, and techniques, including fuel cleaning or treatment or innovative fuel combustion techniques

for control of each such pollutant. In no event shall application of "best available control technology" result in emissions of any pollutants which will exceed the emissions allowed by any applicable standard established pursuant to Sections 111 or 112 of this Act. (Section 169(3).

Although standards of performance are normally structured in terms of numerical emission limits where feasible, alternative approaches are sometimes necessary. In some cases, physical measurement of emissions from a new source may be impractical or exorbitantly expensive. Section 111(h) provides that the Administrator may promulgate a design or equipment standard in those cases in which it is not feasible to prescribe or enforce a standard of performance. For example, emissions of hydrocarbons from storage vessels for petroleum liquids are greatest during tank filling. The nature of the emissions (high concentrations for short periods during filling and low concentrations for longer periods during storage) and the configuration of storage tanks make direct emission measurement impractical. Therefore, a more practical approach to standards of performance for storage vessels has been equipment specification.

In addition, Section 111(j) authorizes the Administrator to grant waivers of compliance to permit a source to use innovative continuous emission control technology. To grant the waiver, the Administrator must find (1) a substantial likelihood that the technology will produce greater emission reductions than the standards require, or an equivalent reduction at lower economic, energy, or environmental cost, (2) the proposed system has not been adequately demonstrated, (3) the technology will not cause or contribute to an unreasonable risk to the public health, welfare, or safety, (4) the governor of the State where the source is located consents, and (5) the waiver will not prevent the attainment or maintenance of any ambient standard. A waiver may have conditions attached to ensure that the source will not prevent attainment of any NAAQS. Any such condition will have the force of a performance standard. Finally, waivers have definite end dates and may be terminated earlier if the conditions are not met or if the system fails to perform as expected. In such a case, the source may be given up to 3 years to meet the standards with a mandatory progress schedule.

2.2 SELECTION OF CATEGORIES OF STATIONARY SOURCES

Section 111 of the Act directs the Adminstrator to list categories of stationary sources. The Administrator "shall include a category of sources in such list if in his judgment it causes, or contributes significantly to, air pollution which may reasonably be anticipated to endanger public health or welfare." Proposal and promulgation of standards of performance are to follow.

Since passage of the Clean Air Amendments of 1970, considerable attention has been given to the development of a system for assigning priorities to various source categories. The approach specifies areas of interest by considering the broad strategy of the Agency for implementing the Clean Air Act. Often, these "areas" are actually pollutants emitted by stationary sources. Source categories that emit these pollutants are evaluated and ranked by a process involving such factors as (1) the level of emission control (if any) already required by State regulations, (2) estimated levels of control that might be required from standards of performance for the source category, (3) projections of growth and replacement of existing facilities for the source category, and (4) the estimated incremental amount of air pollution that could be prevented in a preselected future year by standards of performance for the source category. Sources for which new source performance standards were promulgated or were under development during 1977, or earlier, were selected on these criteria.

The Act amendments of August 1977 establish specific criteria to be used in determining priorities for all major source categories not yet listed by EPA. These are (1) the quantity of air pollutant emissions that each such category will emit or will be designed to emit, (2) the extent to which each such pollutant may reasonably be anticipated to endanger public health or welfare, and (3) the mobility and competitive nature of each such category of sources and the consequent need for nationally applicable new source standards of performance.

The Administrator is to promulgate standards for these categories according to the schedule referred to earlier.

In some cases, it may not be feasible to immediately develop a standard for a source category with a high priority. This situation might occur when a program of research is needed to develop control techniques, or because techniques for sampling and measuring emissions may require refinement. In developing standards, differences in the time required to complete the necessary investigation for different source categories must also be considered. For example, substantially more time may be necessary if numerous pollutants must be investigated from a single source category. Furthermore, even late in the development process, the schedule for completion of a standard may change. For example, inability to obtain emission data from well-controlled sources in time to pursue the development process systematically may force a change in scheduling. Nevertheless, priority ranking is, and will continue to be, used to establish the order in which projects are initiated and resources assigned.

After the source category has been chosen, the types of facilities within the source category to which the standard will apply must be determined. A source category may have several facilities that cause air pollution; emissions from these facilities may vary from insignificant to very expensive to control. Economic studies of the source category and of applicable control technology may show that air pollution control is better served by applying standards to the more severe pollution sources. For this reason, and because there is no adequately demonstrated system for controlling emissions from certain facilities, standards often do not apply to all facilities at a source. For the same reasons, the standards may not apply to all air pollutants emitted. Thus, although a source category may be selected to be covered by a standard of performance, all pollutants or facilities within that source category might not be covered by the standards.

2.3 PROCEDURE FOR DEVELOPMENT OF STANDARDS OF PERFORMANCE

Standards of performance must (1) realistically reflect best demonstrated control practice, (2) adequately consider the cost, the nonair-quality health and environmental impacts, and the energy requirements of such control, (3) be applicable to existing sources that are modified or reconstructed as well as to new installations, and (4) meet these conditions for all variations of operating conditions being considered anywhere in the country.

The objective of a program for developing standards is to identify the best technological system of continuous emission reduction that has been adequately demonstrated. The standard-setting process involves three principal phases of activity: (1) information gathering, (2) analysis of the information, and (3) development of the standard of performance.

During the information-gathering phase, industries are queried through a telephone survey, letters of inquiry, and plant visits by EPA representatives. Information is also gathered from many other sources, and a literature search is conducted. From the knowledge acquired about the industry, EPA selects certain plants at which emission tests are conducted to provide reliable data that characterize the pollutant emissions from well-controlled existing facilities.

In the second phase of a project, the information about the industry and the pollutants emitted is used in analytical studies. Hypothetical "model plants" are defined to provide a common basis for analysis. The model plant definitions, national pollutant emission data, and existing State regulations governing emissions from the source category are then used in establishing "regulatory alternatives." These regulatory alternatives are essentially different levels of emission control.

EPA conducts studies to determine the impact of each regulatory alternative on the economics of the industry and on the national economy, on the environment, and on energy consumption. From several possibly applicable alternatives, EPA selects the single most plausible regulatory alternative as the basis for a standard of performance for the source category under study.

In the third phase of a project, the selected regulatory alternative is translated into a standard of performance, which, in turn, is written in the form of a Federal regulation. The Federal regulation, when applied to newly constructed plants, will limit emissions to the levels indicated in the selected regulatory alternative.

As early as is practical in each standard-setting project, EPA representatives discuss the possibilities of a standard, and the form it might take with members of the National Air Pollution Control Techniques Advisory Committee. Industry representatives and other interested parties also participate in these meetings.

The information acquired in the project is summarized in the background information document (BID). The BID, the standard, and a preamble explaining the standard are widely circulated to the industry being considered for control, environmental groups, other government agencies, and offices within EPA. Through this extensive review process, the viewpoints of expert reviewers are considered as changes are made to the documentation.

A "proposal package" is assembled and sent through the offices of EPA Assistant Administrators for concurrence before the proposed standard is officially endorsed by the EPA Administrator. After being approved by the EPA Administrator, the preamble and the proposed regulation are published in the Federal Register.

As a part of the Federal Register announcement of the proposed regulation, the public is invited to participate in the standard-setting process. EPA invites written comments on the proposal and also holds a public hearing to discuss the proposed standard with interested parties. All public comments are summarized and incorporated into a second volume of the BID. All information reviewed and generated in studies in support of the standard of performance is available to the public in a "docket" on file in Washington, D.C.

Comments from the public are evaluated, and the standards of performance may be altered in response to the comments.

The significant comments and EPA's position on the issues raised are included in the "preamble" of a promulgation package, which also contains the draft of the final regulation. The regulation is then subjected to another round of review and refinement until it is approved by the EPA Administrator. After the Administrator signs the regulation, it is published as a "final rule" in the Federal Register.

2.4 CONSIDERATION OF COSTS

Section 317 of the Act requires an economic impact assessment with respect to any standard of performance established under Section 111 of the Act. The assessment is required to contain an analysis of (1) the costs of compliance with the regulation, including the extent to which the cost of compliance varies depending on the effective date of the regulation and the development of less expensive or more efficient methods of compliance, (2) the potential inflationary or recessionary effects of the regulation, (3) the effects the regulation might have on small business with respect to competition, (4) the effects of the regulation on consumer costs, and (5) the effects of the regulation on energy use. Section 317 also requires that the economic impact assessment be as extensive as practicable.

The economic impact of a proposed standard upon an industry is usually addressed both in absolute terms and in terms of the control costs that would be incurred as a result of compliance with typical, existing State control regulations. An incremental approach is necessary because both new and existing plants would be required to comply with State regulations in the absence of a Federal standard of performance. This approach requires a detailed analysis of the economic impact from the cost differential that would exist between a proposed standard of performance and the typical State standard.

Air pollutant emissions may cause water pollution problems, and captured potential air pollutants may pose a solid waste disposal problem. The total environmental impact of an emission source must, therefore, be analyzed and the costs determined whenever possible.

A thorough study of the profitability and price-setting mechanisms of the industry is essential to the analysis so that an accurate estimate of potentially adverse economic impacts can be made for proposed standards. It is also essential to know the capital requirements for pollution control systems already placed on plants so that the additional capital requirements necessitated by these Federal standards can be placed in proper perspective. Finally, it is necessary to assess the availability of capital to provide the additional control equipment needed to meet the standards of performance.

2.5 CONSIDERATION OF ENVIRONMENTAL IMPACTS

Section 102(2)(C) of the National Environmental Policy Act (NEPA) of 1969 requires Federal agencies to prepare detailed environmental impact statements on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment. The objective of NEPA is to build into the decisionmaking process of Federal agencies a careful consideration of all environmental aspects of proposed actions.

In a number of legal challenges to standards of performance for various industries, the United States Court of Appeals for the District of Columbia Circuit has held that environmental impact statements need not be prepared by the Agency for proposed actions under Section 111 of the Clean Air Act. Essentially, the Court of Appeals has determined that the best system of emission reduction requires the Administrator to take into account counter-productive environmental effects of a proposed standard, as well as economic costs to the industry. On this basis, therefore, the Court established a narrow exemption from NEPA for EPA determination under Section 111.

In addition to these judicial determinations, the Energy Supply and Environmental Coordination Act (ESECA) of 1974 (PL-93-319) specifically exempted proposed actions under the Clean Air Act from NEPA requirements. According to Section 7(c)(1), "no action taken under the Clean Air Act shall be deemed a major Federal action significantly affecting the quality of the human environment within the meaning of the National Environmental Policy Act of 1969." (15 U.S.C. 793(c)(1))

Nevertheless, the Agency has concluded that the preparation of environmental impact statements could have beneficial effects on certain regulatory actions. Consequently, although not legally required to do so by Section 102(2)(C) of NEPA, EPA has adopted a policy requiring that environmental impact statements be prepared for various regulatory actions, including standards of performance developed under Section 111 of the Act. This voluntary preparation of environmental impact statements, however, in no way legally subjects the Agency to NEPA requirements.

To implement this policy, a separate section in this document is devoted solely to an analysis of the potential environmental impacts associated with the proposed standards. Both adverse and beneficial impacts in such areas as air and water pollution, increased solid waste disposal, and increased energy consumption are discussed.

2.6 IMPACT ON EXISTING SOURCES

Section 111 of the Act defines a new source as "any stationary source, the construction or modification of which is commenced" after the proposed standards are published in the Federal Register. An existing source is redefined as a new source if "modified" or "reconstructed" as defined in amendments to the general provisions of Subpart A of 40 CFR Part 60, which were promulgated in the Federal Register on December 16, 1975 (40 FR 58416).

Any physical or operational change to an existing facility which results in an increase in the emission rate of any pollutant for which a standard applies is considered a modification. Reconstruction, on the other hand, means the replacement of components of an existing facility to the extent that the fixed capital cost exceeds 50 percent of the cost of constructing a comparable entirely new source and that it be technically and economically feasible to meet the applicable standards. In such cases, reconstruction is equivalent to a new construction.

Promulgation of a standard of performance requires States to establish standards of performance for existing sources in the same industry under Section 111(d) of the Act if the standard for new sources limits emissions of a designated pollutant (i.e., a pollutant for which air quality criteria have not been issued under Section 108 or which has not been listed as a hazardous pollutant under Section 112). If a State does not act, EPA must establish such standards. General provisions outlining procedures for control of existing sources under Section 111(d) were promulgated on November 17, 1975, as Subpart B of 40 CFR Part 60 (40 FR 53340).

2.7 REVISION OF STANDARDS OF PERFORMANCE

Congress was aware that the level of air pollution control achievable by any industry may improve with technological advances. Accordingly, Section 111 of the Act provides that the Administrator "shall, at least every 4 years, review and, if appropriate, revise" the standards. Revisions are made to ensure that the standards continue to reflect the best systems that become available in the future. Such revisions will not be retroactive but will apply to stationary sources constructed or modified after the proposal of the revised standards.

3. THE METALLIC MINERAL PROCESSING INDUSTRY

3.1 INTRODUCTION

The source category, metallic mineral processing, has been ranked number 14 on the EPA list for standards of performance for the control of air emissions pursuant to Section 111 of the Clean Air Act. Metallic mineral processing typically involves the size reduction of ore and the subsequent separation of the desired mineral or metal from the associated gangue by one of several possible concentration steps. Size reduction operations involve dry and wet crushing and grinding of the ore. Dry crushing is a significant source of particulate emissions and will be discussed extensively in this chapter. Wet grinding processes and wet mineral-separation steps do not generate particulate emissions and will be discussed only briefly. The drying of the products of the concentration process, and the various transfer, storage, and loading operations are sources of particulate emissions and also will be discussed in this chapter.

Several sources of particulate emissions in metallic mineral processing industries will not be covered in this description or elsewhere in this background document. Given the possible hazards associated with radioactive emissions, the emissions from uranium process dryers and from the handling of uranium processing product (yellowcake) will be evaluated by the Office of Radiation Programs and, if appropriate, covered by a National Emission Standard for Hazardous Air Pollutants (NESHAP) for radionuclides. Ship loading and unloading of metallic minerals are not discussed in this document due to the somewhat limited demonstration of technology for controlling emissions from ship holds during these operations for the metallic minerals of concern and the numerous ship/dock configurations.

In addition, new processing facilities that would be expected to utilize shipping operations often require the irregular use of noncompany-owned vessels, and these ships would require substantial retrofitting to incorporate any new control technology. In contrast, control techniques have been widely demonstrated for the dock side conveying and transferring of material prior to entry into the ship hold or after removal from the ship hold. This control technology will be discussed in the section on ore conveyance.

Open source fugitive emissions from blasting operations, haul roads, stockpiles, wastepiles, and tailings ponds are not discussed in this document. Due to the limited demonstrations of the effectiveness of specific control techniques and the variety of local conditions, EPA's Office of Research and Development is currently assessing techniques for the control of open source fugitive emissions. After these studies are evaluated, EPA will consider regulation of these sources. In the interim, open source fugitive emissions are generally regulated by individual States on a site-by-site basis after consideration of the local conditions.

Pyrometallurgical and chemical reaction processes such as concentrate roasting and smelting are not discussed in this document but are covered in other documents (see Environmental Protection Agency 1973, 1974a, 1974b, 1974c, 1974d; Singmaster and Breyer, 1973). Emissions from calcining kilns and pelletizing kilns and furnaces are to be considered in a separate source category.

Ores of the following metals are the primary metallic minerals processed in the United States: aluminum, antimony, beryllium, copper, gold, iron, lead, molybdenum, nickel, silver, titanium, tungsten, uranium, vanadium, zinc, and zirconium. Table 3-1 lists each of these metals, their ore minerals, chemical composition, and type of gangue. As shown in Table 3-1, most metallic ores are composed primarily of nonmetallic constituents. The metals and metallic compounds of economic interest are usually less than 10 percent of the total mined product. The only exceptions to this rule are bauxite (20 to 30 percent aluminum) and iron ore (35+ percent iron). Thus the particulate emissions from most metallic mineral processes are composed primarily of nonmetallic

Table 3-1. METAL ORE CONSTITUENTS[a]

Metal	Major ore mineral(s)	Composition of ore minerals	Type of gangue
Aluminum	Bauxite	Hydrous aluminum oxides	Laterite clay
Antimony	Stibnite Tetrahedrite	Sb_2S_3 $Cu_{12}Sb_4S_{13}$	Vein quartz
Beryllium	Beryl Bertrandite	$Be_3Al_2(SiO_3)_6$ $H_2Be_4SI_2O_9$	Granite pegmatite (highly altered)
Copper	Native copper Chalcopyrite Bornite Chalcocite	Cu $CuFeS_2$ Cu_5FeS_4 Cu_2S	Monzonite porphyry
Gold	Native gold	Au	Vein quartz, amphibolite
Iron	Hematite Magnetite Goethite Limonite Siderite Chamosite	Fe_2O_3 Fe_3O_4 $nFeO \cdot OH$ $Fe_2O_3 \cdot H_2O$ $FeCO_3$ $(Fe_4Al_2)(Si_2Al_2)O_{10}(OH)_8$	Iron silicates and quartz (chert) Sandstone
Lead/Zinc	Galena Cerussite Anglesite Sphalerite Zincite Willemite Franklinite Smithsonite Hemimorphite	PbS $PbCO_3$ $PbSO_4$ ZnS ZnO Zn_2SiO_4 $(Fe,Mn,Zn)(Fe,Mn)_2O_4$ $ZnCO_3$ $Zn_4Si_2O_7(OH)_2 \cdot H_2O$	Carbonates (dolomite, limestone)
Molybdenum	Molybdenite	MoS_2	Monzonite porphyry
Nickel	Garnierite	$H_2(Ni,Mg)SiO_4 \cdot nH_2O$	Laterite clay
Silver	Native silver Argentite Polybasite Proustite Pyragyrite Naumanite Stephanite Tetrahedrite	Ag Ag_2S $Ag_{16}Sb_2S_{11}$ Ag_3AsS_3 Ag_3SbS_3 $(Ag_2,Pb(Se$ Ag_5SbS_4 $(Cu,Fe,Zn,Ag)_{12}(Sb,As)_4S_{13}$	Vein quartz, carbonates

(continued)

Table 3-1. Concluded

Metal	Major ore mineral(s)	Composition of ore minerals	Type of gangue
Titanium/Zirconium (sand type)	Ilmenite	$FeTiO_3$	Residual beach sand
	Zircon	$ZrSiO_4$	
Titanium (hard rock)	Ilmenite	$FeTiO_3$	Granite
Tungsten	Scheelite	$CaWO_4$	Granite
	Ferberite	$FeWO_4$	
	Wolframite	$(Mn,Fe)WO_4$	
	Huebnerite	$MnWO_4$	
Uranium	Uraninite	$U^{+4}O_2 + 2U^{+6}O_3$	Sandstone, shale; also hard-rock volcanics
	Coffinite	$U(SiO_4)_{1-x}(OH)_{4x}$	
	Brannerite	U,Ti,Th,RE oxide	
	Carnotite	$K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$	
	Tyuyamunite	$Ca(UO_2)_2(VO_4)_2 \cdot 7H_2O$	
	Autunite	$Ca(UO_2)_2(PO_4)_2 \cdot 11H_2O$	
	Meta-autunite	$Ca(UO_2)_2(PO_4)_2 \cdot 4H_2O$	
	Torbernite	$Cu(UO_2)_2(PO_4)_2 \cdot 10H_2O$	
	Meta-torbernite	$Cu(UO_2)_2(PO_4)_2 \cdot 4H_2O$	
	Parsonite	$2PbO \div UO_3 \div P_2O_5 \cdot H_2O$	
	Saleeite	$MgO \div 2UO_3 \div P_2O_5 \cdot 8H_2O$	
Vanadium	Carnotite	$K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$	Sandstone, syenite
	Patronite	VS_4	
	Roscoelite	$KV_2(AlSi_3O_{10})(OH)_2$	
	Vanadinite	$Pb_5(VO_4)_3Cl$	
	Decloizite	$Pb_3V_2O_8 \cdot Pb(OH)_2$	
	Tyuyamunite	$Ca(VO_2)_2(VO_4)_2 \cdot 7H_2O$	

[a]Derived from Dana and Ford, 1958, and Bateman, 1950.

constituents. Although there are other metals produced in the United States, they were not included if (1) they are primarily byproducts of the metals in Table 3-1, (2) they are derived from imported concentrates processed outside the country, or (3) they are covered under an existing standard (mercury). Table 3-2 lists these metals and the reasons for their exclusion from the primary list. In addition to metals listed in Table 3-2, the industries processing ores of antimony, beryllium, nickel, and vanadium will not receive full coverage in this document because growth in the primary production of these metals is not expected. Any growth in the domestic processing of these metallic minerals will occur as the byproduction of other metallic minerals (e.g., nickel concentrates produced from copper deposits in Minnesota).

Nineteen states are major producers of one or more processed metal ores, and eleven states are minor ore producers. Processing plants vary from large capacity (> 540 Mg/hr (600 tons/hr)) to small and medium capacity plants (< 540 Mg/hr). The distribution of the 200 existing metallic mineral processing plants varies greatly by size and number from one particular industry to another.

Table 3-3 lists the metallic mineral ores discussed in this document and their processing products. Some of these products may receive additional processing on site as in some highly integrated copper operations. In other cases, these products may be shipped off site for additional processing by the same manufacturer. For example, imported bauxite may be processed into alumina on the Gulf Coast and then shipped to the Pacific Northwest for final reduction to aluminum metal. Some of the products listed in Table 3-3 may be marketed for other uses as a raw material or alloying compound (as with molybdenum disulfide or uranium oxide). Gold, silver, and antimony are typically processed to a highly purified state on site before sale or shipment. Major use categories for the metals under discussion are given in Table 3-4.

3.2 METALLIC MINERAL PROCESSES OR FACILITIES AND THEIR EMISSIONS

The objective of mineral processing is to free the metallic minerals in primary and secondary deposits from mineral(s) of no particular economic value (gangue). In general, the major ore processing steps may include ore unloading, crushing, grinding, screening, concentrating,

Table 3-2. METALS NOT INCLUDED IN THIS DOCUMENT

Metal	Symbol	Reason for exclusion
Arsenic	As	Byproduct of copper ore processing
Bismuth	Bi	Byproduct of lead ore processing
Cadmium	Cd	Byproduct of zinc ore processing
Cesium	Cs	Derived from imported concentrate
Chromium	Cr	Derived from imported concentrate
Cobalt	Co	Byproduct of copper ore processing
Columbium	Cb	Derived from imported concentrate
Gallium	Ga	Byprduct of zinc and aluminum ore processing
Germanium	Ge	Byproduct of zinc ore processing
Hafnium	Hf	Byproduct of zirconium ore processing
Indium	In	Byproduct of zinc ore processing
Lithium	Li	Coproduct of feldspar processing, brines
Magnesium	Mg	Derived from brines
Manganese	Mn	Imported as an alloying compound
Mercury	Hg	Covered by a promulgated NESHAP
Platinum group	Pt	Byproduct of copper ore processing, placer production
Rare earths		Byproduct of titanium/zirconium sand-type ore processing
Rhenium	Re	Byproduct of molybdenum ore processing
Rubidium	Rb	Coproduct of feldspar processing
Scandium	Sc	Derived from imported concentrates
Selenium	Se	Byproduct of copper ore processing
Silicon	Si	Coproduct of silica sand
Strontium	Sr	Derived from imported concentrates
Tantalum	Ta	Derived from imported concentrates
Tellurium	Te	Byproduct of copper ore processing
Thallium	Tl	Byproduct of copper/lead/zinc ore processing
Thorium	Th	Byproduct of titanium/zirconium ore processing
Tin	Sn	Byproduction of molybdenum ore processing
Yttrium	Y	Byproduction of titanium/zirconium and uranium ore processing

Table 3-3. U.S. METALLIC MINERAL ORES AND THEIR PROCESS PRODUCTS

Metals	Symbol	Typical process products
Aluminum	Al	Alumina (aluminum oxide)
Antimony	Sb	Pure metal, sodium antimonate, antimony trioxide
Beryllium	Be	Concentrate (10-12 percent beryllium oxide)
Copper	Cu	Concentrate (25 percent copper sulfide)
Gold	Au	Refined metal often combined with silver
Iron	Fe	Taconite pellets (60 percent iron oxide)
Lead/Zinc	Pb/Zn	Concentrate (90 percent lead and zinc sulfides)
Molybdenum	Mo	Concentrate (95 percent molybdenum sulfide)
Nickel	Ni	Size reduced ore (1.2 percent nickel silicates)
Silver	Ag	Refined metal often combined with gold (dore)
Titanium/Zirconium	Ti/Zr	Sand-type ore: 95 percent ilmenite, zircon concentrates
Tungsten	W	Concentrate (65 percent tungsten oxide)
Uranium	U	Yellow cake (90+ percent uranium oxide, U_3O_8)
Vanadium	V	98+ percent vanadium oxide (V_2O_5)

Table 3-4. MAJOR USES OF METALS[a]

Metal	Metal Uses					
	1	2	3	4	5	6
Aluminum	Building (25%)	Packaging (22%)	Transportation (21%)	Electrical (11%)	Consumer Durables (9%)	Others (12%)
Antimony	Flame retardants (36%)	Transportation including Batteries (26%)	Chemicals (21%)	Ceramics and Glass (8%)	Other (9%)	
Beryllium	Nuclear Reactors and Aerospace Applications (39%)	Electrical (36%)	Electronic Components (15%)	Others (10%)		
Copper	Electrical (34%)	Construction (13%)	Industrial Machinery (13%)	Transportation (11%)	Ordnance (2%)	Others (5%)
Gold	Jewelry and Arts (56%)	Industrial, primarily Electronic (28%)	Dental (15%)	Small Bars, etc., for Investment (1%)		
Iron	Transportation (32%)	Construction (26%)	Machinery (20%)	Cans and Containers (7%)	Oil and Gas Industry (6%)	Others (9%)
Lead	Transportation including Batteries and Gasoline Additives (71%)	Electrical (9%)	Paints (7%)	Ammunition (6%)	Construction (2%)	Others (5%)
Molybdenum	Oil and Gas Industry (30%)	Transportation (29%)	Machinery (26%)	Chemicals (6%)	Others (9%)	
Nickel	Transportation (23%)	Chemicals (15%)	Electrical (13%)	Construction (9%)	Fabricated Metal Products (9%)	Others (31%)
Silver	Photography (34%)	Electrical and Electronic Components (24%)	Sterlingware and Electro-plated ware (14%)	Brazing Alloys and Solders (9%)	Others (19%)	
Titanium	Pigment (98%)	Sponge metal (2%)				
Tungsten	Machinery (74%)	Transportation (11%)	Lighting (7%)	Electrical (4%)	Others (4%)	
Uranium	Fuels (98%)	Non-Nuclear (2%)				
Vanadium	Transportation (29%)	Machinery (29%)	Construction (16%)	Chemicals (6%)	Others (20%)	
Zinc	Construction (40%)	Transportation (27%)	Electrical (12%)	Machinery and Chemicals (11%)	Others (10%)	
Zircon	Foundry Sands (43%)	Refractories (26%)	Alloys (22%)	Ceramics (9%)		

[a] U.S. Bureau of Mines, 1978.

conveying, mineral separation, ore and product storage, product loading, and drying. This section describes individually all processes known to generate uncontrolled particulate emissions other than those operations excluded in Section 3.1.

Although the objective of metallic mineral processing industries may differ from the objective of many nonmetallic processing industries, much of the technology in both sets of industries is virtually identical. Crushing, screening, conveying, storing, and loading operations require the same consideration in both sets of industries. The similarity of these operations was considered in the transfer of emission control technology from the nonmetallic to the metallic mineral processing industries as discussed in Chapter 4.

Because the metallic minerals processing industry is an energy-intensive industry, considerable research has been devoted to minimizing energy use. These concerns are reflected in the design and operation of the processing plants and equipment. For example, wet grinding operations have replaced dry operations in the final milling steps because wet operations use less energy per unit throughput. This shift in technology has an indirect impact in eliminating particle emissions from this operation.

Wet size-reduction operations also are used in many operations in place of more traditional dry secondary and tertiary crushing operations. The energy impacts of this shift in technology have not been evaluated fully, particularly the indirect energy cost due to the significant use of grinding media that are expensive to manufacture. Thus, the future technology used in metallic mineral processing is subject to change. Conceivably, mixed processes will see increased use. In these systems, primary crushing (and perhaps secondary crushing) would be dry operations. Subsequent size-reduction operations would be wet but would not be designed to reduce all the ore to the desired size. The more resistant portions of the ore would be screened out as oversize and subsequently sent to a dry crushing operation.

A conservative approach was taken in the development of this document. It was assumed that most size-reduction operations would be dry as shown in Table 3-5. If the number of dry operations is overestimated, then the cost of controlling emissions (as developed in subsequent chapters) will also be overestimated.

3.2.1 Crushing Operations

Size reduction involves the breaking of large pieces of rock into intermediate sizes (breaking and crushing) or into fine sizes or powders (grinding) to meet either maximum or minimum size specifications. The ability of a particular ore to withstand size reduction depends upon its hardness, crystallographic structure, and the method(s) used in fracturing the ore. Moisture content in the ore is a major factor, especially in pulverizing operations, because increased moisture content has been shown to directly correspond to decreased production rates (Perry, 1963, p. 8-3).

Because the extent of size reduction by a single machine is limited, two or more reduction stages are usually necessary. Crushers are those machines that break relatively large pieces of rock, and grinding mills are machines used for comminuting rock into finer sizes. Primary crushing typically reduces the ore to a maximum size of 10 to 15 cm (4 to 6 in) and secondary crushing further reduces the ore to about 3 cm (1 in) in size. Tertiary crushing reduces the ore to 1 cm (0.5 in).

Rock crushers work by fracturing rock by both compression (rock is squeezed until it fractures) and impaction (instantaneous breaking force). Furthermore, for all crushing processes, attrition (the rubbing of stone on stone or on metal surfaces) also contributes to size reduction. Jaw, gyratory, roll, and impact crushers are the four basic types of crushers used within the industry.

3.2.1.1 Jaw Crushers. Jaw crushers work by using approaching and receding jaws (one movable and one fixed) which use compression forces to break up the ore. Jaw crushers are principally used in primary crushing operations. The size of a jaw crusher can be defined by its feed opening dimensions. These dimensions may range from approximately 8 by 30 cm (3 by 12 in) to 213 by 168 cm (84 by 66 in). Size reductions may range from a ratio of 3:1 to 10:1, depending on the nature of the rock (PEDCo, 1979). Crusher capacities vary depending on the unit and its discharge setting. In general, jaw crushers are run well below their maximum capacity and run intermittantly.

There are three main groups of jaw crushers: (1) the Blake, which has a movable jaw pivoted at the top, giving the greatest movement to the smallest pieces of ore; (2) the Dodge, which has a movable jaw pivoted at the bottom, giving the greatest movement to the largest pieces of ore; and (3) modified combinations of these two methods, which attempt to give near equal movement to all sizes of rock (Perry, 1963). Although there are numerous variations of jaw crushers, they all fall into two main categories: (1) variations in toggle motion and (2) variations in the slope of the crusher jaws.

The most commonly used jaw crusher is the Blake (double-toggle type) (see Figure 3-1). It features an eccentric shaft that drives a Pitman arm (connecting rod) which raises and lowers a pair of toggle plates. The toggle plates activate the opening and closing of the moving jaw that is suspended from a fixed shaft. Typically, the jaw plates are corrugated to assist in gripping the ore. Table 3-6 lists the typical operating parameters for jaw crushers.

3.2.1.2 Gyratory Crushers. In gyratory crushers, material is fed into the top of the crusher and is crushed between a rotating head and a fixed cone. Gyratory crushers have a much greater capacity than jaw crushers with equivalent feed openings. Generally, the crushing rate of a gyratory crusher depends on the amount of product/size material in the feed and not the hardness of the material.

Gyratory crushers can be described in terms of feed opening (A X B in Figure 3-2), cone diameter (D in Figure 3-2), and the range of open side discharge settings (C in Figure 3-2). For a given feed opening and cone diameter, crushing capacity is a direct function of open side discharge setting. In primary crushing operations, crushing occurs in the upper half of the machine and the lower half houses the driving mechanisms as shown in Figure 3-2. Gyratories can typically achieve a size reduction of 6:1 or 7:1 (Richards and Locke, 1940). Gyratory crushers operate continuously (some part of the crusher head is working at all times) and, thus, often are considered to be more advantageous than jaw crushers because uniform transmission of energy is more economical than intermittant transmission.

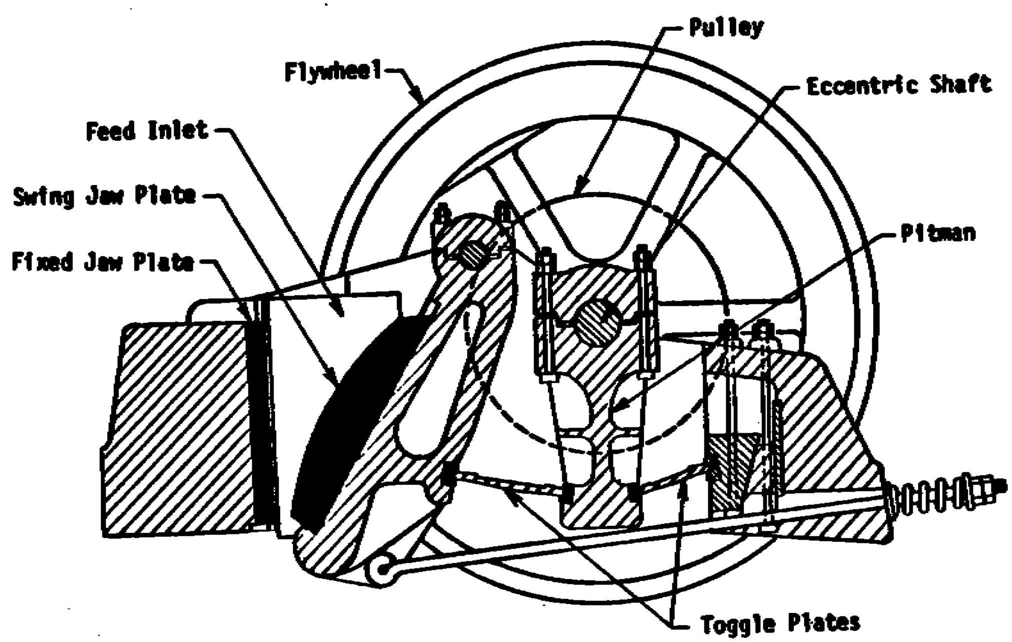


Figure 3-1. Blake jaw crusher (Allis-Chalmers Mfg. Co.).

Table 3-6. OPERATING DATA FOR JAW CRUSHERS[a]

Size		Set range[b]		Capacity range		Energy requirements	
cm	in	cm	in	Mg/hr	tons/hr	kW	hp
8 x 30	3 x 12	1.9 - 3.8	0.75 - 1.5	6 - 14	7 - 15	7	10
15 x 41	6 x 16	1.9 - 5.1	0.75 - 2	9 - 32	10 - 35	11 - 15	15 - 20
30 x 61	12 x 24	2.5 - 7.6	1 - 3	18 - 58	20 - 65	11 - 22	15 - 30
38 x 76	15 x 30	3.2 - 7.6	1.25 - 3	27 - 68	30 - 75	15 - 22	20 - 30
41 x 91	16 x 36	3.8 - 10.2	1.5 - 4	45 - 136	50 - 150	22 - 37	30 - 50
51 x 91	20 x 36	5.1 - 10.2	2 - 4	63 - 136	70 - 150	22 - 37	30 - 50
61 x 91	24 x 36	5.1 - 12.7	2 - 5	63 - 158	70 - 175	22 - 37	30 - 50
43 x 107	17 x 42	5.1 - 10.2	2 - 4	72 - 180	80 - 200	56	75
51 x 107	20 x 42	5.1 - 10.2	2 - 4	72 - 180	80 - 200	56	75
64 x 107	25 x 42	5.1 - 20.3	2 - 8	72 - 270	80 - 300	30 - 45	40 - 60
69 x 107	27 x 42	7.6 - 20.3	3 - 8	90 - 270	100 - 300	30 - 45	40 - 60
76 x 107	32 x 42	8.9 - 20.3	3.5 - 8	136 - 270	150 - 300	45 - 56	60 - 75
41 x 122	16 x 48	5.1 - 15.2	2 - 6	108 - 360	120 - 400	75	100
46 x 122	18 x 48	5.1 - 15.2	2 - 6	108 - 360	200 - 400	75	100
91 x 122	36 x 48	10.2 - 25.4	4 - 10	180 - 540	200 - 600	56 - 93	75 - 125
102 x 122	40 x 48	12.7 - 35.6	5 - 14	225 - 720	250 - 800	56 - 93	75 - 125
107 x 122	42 x 48	10.2 - 30.5	4 - 12	180 - 630	200 - 700	75 - 112	100 - 150
122 x 152	48 x 60	15.2 - 35.6	6 - 14	360 - 900	400 - 1,000	112 - 150	150 - 200

[a]Derived from Universal Engineering Corp., undated, Allis-Chalmers, 1977a, and Process Technology Corp., undated.

[b]Size of opening at jaw closure.

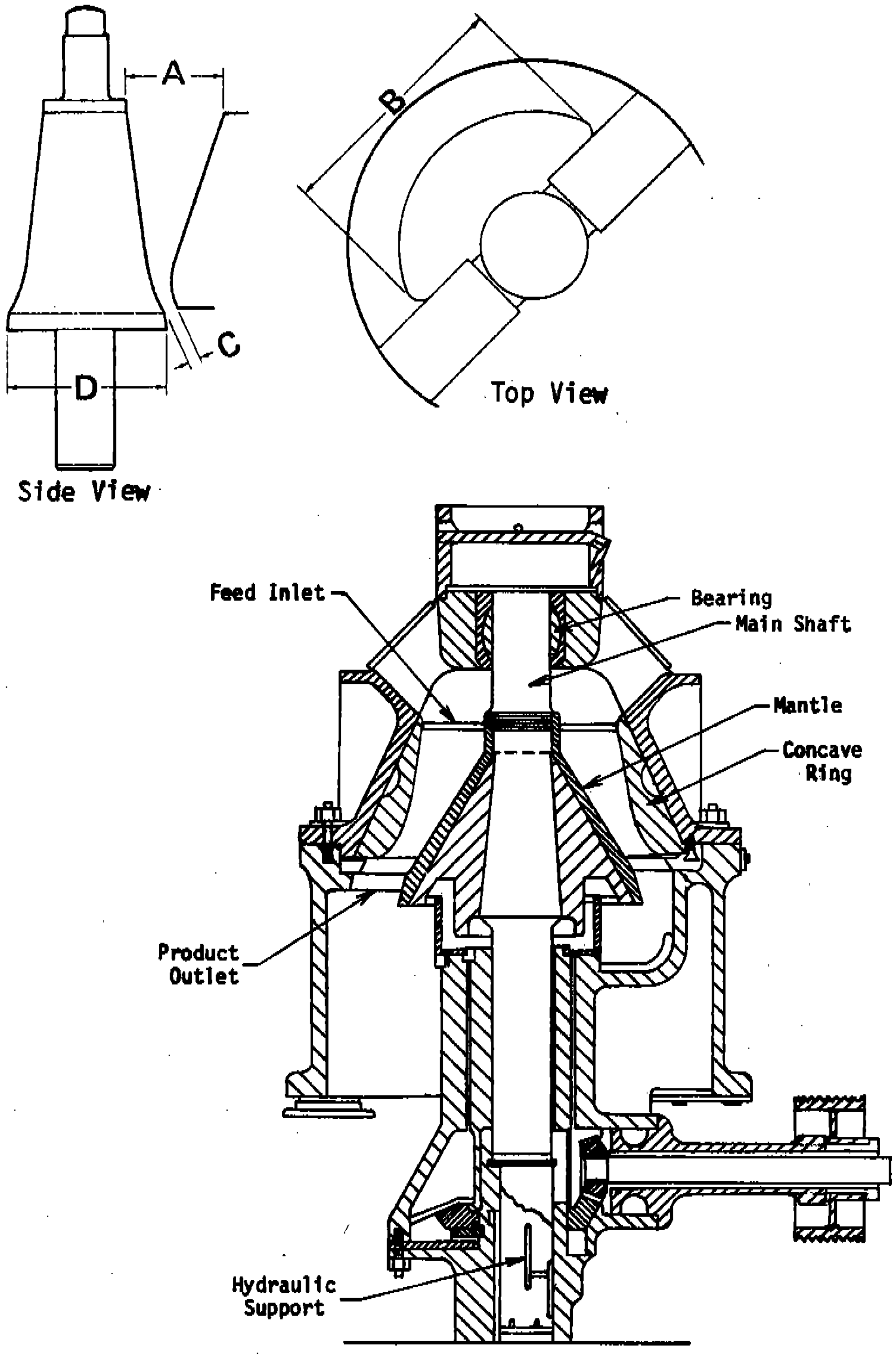


Figure 3-2. Reduction gyratory crusher (Allis-Chalmers Mfg. Co.).

Table 3-7 provides operating data for gyratory crushers. Manufacturers' listed size designation (column 1 in Table 3-7) refers to dimensions A and D on Figure 3-2.

The three basic types of gyratory crushers are: pivoted-spindle, fixed-spindle, and cone. The pivoted- and fixed-spindle crushers are used for primary crushing; secondary and tertiary crushing is accomplished by cone crushers.

The pivoted-spindle crusher uses a crushing head that is mounted on a shaft, suspended from above, that is free to pivot. The bottom of the shaft is seated in an eccentric sleeve that revolves causing the crusher head to gyrate in a circular path within a stationary concave circular chamber. This action is similar to jaw crushing because in both cases the crusher element reciprocates to and from a fixed crushing plate. The crusher setting is determined by the open-side setting at the discharge end. This setting is adjusted by raising or lowering the crusher head.

The fixed-spindle gyratory also has a crushing head mounted on an eccentric sleeve; however, this is fitted over a fixed shaft. The full stroke is exerted on the largest particles as they enter the bowl.

Cone crushers are used primarily for secondary and tertiary crushing operations. Basically, the cone or conical head is gyrated by an eccentric sleeve driven through gears and a countershaft. The conical head gyrates in about the same manner as a primary gyratory crusher, but the cone covers a greater area and gyrates at a faster rate. Ore material receives a series of rapid blows as it passes through the crushing cavity. Cone crushers yield a high percentage of fines due to attrition. The two most common types of cone crushers are the Symons and the Telsmith. In addition to the Symons standard crusher, a Symons short head cone crusher is available for even greater size reductions.

3.2.1.3 Roll Crushers. Roll crushers are generally used in the final fine-crushing stage or stages of ore processing because they are better suited for the production of fine products.

Roll crushers may use either single or double rollers. The roll diameters typically range from 0.6 to 2.0 meters (24 to 78 in) and half narrow face widths about one-half the size of the roll diameter. Rolls may be either smooth, toothed, or corrugated. Rock particles, which are

Table 3-7. OPERATING DATA FOR GYRATORY CRUSHERS[a]

Size designation		Open side discharge setting		Capacity range		Energy requirements		Type of crusher[b]
cm	in	cm	in	Mg/hr	tons/hr	kW	hp	
33 - 91	13 - 36	5.1 - 7.6	2 - 3	180 - 270	200 - 300	93	125	2
41 - 127	16 - 50	5.1 - 8.9	2 - 3.5	315 - 430	350 - 480	112	150	2
61 - 152	24 - 60	6.4 - 11.4	2.5 - 4.5	430 - 660	480 - 730	224	300	2
76 - 140	30 - 55	6.4 - 14.0	2.5 - 5.5	380 - 720	420 - 900	224	300	1
76 - 152	30 - 60	10.2 - 14.0	4 - 5.5	135 - 830	150 - 925	112 - 186	150 - 250	1
91 - 140	36 - 55	10.2 - 14.0	4 - 5.5	540 - 765	600 - 850	224	300	1
76 - 178	30 - 70	6.4 - 14.0	2.5 - 5.5	630 - 1,350	700 - 1,500	298	400	2
107 - 165	42 - 65	11.4 - 17.8	4.5 - 7	790 - 1,485	880 - 1,650	298	400	1
107 - 178	42 - 70	11.4 - 19.0	4.5 - 7.5	390 - 1,530	430 - 1,700	179 - 298	240 - 400	1
107 - 218	42 - 86	12.7 - 19.0	5 - 7.5	600 - 2,320	670 - 2,580	149 - 261	200 - 350	1
122 - 190	48 - 75	14.0 - 20.3	5.5 - 8	1,370 - 2,880	1,525 - 3,200	280 - 366	375 - 490	1
137 - 190	54 - 75	15.2 - 20.3	6 - 8	1,440 - 2,730	1,600 - 3,030	280 - 366	375 - 490	1
137 - 203	54 - 80	15.2 - 21.6	6 - 8.5	1,640 - 3,390	1,825 - 3,770	298 - 373	400 - 500	1
76 - 228	60 - 90	16.5 - 22.9	6.5 - 9	1,760 - 3,600	1,955 - 4,000	410 - 522	550 - 700	1
76 - 259	60 - 102	17.8 - 25.4	7 - 10	2,825 - 6,480	3,140 - 7,200	448 - 560	600 - 750	1
76 - 227	60 - 109	21.6 - 30.5	8.5 - 12	3,870 - 5,940	4,300 - 6,600	746	1,000	1

[a]Derived from Allis-Chalmers, 1975a, and Rexnord, Inc., 1976a.

[b]1 = primary; 2 = secondary.

caught between the rolls and crushed, have a reduction ratio of about 3:1 or 4:1 (PEDCo, 1979). Figure 3-3 depicts a single-roll crusher.

In a double-roll crusher, two rolls of the same diameter are revolved toward each other at identical speeds ranging from 50 to 300 revolutions per minute (rpm). Usually, one roll moves in fixed bearings while the other roll has movable bearings. The distance between the rolls is adjustable, and springs hold the movable roller to a set clearance space.

A single-roll crusher consists of a toothed or knobbed roll and a curved crushing plate, which may be corrugated or smooth and which replaces the function of a second roll. Generally, the crushing plate is hinged at the top and its setting is maintained by a spring at the bottom. Feed is caught between the roll and the crushing plate and is broken by a combination of compression, impaction, and shear forces at speeds ranging from 25 to 125 rpm. Single roll units accept feed sizes up to 0.51 meters (20 in). For many purposes, the single roll crusher is as effective as the larger multiple roll units; however, they are primarily used for rocks with lower hardnesses (i.e., limestones).

The capacity of roll crushers is a direct function of the length and diameter of the rolls (increasing length and diameter yields increased capacity). When the rolls are kept full, crushing is accomplished not only by the action of the rolls (free crushing) but also by attrition (choke crushing). In free crushing, the rolls are fed at a rate that allows each particle to be crushed and ejected before the next particle is crushed. Choke crushing is used in the production of a fine sized product (if other types of crushers are unsuitable), while free crushing produces a larger proportion of coarser sizes. Free crushing is considered to be more advantageous because rolls crush by direct pressure and are usually set to crush a particular size (allowing smaller particles to drop through without comminution). This process is noted for producing a minimum amount of fines.

3.2.1.4 Impact Crushers. Impact crushers (including hammer mills and impactors) use the force of massive impellers or hammers, which rotate at fast speeds, to shatter free-falling rock particles. These units are noted for their high reduction ratios, and produce a product that has a wide range of particle sizes and a large proportion of fines.

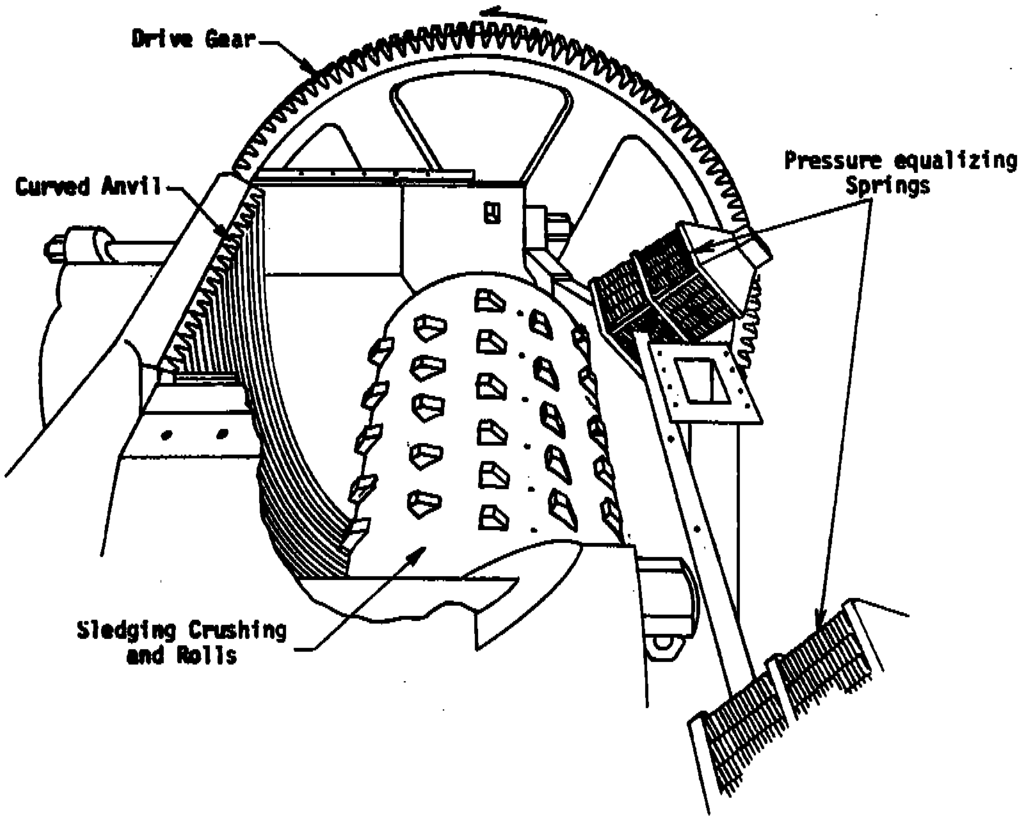


Figure 3-3. Fairmount single-roll crusher (Allis-Chalmers Mfg. Co.).

Hammer mills can be used as either primary or secondary crushers, and are primarily used in metallic ores that have lower hardnesses (i.e., uranium-containing sandstone and bauxitic clays). Hammer mills are used for finer crushing than can be accomplished by roll crushers. A hammer mill, depicted in Figure 3-4, consists of pivoted hammers mounted on a horizontal shaft. Crushing takes place by impact between the hammers and fixed breaker plates. In addition, a cylindrical grating may be positioned beneath the rotor, at the discharge opening, to retain material until it is reduced to a size small enough to pass between the base of the grating. The size of the product can be regulated by changing the spacing of the grate bars and by either lengthening or shortening the hammers. As rock particles are fed into the crushing chamber, they are shattered by the hammers, which may attain peripheral speeds up to 75 meters per second (250 ft/s), and by impact with a steel breaker plate. Rotor speeds range from 250 to 1,800 rpm, and capacities may exceed 900 megagrams per hour (1,000 tons/hr).

Impact crushers are similar to hammer mills; however, they do not have grates or screens to restrain crushed rock. Feed is broken by impact alone. Adjustable breaker bars are used to deflect material back into the part of the impellers. Primary reduction units are available which can reduce material to about 2.5 centimeters (1.0 in); however, these units are usually limited to ores of lower hardnesses. Typical operating data for impact crushers are presented in Table 3-8.

3.2.1.5 <u>Fluid Energy Mills</u>. Fluid energy mills are not used in the metallic mineral industry because the size reduction accomplished exceeds that required by most metallic mineral processes. These mills are used in the nonmetallic mineral industry, for example, to process fullers earth clays. Because emission tests from nonmetallic industries are included in the data base discussed in Chapter 4, a brief description of this process is necessary.

When the desired material size is in the range of 1 to 20 micrometers, an ultrafine grinder such as the fluid energy mill is required. A typical fluid energy mill is shown in Figure 3-5. In this type of mill, the particles are suspended and conveyed by a high velocity gas stream

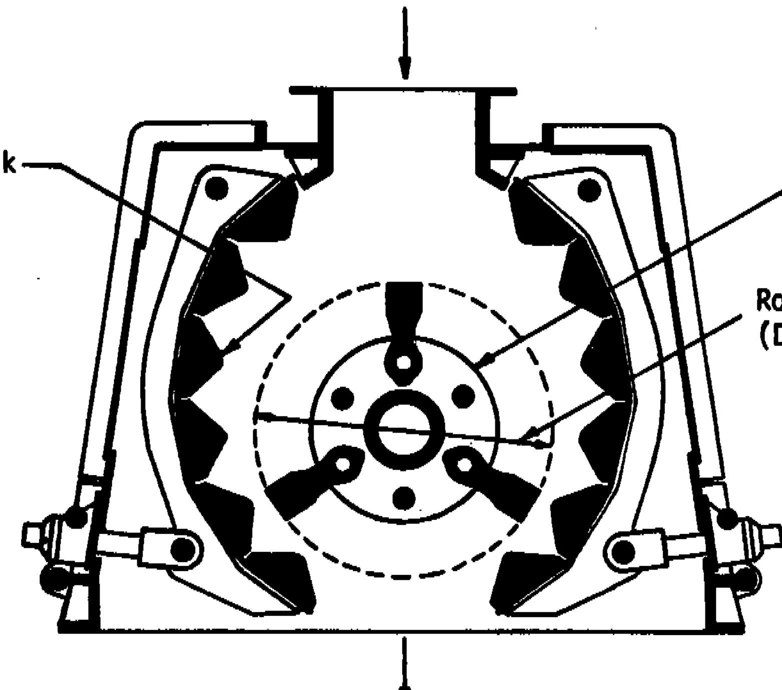


Figure 3-4. Hammer Mill

Table 3-8. OPERATING DATA FOR IMPACT CRUSHERS[a]

Feed opening		Capacity range		Energy requirements	
cm	in	Mg/hr	tons/hr	kW	hp
86 x 142	34 x 56	180 - 315	200 - 350	112 - 186	150 - 250
97 x 160	38 x 63	270 - 540	300 - 600	149 - 298	200 - 400
142 x 234	56 x 92	540 - 1,260	600 - 1,400	298 - 522	400 - 700

[a]Rexnord, Inc., 1975 and 1976c.

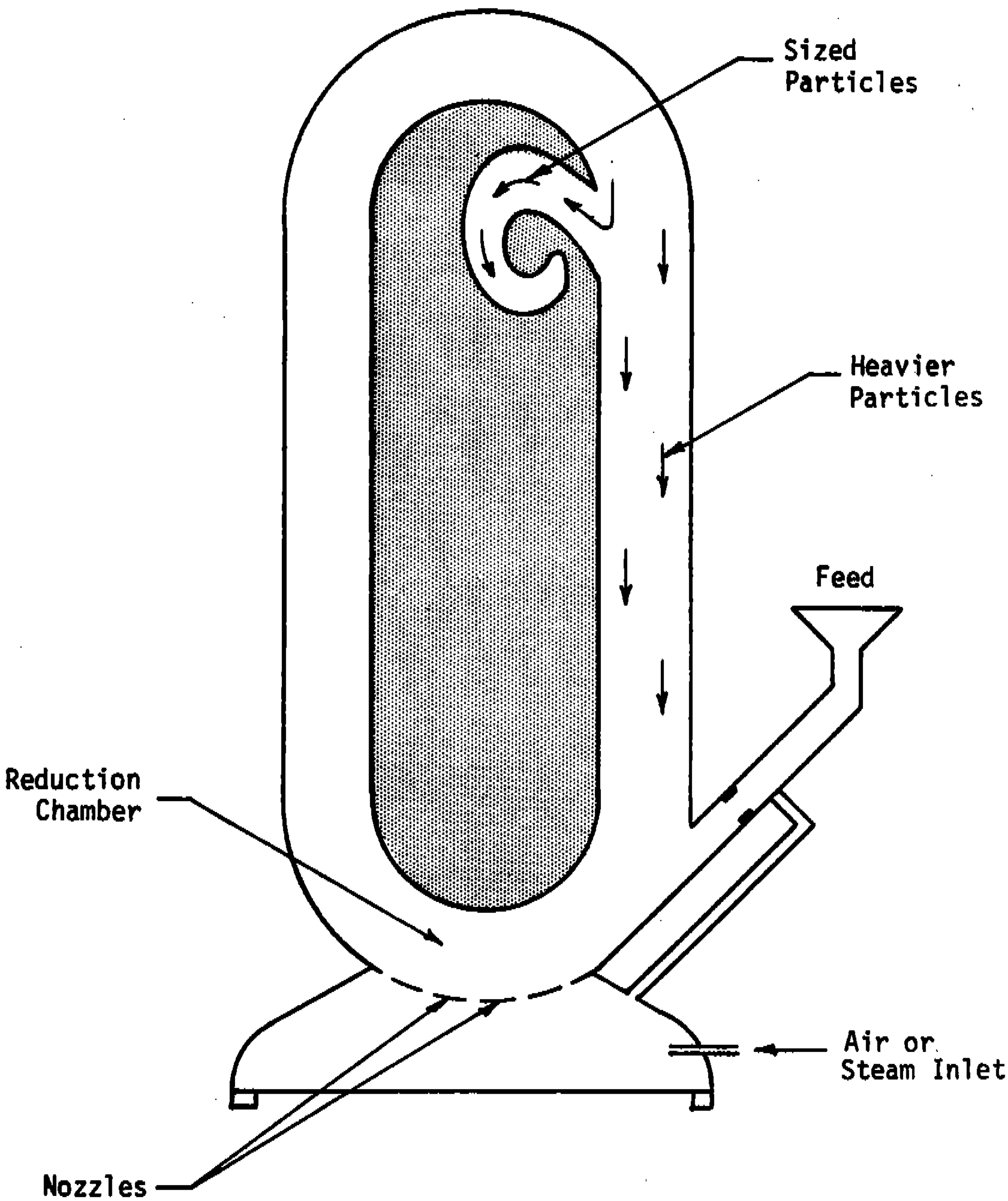


Figure 3-5. Fluid-energy mill.

in a circular or elliptical path. Size reduction is caused by impaction and rubbing against mill walls and by interparticle attrition. Classification of the particles takes place at the upper bend of the loop shown in Figure 3.17. Internal classification occurs because the smaller particles are carried through the outlet by the gas stream while the larger particles are thrown against the outer wall by centrifugal force. Product size can be varied by changing the gas velocity through the grinder.

3.2.1.6 Crushing and Grinding Circuits. Size reduction systems are operated on either a batch or a continuous basis. Most operations use the continuous method because batch grinding often produces a product that is overground. In addition, batch grinding is less energy efficient than continuous grinding. Continuous operations are accomplished using either an open or closed circuit. As shown in Figure 3-6, in a continuous open circuit the product discharged from a size reduction operation goes directly to the next operation. In a continuous closed circuit, the discharges go to a screen or size classifier that separates the insufficiently ground portion of the ore and recycles it to the original feed. With the exception of the coarse grinding stages, where a definite maximum particle size is not a major factor, the preferred method is to use closed circuits. Even in coarse grinding, the circuit still may be closed by using screens to retain material until it is the proper size for discharge.

3.2.2 Emissions from Crushing Operations

The primary purpose for reporting emission factors in this chapter is to indicate the range of emissions which might be expected from the operations of concern in the metallic minerals processing industry. The range of emissions can be used to indicate the severity of the problems that may be encountered and the suitability of various control techniques, particularly in light of worst case conditions. These factors should not be used indiscriminately in the calculation of emission levels from individual facilities; however, we believe they are typical of the levels that would be found in the industry and thus may be used in industry-wide studies as presented in this document.

Crushing operations are a major source of particulate emissions. Theoretically, emissions may be influenced by a large number of factors

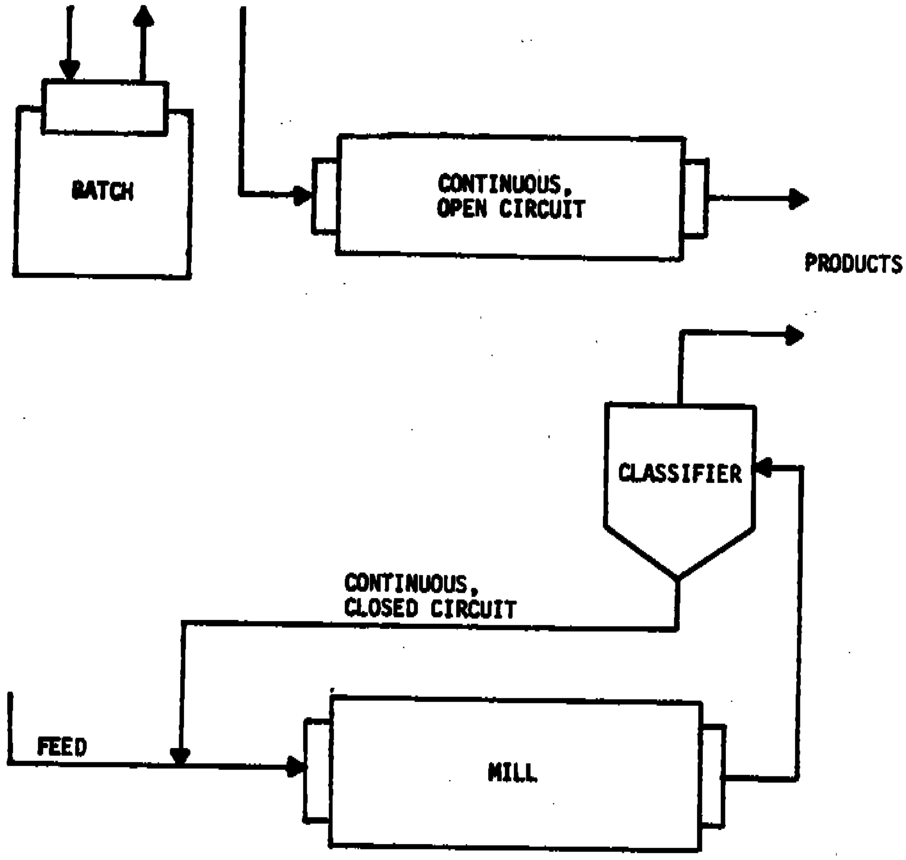


Figure 3-6. Grinding systems
From Chemical Engineer's Handbook by J. H. Perry, 1963. McGraw-Hill Book Company, Inc. Used with the permission of McGraw-Hill Book Company.

that include the moisture content of the rock, the type of rock processed, the type of crusher employed, the size of the final product (i.e., primary, secondary, or tertiary stage) as well as whether the process uses open- or closed-circuit methods.

The type of force (impaction, compression, or attrition) exerted on the raw materials by a particular crushing method could affect the size distribution of the product. The amount of fines produced in turn may affect the amount of emissions. In addition, the fan-like action produced by the opening and closing of the jaw mechanisms on jaw crushers might be expected to produce a higher amount of emissions compared with the gyratory crushers.

In general, impact crushers produce a larger proportion of fines than compression crushers which reflects the higher reduction ratios expected for hammer mills (pulverization) compared with jaw and gyratory crushers. In addition to generating more fines, impact crushers also impart more velocity to the particles because of the fan-like action produced by the whirling hammers. For these reasons, impact crushers might be expected to generate more uncontrolled particulate emissions per megagram of ore processed than other types of crushers.

Uncontrolled emissions from jaw, gyratory (including cone), and roll crushers might be expected to correspond to the reduction stage of the ores. Basically, the greater the reduction stage (i.e., tertiary crushing), the higher the emissions.

A summary of factors that might affect the amount of emissions generated by crushing operations is presented in Table 3-9. Little work has been done to date to correlate these factors with uncontrolled emission rates. For the purposes of designing control equipment, an uncontrolled emission rate is generally assumed to be 12 to 23 grams per dry normal cubic meter (g/DNm^3) or 5 to 10 grains per dry standard cubic foot (gr/dscf) by air emission control equipment designers (Skalos, 1980; Soderberg, 1980). As will be discussed in Chapter 4, the air flow rates through control equipment are most often determined by the size of hood openings and the necessity of maintaining certain minimum air flow rates and velocities at the hood openings and in the ducts rather than

Table 3-9. FACTORS AFFECTING EMISSIONS FROM CRUSHING OPERATIONS

	Crusher types			
Crushing parameters	Jaw	Gyratory	Roll	Impact
Type of force[a]	Compression Attrition	Compression Attrition	Compression Attrition	Impaction Attrition
Crushing stages[b]	Primary	Primary Secondary Tertiary	Secondary Tertiary	Primary Secondary
Size reduction ratios[c]	3:1 to 10:1 depending on raw material	6:1 or 7:1	3:1 or 4:1	Could be high depending on setting

[a] Compression forces generate the least amount of fines, while impaction forces generate a larger proportion of fines. All crushing operations produce some fines through attrition.

[b] Emissions could be expected to be lower for operations processing coarse material than fine material.

[c] Typically, the higher the reduction ratios, the more likely that there will be increased production of dust sized particles, and thus emissions.

by considerations of uncontrolled emission rate. Tests conducted by EPA and reported in Chapter 4 indicate that uncontrolled emission rates are generally below 12 g/DNm^3 (5 gr/dscf) and often below 2.5 g/DNm^3 (1 gr/dscf). There was some indication in these tests that increased ore moisture level will lower uncontrolled emission levels; however, the trend was not entirely clear. Given the wide variety of conditions tested, it does not appear likely that any combination of factors that could theoretically affect uncontrolled emissions rates would result in an increase in emission levels above design criteria of control equipment if proper consideration is given to maintaining required air flow rates.

In addition to the particulate matter concentration from an operation, the particle size distribution of the uncontrolled emissions can affect the selection of control equipment. Generally, the tests described in Chapter 4 found no difference in the particle size distributions of emissions by reduction stage (i.e., primary, secondary, tertiary). Median particle size for emissions from crushing operations was in the range of 5 to 15 microns. The use of closed circuits, which allow small sized ore to bypass a particular reduction step, may also help reduce the emission of fines.

Only when the size reduction operation reduces the processed ore to a size range under 50 microns does the particle size distribution of the uncontrolled emissions obviously reflect the reduction stage. A test of the particle size distribution of the emissions from a fluid energy mill reported in Chapter 4 supports this premise. In the metallic mineral industry final size reduction is accomplished with wet grinding operations. Thus, the fine particle size distribution found in the fluid energy mill is not often expected in this industry, particularly where high uncontrolled emissions are present.

3.2.3 Screening Operations

Screening is the separation of a mixture composed of various rock sizes into two or more portions by a screening surface. Basically, material is dropped onto a screening surface that has openings of a designated size. Material remaining on the screen surface is the oversize or "plus" material; material passing through the screen is the undersize or "minus" material. Multiple screens may be used to divide material into several successively finer fractions of known particle size distribution.

Screen sizing can be used to provide a variety of functions in ore concentration plants. In crushing operations, screens can be used to bypass sufficently reduced material from crushing operations. Screens also can be used to form a closed circuit in conjunction with crushing machines to limit the maximum size of the final product; this increases the capacity and efficiency of the crusher. Screening can divide crushed ore into a series of products, each having a limited range of size. This method grades the ore into separate feed fractions which can be fed to different machines that are adjusted for the feed size. This provides better separations than can be accomplished from unsized feed. Finally, for some industries, product size is an essential part of the final product specifications, and screening is used for commercial grading to segregate products meeting certain specifications.

Screening surfaces may consist of woven wire, perforated or punched plates, metal bars, or wedge wire sections. The type of material used for screens depends on the aperture desired and the nature of the work. For very heavy coarse material, parallel iron bars or rails may be employed. In finer work, punched plates, woven wire or rod screens are used. The efficiency of screening operations largely depends on the rate of screening and on the aperture of the screen. Typically, increasing the rate of feed to a screen decreases the screen's efficiency. Screening efficiency is also dependent upon the size distribution of the feed and the type of motion imparted to the screen surface. The efficiency of screening operations is commonly defined as the ratio of undersize that passes through screen to the true undersize. This value is determined from screen tests and subsequent calculations on the feed and oversize products. Screening efficiencies vary widely, and average about 70 to 80 percent (Richards and Locke, 1980). The two basic types of screens used in metallic ore dressing are stationary screens, which include some types of grizzlies, and moving screens, which include shaking screens, vibrating screens, and revolving screens.

3.2.3.1 Grizzlies. Grizzlies consist of a set of parallel uniformly spaced bars, rods, or rails held apart by spacers at a predetermined opening. Figure 3-7 depicts a bar screen (grizzly). Grizzlies may be placed in either an inclined or horizontal position (usually inclined between 25 and 39 degrees). The bars are typically wider on the top surface than on the underside to ensure free discharge of the undersize particles. Spacing between the bars can range from 5 to 20 cm (2 to 8 in). Grizzlies are usually constructed of manganese steel or other highly abrasion-resistant materials. Grizzlies are primarily used to remove crusher undersize prior to primary crushing operations, thus, reducing the load on the primary crusher.

Vibrating grizzlies are simple bar grizzlies mounted on eccentrics which give the entire assembly a back and forth (oscillating) movement at approximately 100 strokes a minute. This promotes a more even flow through and across the bars.

3.2.3.2 Shaking Screens. Shaking screens consist of rectangular frames which hold either a wire cloth screening surface or a perforated plate that is slightly inclined and suspended by loose rods or cables, or suspended from a base frame by flexible flat springs. The screen is mechanically shaken parallel to the plane of material flow. Frequencies range from 60 to 800 strokes per minute and amplitudes range from 2 to 23 cm (0.75 to 9.0 in). They are generally used for screening coarse material 12 mm (0.5 in) or larger.

3.2.3.3 Vibrating Screens. Vibrating screens are standard when large capacity and high efficiency are desired. They have replaced most other screening types because of their much greater capacities. A vibrating screen consists of an inclined flat or convex screening surface that is rapidly vibrated in a plane normal or nearly normal to the screen surface (see Figure 3-8). These vibrations may be generated mechanically by an eccentric shaft, unbalanced fly wheel, cam or tappet assembly, or electrically by an electromagnet. Mechanically vibrated screens are operated at 1,200 to 1,800 rpm and with amplitudes of 0.3 to 1.3 cm (0.3 to 0.5 in). In general, the type of motion imparted to the particles and the efficiency of the machine depends upon the feed. For example, in medium to coarse sizing a screen using an eccentric shaft would be chosen.

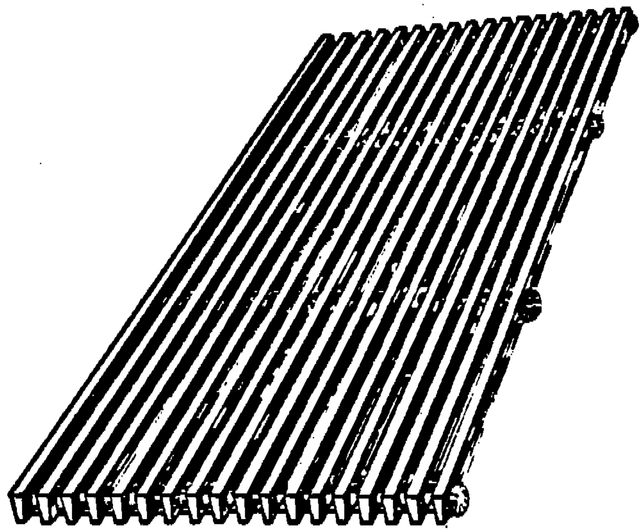


Figure 3-7. Grizzly bar screen
(Richards and Locke, 1940)

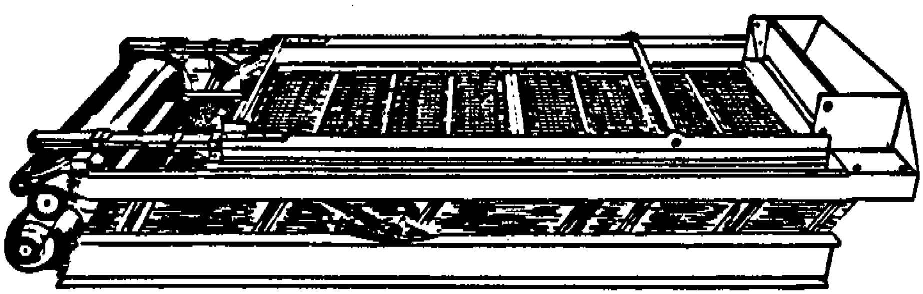


Figure 3-8. Symons 4- by 8-foot double-deck vibrating screens
(Richards and Locke, 1940)

Other variations may be more suitable for finer sized fractions. Table 3-10 tabulates typical power requirements for vibrating screens.

3.2.3.4 Revolving Screens (trommel). Revolving screens consist of an inclined cylindrical frame that has a screening surface of wire cloth or perforated plates wrapped around it. Feed material is introduced at the upper end and as the screen rotates, undersized material passes through the screen openings while oversize material is discharged at the lower end. Revolving screens are available up to 1.2 m (4 ft) in diameter, and usually revolve at 15 to 20 rpm (see Figure 3-9).

3.2.4 Emissions from Screening Operations

Dust is emitted from screening operations as a result of the agitation of dry material. The amount of dust emitted may depend upon the grain size of the feed, the moisture content of the feed, and the agitation frequency and amplitude. In general, screens agitated at large amplitudes and high frequencies could be expected to emit more dust than those operated at smaller amplitudes and lower frequencies for equivalent feed sizes. In addition, the screening of fines produces more emissions, due to the increase of dust-sized particles, than the screening of coarser feed. Table 3-11 lists some parameters that affect emissions from screening operations.

Typical design criteria for control equipment for screens allow for emission rates of 12 to 23 g/DNm^3 (5 to 10 gr/dscf) (Soderberg, 1980). Tests of uncontrolled emissions from screens (see Chapter 4) indicate that rates under 2.5 g/DNm^3 (1.0 gr/dscf) are more typical.

3.2.5 Grinding Operations

Grinding involves the reduction of ore material into particle sizes smaller than those attainable by crushers. The chief purposes of grinding are to liberate metallic minerals from gangue, reduce ore materials to sizes meeting specific process requirements (i.e., for chemical beneficiation), and to produce particle sizes meeting commercial product requirements (particle size limitations). Grinding equipment typically consists of a cylindrical or conical shell that rotates on a horizontal axis. The shell is charged with a grinding medium such as balls of steel, flint or porcelain, or with steel rods. In some cases, large particles in the

Table 3-10. POWER REQUIREMENTS FOR VIBRATING SCREENS[a]

Screen size		Energy requirements	
m	ft	kW	hp
0.9 x 3.6	3 x 12	7	10
0.9 x 4.8	3 x 16	7	10
1.2 x 3.6	4 x 12	7	10
1.2 x 4.2	4 x 14	11	15
1.2 x 4.8	4 x 16	11	15
1.5 x 3.6	5 x 12	11	15
1.5 x 4.2	5 x 14	11	15
1.5 x 4.8	5 x 16	15	20
1.8 x 4.2	6 x 14	15	20
1.8 x 4.8	6 x 16	15	20
2.1 x 6	7 x 20	15	20
2.4 x 4.8	8 x 16	19	25

[a]Derived from Bixby-Zimmer, undated; Rexnord, 1972; and Allis-Chalmers, 1977b, 1975b, and 1973a.

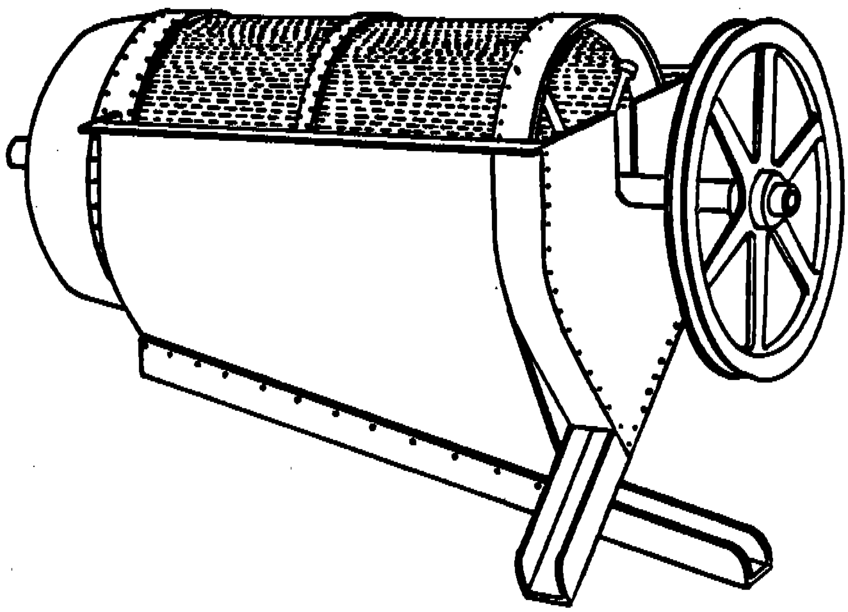


Figure 3-9. Revolving trommel
(Richards and Locke, 1940)

Table 3-11. PARAMETERS FOR SCREENING OPERATIONS

Type of screen	Rate of screening[b]	Aperture size[c]	Amplitude[d]
Grizzlies	100 strokes/min	> 5 cm (2 in)	stationary
Shaking screen	60-80 strokes/min	varies	5-58 cm (2-23 in)
Vibrating screen	1,200-1,800 strokes/min	0.25 mm-250 mm (0.01-10 in)	0.3-1.3 cm (0.1-0.5 in)
Revolving screen (trommel)	8-30 rpm	2.5 mm-50 mm (0.1-2 in)	NA[a]

[a]NA = Not applicable to this method.

[b]Increase in rate of screening may increase emissions.

[c]Decrease in aperture size may increase emissions.

[d]Increase in amplitude may increase emissions.

feed material can act as the charge. The basic types of grinding mills are rod, ball or pebble, and autogenous or semiautogenous. As indicated by their names, these grinding mills use different types of grinding media. Autogenous and semiautogenous mills rely either wholly or partially on the ore itself to serve as the grinding medium. Grinding mills may be operated as either wet or dry processes; because wet grinding operations consume approximately 30 percent less energy than dry grinding per unit throughput, only wet grinding operations are expected in the future.

3.2.6 Emissions from Grinding Operations

Because wet grinding is the preferred technology for future metallic mineral processing operations, particulate emissions from grinding operations are not expected.

3.2.7 Conveying Operations

Handling systems are necessary to transport materials from one process point to another. The selection of the correct system for material of a specific bulk in a particular situation is a very complicated procedure. Some of the more important factors to be considered in materials handling are capacity requirements, length of transport, lift, material characteristics, and processing requirements. The most common systems include feeders, belt conveyors, bucket elevators, screw conveyors, and pneumatics. There are two chief classes of conveyors – those that move forward with the product (endless conveyors), and those in which the product is moved by the propelling motion of a screw thread or by the jerking of an oscillating tube or trough.

3.2.7.1 Feeders. Feeders are relatively short, heavy-duty conveying systems that deliver ore to process equipment at a predetermined uniform rate which can be adjusted to the type of feed. The more commonly used feeders are the apron, belt, reciprocating plate, vibrating, and wobbler (see Figure 3-10).

Apron feeders consist of overlapping metal pans (aprons) that are hinged or linked together by chains to form an endless conveyor supported by rollers spaced between a head and tail assembly (PEDCo, 1979). They are constructed to withstand high impact and abrasion and are available in various widths and lengths. Special pan plates are available that can minimize drop at the discharge point.

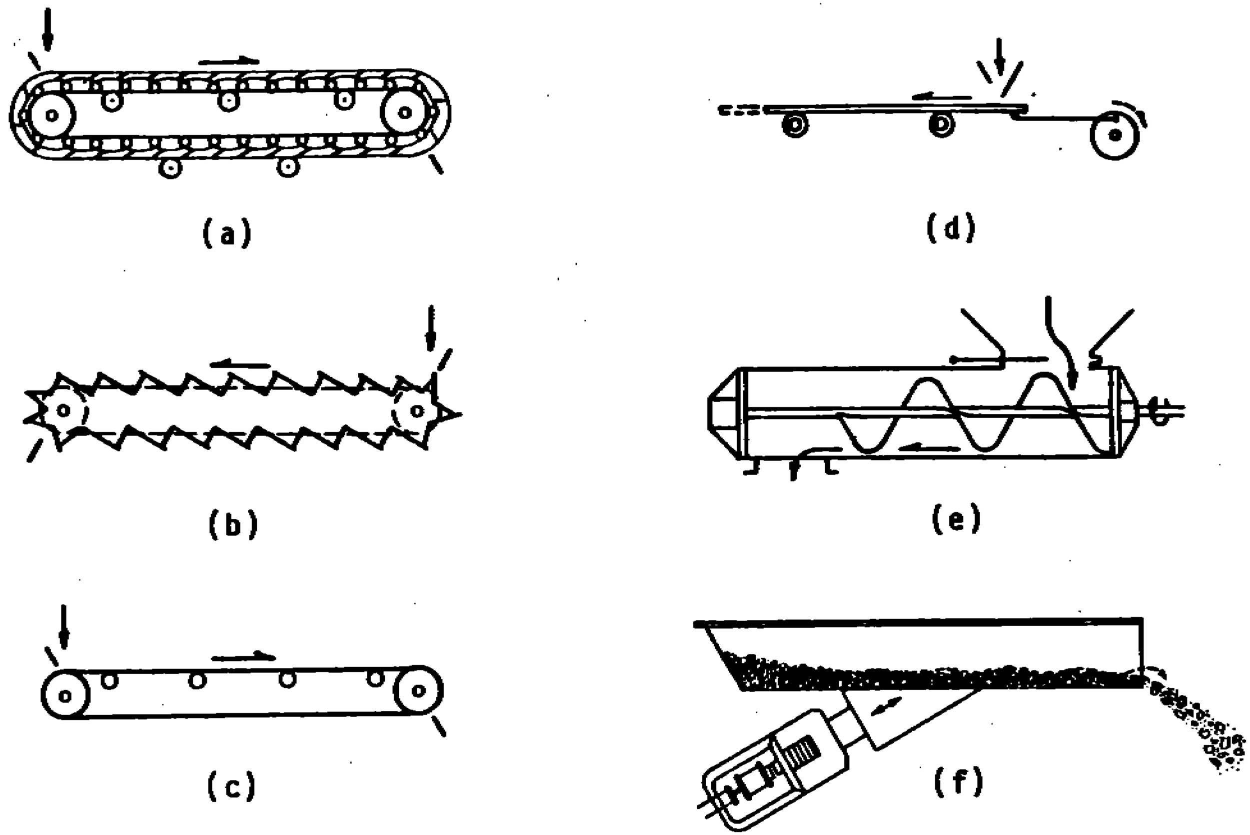


Figure 3-10. Feeders for bulk materials
a. Heavy-duty apron.
b. Apron with overlapping pans.
c. Belt (flat or troughed).
d. Reciprocating plate.
e. Screw (single or multiple).
f. Electrical vibrating.
(From Chemical Engineer's Handbook by J. H. Perry, 1963. McGraw-Hill Book Company, Inc. Used with the permission of McGraw-Hill Book Company.)

Belt feeders are short, heavy-duty conveyors with closely spaced support rollers. Adjustable gates are used to regulate feed rates. Their chief advantage is the elimination of dribble which is a problem encountered with apron-type feeders. They are available in 0.4 to 1.8 m (1.5 to 6 ft) widths and 1 to 8 m (3 to 24 ft) lengths and are operated at speeds of 12 to 30 m (40 to 100 ft) per minute.

Reciprocating plate feeders consist of a heavy-duty horizontal plate driven in a back and forth motion which causes material to move forward at a uniform rate. The feed rate is controlled by adjusting the frequency and length of the strokes. Reciprocating feeders usually run between 15 and 40 strokes per minute. They are more commonly used for materials that are not seriously abrasive.

Vibrating feeders consist of a steel pan or feed chute which is freely supported or suspended and is vibrated electromagnetically in a direction oblique to its surface (see power requirements, Table 3-12) (Richards and Locke, 1940). Material in the pan is moved along the pan surface by these vibrations, the rate of movement depending on the amplitude and frequency of the vibration. In general, vibrating feeders operate at high frequencies and low amplitudes. Feed rate is controlled by the slope of the feeder and the amplitude of the vibrations.

Wobbler feeders consist of a series of closely spaced elliptical bars that are mechanically rotated causing oversize material to tumble forward to the discharge end and undersize material to pass through the spaces. The feed rate is controlled by the bar spacing and the speed of rotation.

3.2.7.2 Belt Conveyors. Belt conveyors are the most widely used means of material transport, elevating, and handling. A belt conveyor consists of an endless belt running on two large pulleys or drums and with intermediate supporting idlers. The belts are usually made of special quality (reinforced) rubber to withstand the wear. The belt is stretched between a drive or head pulley and a tail pulley. Rubber-belt conveyors usually discharge at one end, but the ore also may be discharged at any desired point along the side by fixing an oblique scraper or special trippers (to raise and lower the belt) to the conveyor. Belt

Table 3-12. POWER REQUIREMENTS FOR VIBRATING FEEDERS[a]

Feeder size		Energy requirements	
m	ft	kW	hp
0.9 x 3.6	3 x 12	11	15
0.9 x 4.2	3 x 14	11	15
0.9 x 4.8	3 x 16	11	15
0.9 x 6	3 x 20	19	25
1.1 x 3.6	3.5 x 12	11	15
1.1 x 4.2	3.5 x 14	11	15
1.1 x 4.8	3.5 x 16	11	15
1.1 x 6	3.5 x 20	19	25
1.2 x 3.6	4 x 12	11	15
1.2 x 4.2	4 x 14	11	15
1.2 x 4.8	4 x 16	11	15
1.2 x 6	4 x 20	19	25
1.4 x 3.6	4.5 x 12	11	15
1.4 x 4.2	4.5 x 14	11	15
1.4 x 4.8	4.5 x 16	11	15
1.4 x 6	4.5 x 20	19	25
1.5 x 3.6	5 x 12	11	15
1.5 x 4.2	5 x 14	19	25
1.5 x 4.8	5 x 16	19	25
1.5 x 6	5 x 20	22	30
1.5 x 7.3	5 x 24	22	30
1.8 x 4.2	6 x 14	19	25
1.8 x 4.8	6 x 16	22	30
1.8 x 6	6 x 20	22	30
1.8 x 7.3	6 x 24	30	40

[a] Data from Allis-Chalmers, 1973b.

conveyors may range from 0.36 to 2.0 m (14 to 80 in) in width, with operating speeds ranging from 30 to 270 meters/min (100 to 800 ft/min). Table 3-13 presents operating parameters for belt conveyors.

3.2.7.3 Elevators. Bucket elevators are used when substantial height differentials are required within a limited space. In general, they consist of buckets that are attached to a single- or double-strand chain or belt that is supported and driven by a head and foot assembly. The three most common types of bucket elevators are the high-speed centrifugal discharge, slow-speed positive or perfect discharge, and the continuous discharge (see Figure 3-11).

Centrifugal discharge elevators are the most common type. As the buckets round the tail pulley, which is housed within a suitable curved boot, they scoop up their load and elevate it to the point of discharge. The buckets are spaced to allow the material to discharge by the centrifugal action of the buckets when they round the head pulley. This type of elevator can handle almost any free-flowing or small lump material. Speeds can be relatively high for dense materials but must be lowered for finer sized materials to prevent fanning action.

Continuous elevators are generally used for larger lump materials or materials too difficult to handle with centrifugal discharge units. The gentle discharge makes this type of elevator effective for handling finely pulverized material. This method utilizes closely spaced buckets. The back of the preceding bucket is used as a discharge chute.

Slow-speed positive elevators are almost identical to the centrifugal discharge elevators; however, the buckets are mounted on two strands of chain, and are snubbed back under the head sprocket to invert them for positive discharge (Perry, 1963). These units are designed especially for materials that have a tendency to pack. In extreme cases, knockers may be used to hit the buckets at the discharge point to help free material.

3.2.7.4 Screw Conveyors. Screw conveyors are the most versatile of the conveyors. They consist of a steel shaft with a spiral or helical fin that, when rotated, pushes material along a trough. They are sometimes used to convey finer sized ores.

Table 3-13. OPERATING PARAMETERS FOR BELT CONVEYORS[a]

Belt width		Capacity		Maximum size of lumps: Equal size lumps		Maximum size of lumps: Mixed with 90% fines		Maximum belt speeds for material weighting (100 lb/ft^3)		Power requirements[b]	
cm	in	Mg/hr	tons/hr	cm	in	cm	in	cm/sec	ft/min	kW	hp
46	18	144	160	8	3	13	5	255	500	4 - 19	5 - 25
61	24	270	300	13	5	20	8	306	600	7 - 37	10 - 50
76	30	432	480	15	6	28	11	332	650	7 - 56	10 - 75
91	36	630	700	20	8	38	15	332	650	11 - 93	15 - 125
107	42	882	980	25	10	46	18	332	650	15 - 112	20 - 150
122	48	1,188	1,320	30	12	53	21	332	650	15 - 112	20 - 150
137	54	1,539	1,710	36	14	61	24	332	650	NA	NA
152	60	1,944	2,160	41	16	71	28	332	650	NA	NA

[a]Rexnord, Inc., 1976b.

[b]NA = Not available.

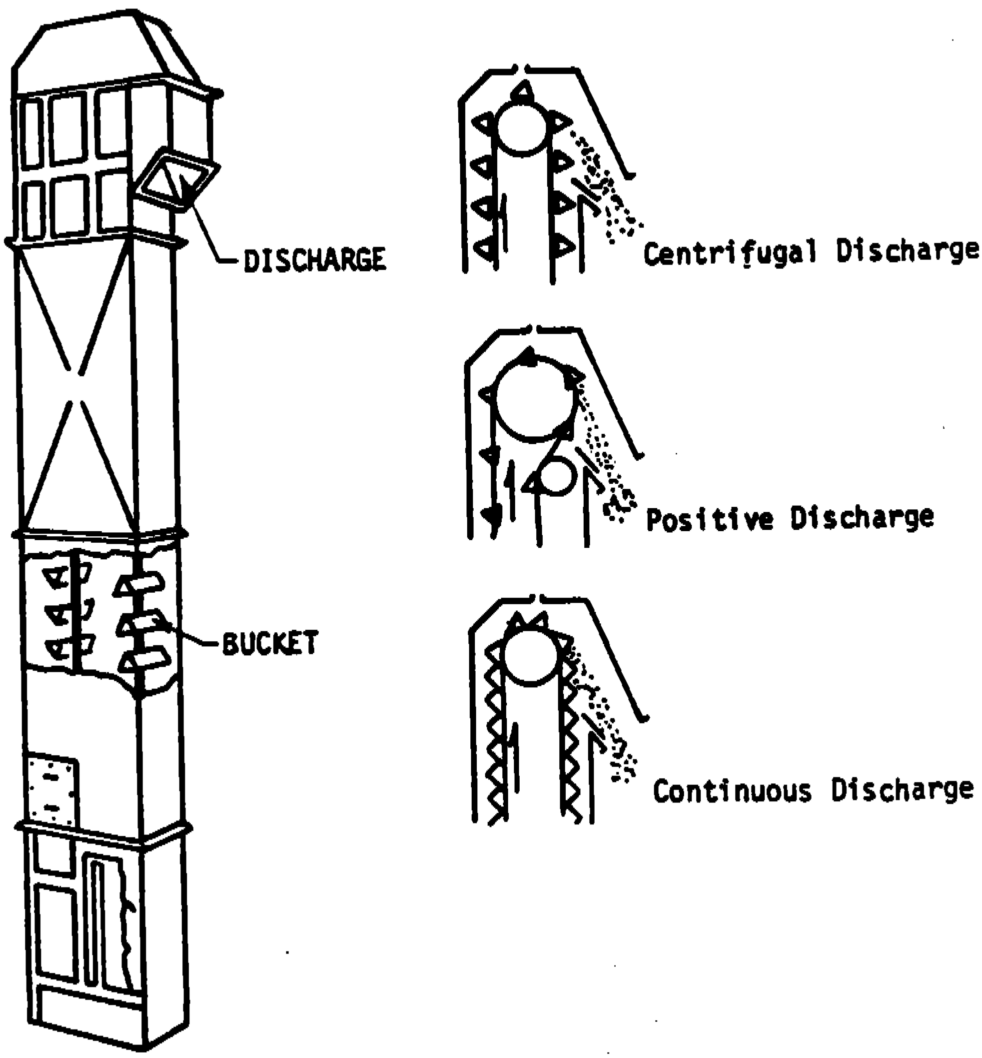


Figure 3-11. Bucket elevator types

3.2.7.5 Pneumatic Conveyors. Pneumatic conveyors consist of tubes or ducts that convey material by means of a high-velocity airstream or by vacuum pressure generated by an air compressor. Generally, for a given length and capacity, the pneumatic conveyor requires more horsepower per ton of transported material than mechanical conveyors. Pneumatic systems may be advantageous where light or fine material is used.

3.2.8 Emissions from Conveying Operations

Particulate emissions may be generated from any of the conveying operations. The level of uncontrolled emissions depends on the size of the material handled, the degree of agitation of the material (vibrations), the belt speed, the moisture content of the material, the free-fall distance of the material, and the forces imparted to particles at discharge points (elevators).

Most of the emissions from material handling occur at transfer points. These points include transfers from one conveyor to another, or discharge of materials into hoppers or storage piles (stockpiles). Additional emissions may be generated due to climatic factors (wind), and also some operations, such as pneumatic conveyors, that agitate material by air flow and may increase the dust level within the system.

Design criteria for control equipment for transfer points often allow for uncontrolled emissions at the head of a conveyor transfer point of 5 to 10 g/DNm^3 (2 to 5 gr/dscf) and at the receiving belt of 10 to 30 g/DNm^3 (5 to 15 gr/dscf) (Soderberg, 1980). Tests of conveyor transfer points showed typical uncontrolled emissions of less than 2.5 g/DNm^3 (1.0 gr/dscf). At one facility tested, dry bauxite ore with a high percentage of fine particles is transferred between a boom and a conveyor belt. This transfer operation involved a 30-foot free fall. Uncontrolled emissions of 10.9 g/DNm^3 (3.8 gr/dscf) have been reported from this transfer point (Sweet, 1980).

3.2.9 Drying Operations

Ores containing excess moisture due to wet beneficiation, climate factors, or specific rock characteristics must be dried. Excess moisture is a major problem that can result in higher freight charges, frozen stockpiles or railcars, and can pose major difficulties in subsequent ore processing stages (i.e., smelting operations). The main types of driers used in metallic ores are rotary, screw conveyors, and rotary kilns. As discussed below, kilns are primarily used in calcining and other operations causing chemical changes.

3.2.9.1 Rotary Driers. Rotary driers are a type of machine where various materials are subjected to the actions of hot air or hot gases from an adjoining furnace tube (Figure 3-12). The dryer tube is typically mounted at a small angle to the horizontal of the kiln. Moisture is released as the material moves from one end of the tube to the other as the tube is rotated. Moisture release is accomplished by either direct heat transfer (heat is added to the solids by direct exchange between flowing air or gas and the solids) or indirect heat transfer (the heating medium is separated from physical contact with the solids by a metal tube or wall). Drying of most metallic ores involves direct heat transfer. The length of the cylinder may be from 4 to more than 10 times the cylinder diameter, which may vary from less than 1 to more than 10 feet. Gas or air flowing through the cylinder may increase or retard the movement of material, depending on whether the gas or air flow is countercurrent or cocurrent to the solid flow.

3.2.9.2 Screw Conveyors. Screw conveyors can be adapted for drying material by the use of hollow screws and pipes which may be attached to circulate hot fluids. In these cases, the screw conveyor is sealed from the outside atmosphere. This type of drying operation is used infrequently in the metallic minerals industry.

3.2.9.3 Rotary Kilns. Rotary kilns may also be used to dry materials although they are primarily used in calcining and roasting operations. They replace ordinary rotary dryers when the wall temperature exceeds 370 to 420°C (700 to 800°F). Usually, they consist of a horizontal furnace that has a cylindrical body and conical ends lined in part or entirely with refractory material (Figure 3-13). Feed is introduced to the upper part of the kiln by inclined chutes, overhung screw conveyors, etc. The product then moves through the kiln and the dried material is discharged at the lower end onto conveyors or cooling devices which may include rotating inclined cylinders, shaking grates, etc. Kiln length is a major factor in determining thermal efficiency. Kilns with a high ratio of length to diameter have greater thermal efficiencies than those with a low ratio.

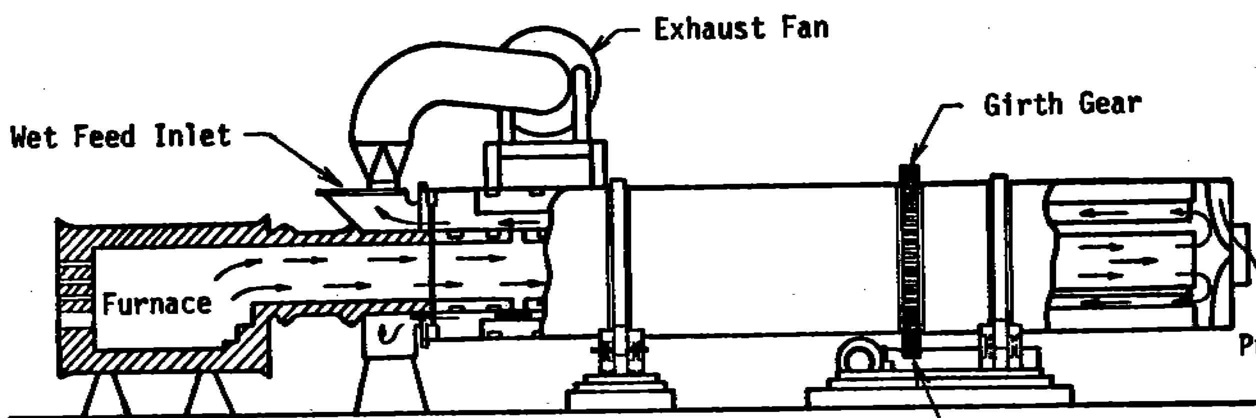


Figure 3-12. Rotary dryer
(From Chemical Engineer's Handbook by J. H. Perry, 1963. McGraw-Hill Book Company, Inc. Used with the permission of McGraw-Hill Book Company.)

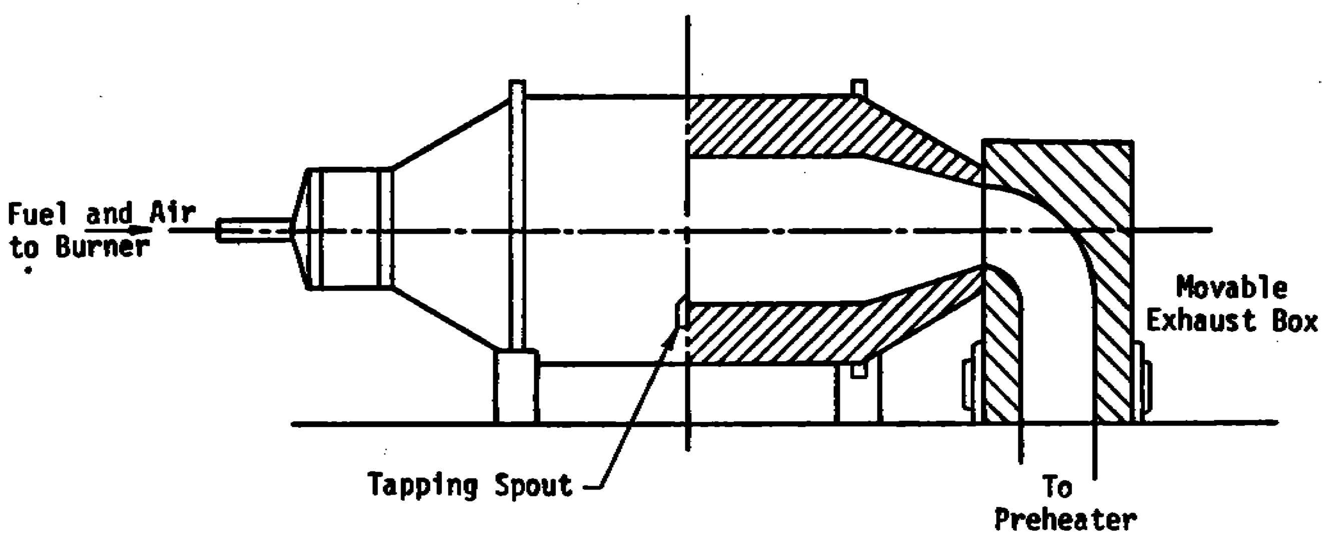


Figure 3-13. Rotary kiln
(From Chemical Engineer's Handbook by J. H. Perry, 1963. McGraw-Hill Book Company, Inc. Used with the permission of McGraw-Hill Book Company.)

3.2.10 Emissions from Drying Operations

Because the material being dried is usually agitated in order to expose more drying surface to the hot air current, significant quantities of particulate emissions in the exhaust stream from a dryer are possible. Dryers are typically used to dry the final product of the mineral processing operation; thus the value of material leaving the stack could be significant. Where emissions are high (in excess of 20 to 30 gm/DNn^3 (10 to 15 gr/dscf)), there is usually a financial incentive to install product recovery devices such as dry cyclones which would reduce the loading to the final control device.

Design criteria for control equipment for dryer exhausts are based on uncontrolled emissions of 12 to 35 g/DNm^3 (5 to 15 gr/dscf) (Soderberg, 1980). Tests reported in Chapter 4 indicate uncontrolled emissions between 1 and 25 g/DNm^3 (0.2 and 10 gr/dscf). Median particle sizes for dryers tested in Chapter 4 were between 2 and 10 microns.

3.2.11 Bagging and Bulk Loading Operations

Processed ore material may be transported by bulk loading or by bagging to customers. For materials shipped to a single customer in annual excess of 4.5 gigagrams (10 million pounds), the most economical means for both shipper and receiver is bulk shipments. In these cases, the carrier (railroad car, truck, or ship) is the actual shipping container. Below 10 million pounds, material is usually shipped using either a returnable reusable container or a one-trip expendable container.

Machinery used for packing bulk materials includes weighing and bagging equipment and, for packing dry materials into drums and barrels, filling and weighing equipment.

3.2.12 Emissions from Bagging and Bulk Loading Operations

Bagging operations are a source of particulate emissions. Dust-laden air is emitted during the final stages of bag filling when air is forced out of the bags. An additional source of emissions is provided by container agitation (vibrators) that is used to compact materials to increase packaging efficiency. Fine product materials that are not bagged for shipment are either bulk loaded in tank trucks, drums, or enclosed railroad cars. Product loading varies from plant to plant and differs for the materials handled (i.e., uranium ores may require a sealed drum while copper may be bulk loaded onto open railroad cars or trucks). The usual method of loading (unloading) is by gravity feed through plastic sleeves. Bulk loading of fine material is a source of emissions because dust-laden air is forced out of the truck, drum, or railroad car during product transfer. Emissions would be affected by the same factors discussed under conveyor transfer operations. Emission rates are also comparable.

3.2.13 Emission Factors for Related Industries

Engineering estimates of uncontrolled emissions for crushed stone or rock handling facilities have been made (EPA, 1979). These factors, included in Table 3-14, are suggestive of the range of emissions that might be expected from the metallic minerals processing industries that employ similar processes.

3.3 PROCESS EMISSIONS ALLOWED UNDER CURRENT STATE REGULATIONS

Individual states currently use a variety of regulations and formulas to determine allowable particulate emissions under the state implementation plans (SIP). Table 3-15 tabulates the various process weight equations used by some states to determine allowable emissions from the metallic mineral industry under the SIPs. Table 3-15 shows that the allowable emissions (in pounds per hour) are an exponential function of the tons of material processed through each unit process.

In nonattainment areas stricter standards may be applied. The State of Oregon, for example, will require an alumina handling operation now under construction to limit emissions to 0.05 g/DNm^3 (0.02 gr/dscf).

The major uncertainty in the application of SIP process weight curves is the lack of a clear definition of a "unit process," as applied to the metallic mineral processing industry. Because processing is, in most cases, primarily a size-reduction operation, all crushing, grinding, and screening operations could be grouped as one unit process. In contrast, the process weight curves could be applied separately to each crushing, grinding, or screening operation.

To calculate the difference in emissions between the SIPs and the proposed NSPS, the model plants were divided into several unit processes. For the all-inclusive model plant (such as copper), six unit processes

Table 3-14. PARTICULATE EMISSION FACTORS FOR ROCK-HANDLING PROCESSES[a]

Type of process	Uncontrolled total[b]		Settled out in plant, %	Suspended emission	
	lb/ton	kg/Mg		lb/ton	kg/Mg
Dry crushing operations					
Primary crushing	0.5	0.25	80	0.1	0.05
Secondary crushing and screening	1.5	0.75	60	0.6	0.3
Tertiary crushing and screening (if used)	6	3	40	3.6	1.8
Recrushing and screening	5	2.5	50	2.5	1.25
Fines mill	6	3	25	4.5	2.25
Miscellaneous operations					
Screening, conveying, and handling	2	1			
Storage pile losses					

[a]U.S. EPA, 1979.

[b]All values are based on raw material entering primary crusher, except those for recrushing and screening, which are based on throughput for that operation.

Table 3-15. STATE PROCESS WEIGHT EQUATIONS

Maximum allowable emissions[a] (AE) in pounds per hour	States
$AE = 55\ p^{0.11} - 40$	Alabama[b], Arizona, Florida, Georgia[c], Idaho, Illinois[d], Kansas Louisiana, Michigan, Montana, Oklahoma, Tennessee[e], Virginia, Wyoming[e]
$AE = 17.31\ p^{0.16}$	Alabama[f], California, Colorado, Kentucky, Maine, Minnesota, Tennessee[c], Wisconsin, Wyoming[c]
$AE = 11.78\ p^{0.11} - 18.14$	Nevada[g]
$AE = 0.76\ p^{0.42}$	Pennsylvania
$AE = 24.8\ p^{0.16}$	Illinois[h]
$AE = 4.1\ p^{0.67}$	Georgia[e]

[a]Process rate (p) in tons/hr and greater than 30 tons/hr, unless otherwise noted.

[b]For Alabama, a Class I source is located in a county with 50% or more of its population in urban areas, and where secondary national ambient air quality standards are exceeded.

[c]For new sources.

[d]For existing sources with (p) greater than 450 tons/hr.

[e]For existing sources.

[f]For Alabama, a Class II source is in a county not satisfying Class I conditions.

[g]Process weights (p) and emissions in kg/hr.

[h]For new sources with (p) greater than 450 tons/hr.

were defined as primary, secondary, and tertiary crushing, dryers, fine ore bin storage, and product loadout. All screening and conveying operations were combined with these unit processes. The allowable emissions for each unit process were then calculated on the basis of ore processed by each unit process. In cases where larger plants would employ parallel crushing operations, the process weight curves were applied to each crushing complex as a separate unit process on the basis of the ore processed by that unit. Because process weight curves vary from state to state, selection of the most appropriate curve for each mineral was based on the probable location of new facilities or major ore reserves. Table 3-16 presents the process weight equations initially used to calculate emission reductions under the NSPS. Table 3-17 shows the emissions allowable under the State Implementation Plans.

After the calculations described above were performed, and these results were compared with the expected performance of currently-used emission control equipment, it became apparent that many facilities could reduce emissions to a lower level than required by the SIP process weight curves. Thus, it was likely that the real impact of a proposed new source performance standard (NSPS) would be overestimated. Therefore, a second set of calculations was performed, based on modeling the expected performance of the most popular, currently-used emission control device (a 6-inch pressure drop wet scrubber) (Sparks, 1978). These calculations will be described in greater detail in Chapter 4. These calculations will also be used as a basis on which the cost-benefit analysis of the regulatory alternatives will be performed (see Chapter 8). The results of the calculations are presented in Table 3-17 for plants projected between now and 1985.

Table 3-16. METALLIC MINERAL PROCESS WEIGHT CURVES

Mineral	Process weight equation[a]
Aluminum	$AE = 55\ p^{0.11} - 40$
Copper	$AE = 55\ p^{0.11} - 40$
Gold	$AE = 11.78\ p^{0.11} - 18.14$[c]
Iron	$AE = 17.31\ p^{0.16}$
Lead/Zinc	$AE = 55\ p^{0.11} - 40$
Molybdenum	$AE = 17.31\ p^{0.16}$
Silver	$AE = 55\ p^{0.11} - 40$
Titanium/Zirconium	$AE = 55\ p^{0.11} - 40$
Tungsten	$AE = 11.78\ p^{0.11} - 18.14$[b]
Uranium	$AE = 3.59\ p^{0.62}$[c]
	$AE = 55\ p^{0.11} - 40$[d]

[a]Process rate (p) in tons/hr, unless otherwise noted.

[b]Process rate (p) in kg/hr.

[c]For 25 ton/hour plant.

[d]For 75 ton/hour plant.

Table 3-17. BASELINE EMISSIONS BASED ON MODELLING ON WET SCRUBBER PERFORMANCE

Metal	New and expanded plant sizes (tons ore/hr)	Emissions under modelled baseline[a] Mg/hr	(tons/yr)	Emissions allowed under SIP's Mg/yr	(tons/hr)
Aluminum	1 @ 150	153	(168)	587	(645)
	1 @ 300	263	(289)	667	(733)
Copper	1 @ 150	519	(570)	1,284	(1,413)
	1 @ 600	1,021	(1,124)	2,457	(2,703)
Gold	1 @ 75	195	(215)	510	(561)
	1 @ 150	236	(260)	584	(642)
Iron	1 @ 1,200	1,313	(1,444)	1,859	(2,045)
	1 @ 2,400	2,666	(2,932)	3,324	(3,657)
Lead/Zinc	1 @ 300	470	(517)	1,254	(1,380)
	1 @ 600	698	(767)	1,682	(1,850)
Molybdenum	1 @ 300	687	(756)	1,263	(1,390)
	2 @ 1,200	1,400	(1,540)	2,165	(2,380)
Silver	2 @ 50	194	(213)	472	(519)
	1 @ 150	305	(336)	586	(645)
Titanium/ Zirconium	1 @ 300	280	(308)	427	(470)
	1 @ 600	449	(493)	601	(661)
Tungsten	1 @ 25	163	(180)	562	(618)
Uranium	2 @ 25	78	(86)	140	(154)
	3 @ 75	120	(132)	183	(201)

[a]6-inch pressure drop wet scrubber. Where multiple plants at a specific size are projected, emissions are from an individual plant.

3.4 REFERENCES FOR CHAPTER 3

Allis-Chalmers. 1973a. Model S H Ripl-Flo Inclined Vibrating Screens. Appleton, Wisconsin. Bulletin 26 B 6151-05. 5 pp.

_____. 1973b. Standard Low-Head Vibrating Feeders. Appleton, Wisconsin. Bulletin 26 B 9978-05. 3 pp.

_____. 1975a. Superior Gyratory Crushers. Appleton, Wisconsin. Bulletin 17B-5477. 19 pp.

_____. 1975b. Vibrating Screens - Theory and Selection. Appleton, Wisconsin. Bulletin 26 M 5506. 27 pp.

_____. 1977a. A-1 Jaw Crushers. Appleton, Wisconsin. Bulletin 17B-5883. 11 pp.

_____. 1977b. Low-Head Horizontal Vibrating Screen. Appleton, Wisconsin. Bulletin 26 B 6330-05. 5 pp.

Bixby-Zimmer Engineering Co., undated. Our Business is Making Screens that Make You Money. Galesburg, Illinois. Bulletin 974. 39 pp.

Environmental Protection Agency (EPA). 1979. Compilation of Air Pollution Emission Factors, Supplements 1-7. AP-42.

Environmental Protection Agency (EPA). 1980. Air Pollutant Control Techniques for Crushed and Broken Stone Industry. EPA-450/3-80-019. Research Triangle Park, North Carolina.

Perry, J. H. 1963. Chemical Engineer's Handbook. McGraw-Hill Book Company, Inc. New York, New York. pp. 7-10, 8-3, 8-4, 8-10, 8-14, 8-15, 8-19, 8-20.

Process Technology Corporation. 1978. Kue-Ken Jaw Crushers. Oakland, California. Bulletin 802. 12 pp.

Rexnord, Inc. 1972. Nordberg Heavy-Duty GP Screens. Milwaukee, Wisconsin. Bulletin 389B. 8 pp.

_____. 1975. Symons Cone Crushers. Milwaukee, Wisconsin. Bulletin 322G. 24 pp.

_____. 1976a. Nordberg Primary Gyratory Crushers. Milwaukee, Wisconsin. Bulletin 408. 22 pp.

_____. 1976b. Nordberg Stationary Belt Conveyors. Milwaukee, Wisconsin. Bulletin 409. 24 pp.

_____. 1976c. Nordberg Dynapactor Impact Crushers. Milwaukee, Wisconsin. Bulletin 414. 11 pp.

Richards, R. H. and C. Locke. 1940. Textbook of Ore Dressing. McGraw-Hill Book Company, Inc. New York, New York. 608 pp.

Skalos, C., Dravo Corporation. 1980. Telephone conversation with E. Monnig, TRW, September 26. Emission rates for metallic mineral operations.

Smidth, F. L. 1978. Mining Mills Basic Data. Copenhagen, Denmark. 17 pp.

Soderberg, H. American Air Filter. 1980. Telephone conversation with E. Monnig, TRW, August 7. Emission rates for metallic mineral operations.

Sparks, L. E., 1978. SR-52 Programmable Calculator Programs for Venturi Scrubbers and Electrostatic Precipitators. EPA-600/7-78-026. U.S. Environmental Protection Agency. Research Triangle Park, North Carolina.

Sweet, E., Reynolds Metals, Inc. 1980. Telephone conversation with E. Monnig, TRW, October 1. Emission rates for metallic mineral operations.

Universal Engineering Corp. Undated. Universal Jaw Crushers. Cedar Rapids, Iowa. Bulletin 8-100-117b. 8 pp.

U.S. Bureau of Mines. 1978. Mineral Commodity Summaries. Washington, D. C. 200 pp.

4. EMISSION CONTROL TECHNIQUES

4.1 INTRODUCTION

This chapter discusses the basis for the selection of systems of particulate emission reduction for the metallic mineral processing industries. After considering the technical factors affecting the application of various control systems, test data regarding the effectiveness of particular systems are presented. The implications of these test data on the selection of control systems are then discussed.

Fabric filter baghouses and wet scrubbers are commonly used particulate emission control systems in the metallic mineral processing industries. Exhaust characteristics such as temperature, moisture content, particle loading, and particle size distribution must be considered when these systems are applied to a particular exhaust stream. Baghouse and wet scrubber control technology can perform equally well on many exhaust streams in the metallic mineral industries; however, there may be factors that determine the selection of one type of system over another. In addition to the exhaust stream characteristic noted above, these factors include the ease of disposal of collected particles (whether wet or dry), the energy use of alternative systems, and the cost of alternative systems. These factors are discussed in this chapter and in Chapters 7, 8, and 9.

Two other types of control equipment, dry cyclones and dust suppression systems with water/surfactant sprays, have been used on a limited basis in the metallic mineral industries. Used by themselves, neither dry cyclones nor wet suppression systems can provide emission control as effective as baghouses or wet scrubbers. However, either dry cyclones or wet suppression may be used with good results to reduce the load on these more efficient control devices.

Dry cyclones are frequently used as prefilters for more efficient control devices. Dryers and pneumatic conveyance systems that handle fine material may require dry cyclones for efficient product recovery before using an air pollution control device. When dry cyclones are used in this manner for product recovery, they are more properly classified as mineral processing equipment rather than emission control equipment.

The emphasis on baghouse and wet scrubber control technology in this document is a reflection of current industry practice. Electrostatic precipitators (ESP's) can also provide very effective particulate matter removal. Their use in the metallic mineral industries has been confined to high temperature, high flow exhaust streams from calcining and pelletizing operations. As noted in Chapter 3, these process operations are not covered in this document. ESP's will be discussed briefly in this chapter.

The discussion in Chapter 3 of uncontrolled emission rates from various processes indicates that a wide range of exhaust conditions are expected in the metallic mineral industries. A significant issue considered throughout this document is the level of control baghouses and wet scrubbers can achieve under worst-case inlet conditions. The design of control equipment to meet worst-case inlet conditions is discussed extensively in this chapter. The economic, energy, and environmental impacts discussed in later chapters are also based on worst-case inlet conditions and the design criteria and cost of equipment necessary to meet worst-case inlet conditions.

Emphasis on worst-case inlet conditions and the design of control equipment to handle these conditions should not be interpreted as a recommendation or a requirement that certain types of equipment would be necessary to meet a specific emission level under all conditions found in the metallic mineral industries. The selection of control equipment for an actual emissions source requires consideration of the characteristics of only that source. Rather, the discussions of worst-case conditions are based on two premises. First, if an emission level can be demonstrated as achievable under worst-case conditions, then it is achievable under all conditions found in the industry. Second, if the cost of achieving an emission level is based on the cost of control equipment designed to meet that emission limit under worst-case inlet conditions, then the actual cost of control equipment designed to meet the emission level under less than worst-case conditions should be less.

In order to broaden the range of conditions considered for the performance of the control equipment, test data for non-metallic mineral processing facilities are also included in the data base discussed in this chapter. Data from the non-metallic industry further demonstrate baghouse performance. Data from the non-metallic mineral industries may be appropriately transferred to the metallic mineral industries for several reasons. As noted in Chapter 3, much of the process equipment of interest in this document is similar in the metallic and non-metallic processing industries. Because the ores from which metallic elements are extracted are primarily non-metallic in character, the emissions from metallic mineral processing operations are primarily non-metallic mineral constituents. Furthermore, the similarity of emissions from metallic and non-metallic processes in key parameters such as particle size distribution and mass loading provide additional evidence of similarity between the two industries. These measurements were routinely made during the testing of both metallic and non-metallic processing facilities and form the basis for extrapolating control efficiency from one industry, whether metallic or non-metallic, to another.

Finally, a comparison of non-metallic and metallic test data indicates that several sources tested in the non-metallic mineral industries provide more difficult control conditions than those tested in the metallic mineral industries. These tests provided information on the performance of baghouses under rigorous conditions and thus increase understanding of the range of circumstances in which baghouses might be used. These tests also help anticipate the performance of baghouses under "worst-case" conditions in the metallic mineral industries.

In addition to the adverse control conditions provided by the non-metallic industries, an additional set of control requirements was projected. When the control of high-moisture emissions is required under conditions where condensation can occur, the effectiveness of baghouses may be reduced when the baghouse fabric is blinded. Given the above conditions, wet scrubbers might be the preferred control equipment. When such high moisture conditions were tested, control equipment particulate loadings were low at these facilities and therefore did not indicate the entire range of conditions under which scrubbers might operate. Because inlet loading might be higher under some circumstances, the performance of venturi scrubbers was mathematically modelled given higher uncontrolled emission rates than occurred at facilities with moisture problems. These higher uncontrolled emission rates occur at facilities that are adequately controlled by baghouses where moisture is not a problem, and the modelling exercises show that these emissions could be controlled by wet scrubbers. These modelling exercises are based on hypothetical conditions yet are illustrative of the performance of venturi scrubbers under worst-case conditions. The results of this modelling are presented in Section 4.6.

A final introductory note on the subject of particle size testing is appropriate because of the important role of particle size data in the prediction of control equipment efficiency. The microscopic and individual analysis of particles emitted from the variety of mineral processing facilities under consideration here would reveal an array of shapes, sizes, and densities. Individual consideration of the efficiency of control equipment on every member of this array is, of course, impractical. Currently used aerodynamic sizing techniques reduce this infinite array of factors to one common denominator. The typical cascade impactor sampling device groups particles by their aerodynamic behavior under a set of known conditions. These groups of particles are then assigned an equivalent aerodynamic diameter ($\bar{x}$) which is the diameter of a sphere of unit density that would behave in the impactor in the same manner as the actual group of particles. These aerodynamic diameters become the basis for predicting the efficiency of control equipment and make it possible to compare particles emitted from a wide range of minerals.

4.2 FABRIC FILTERS

Fabric filters are high efficiency collection devices frequently used in the metallic mineral processing industries. The greatest variations in the design of baghouses arise from the methods of cleaning the fabric filter, the choice of fabric for the filter, and the size of the unit.

The actual extraction of dust is accomplished by one of several methods as shown in Figure 4-1. The airstream enters the baghouse and is pulled through fabric sleeves that are arranged throughout the apparatus. In one design, external draw on the apparatus pulls the air to the outside of these fabric sleeves which is a "clean area." The dust remains trapped in the weave of the sleeve forming a cake and the cleansed air is exhausted to the atmosphere. The reverse operation can also be utilized; that is, particle-laden air can be pulled from the outside to the inside of the bag and exits through either the top or the bottom of the bag. The dust then accumulates on the outside of the sleeves.

The accumulated dust forms a filter cake on the bags which must be removed periodically if there is to be sufficient flow through the system. The system must be designed such that the dust is removed in such a manner that it does not become re-entrained. Major methods of cleaning are shaking (rapping) and reversing air flow by air jets or pulses. Shaking consists of manually or automatically shaking the bag hangers or rapping the side of the baghouse to shake the dust free into a receiving hopper below. Shaking typically occurs on a section of the baghouse temporarily isolated from the gas stream. After sufficient time is allowed for the dust to settle the section is returned to service.

A more complex cleaning method involves reversing air flow down the tubes at such a rate that there is no net movement of air through the bag. As shown in Figure 4-2, this causes the bag to collapse and the filter cake to break up. A blast of air to the inside of the bag then removes the collected material. This method of cleaning usually requires compartmentalizing the baghouse so that sections of the baghouse can be isolated during the cleaning cycle.

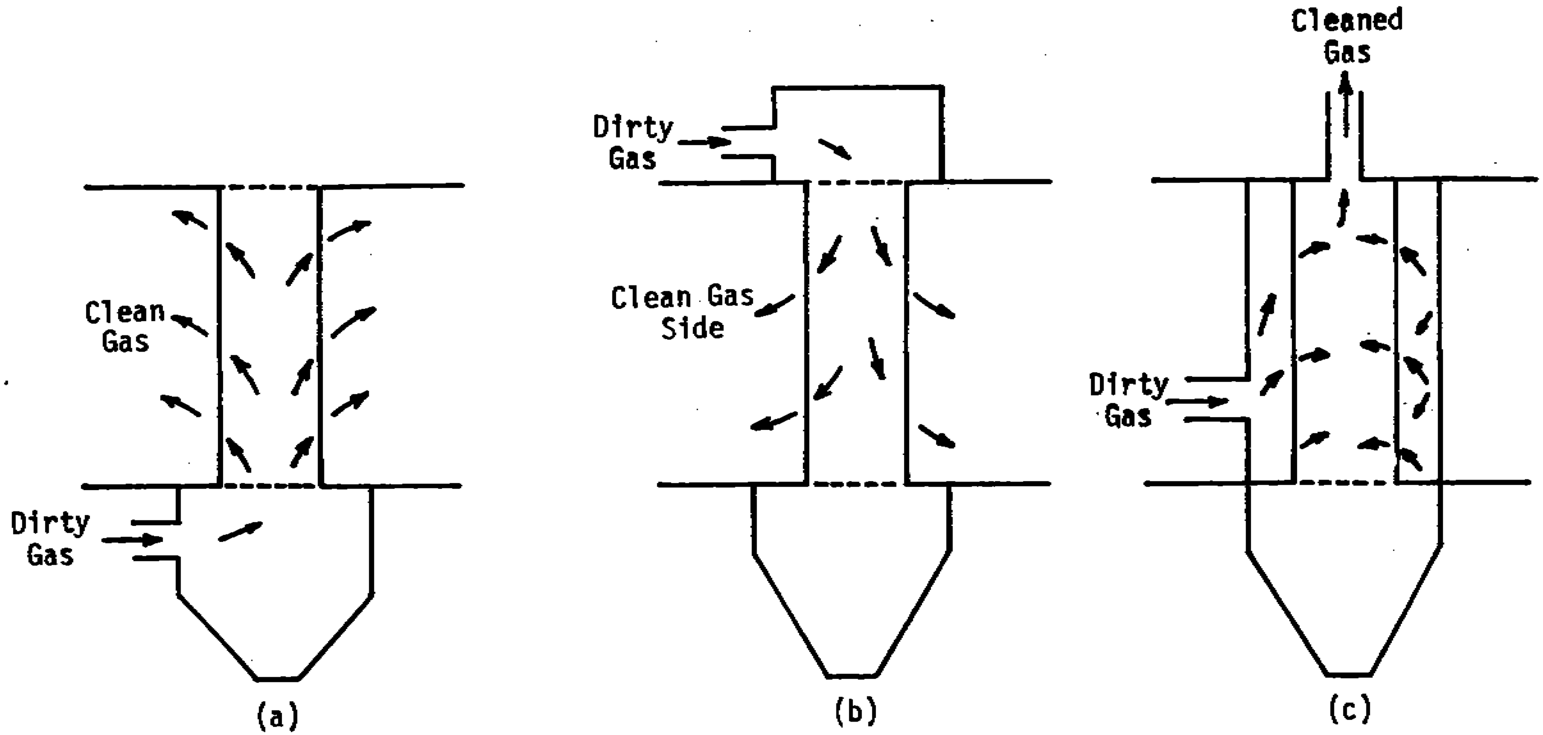


Figure 4-1. Types of filtering systems: (a) bottom feed; (b) top feed; (c) exterior filtration (Theodore and Buonicore, 1978).

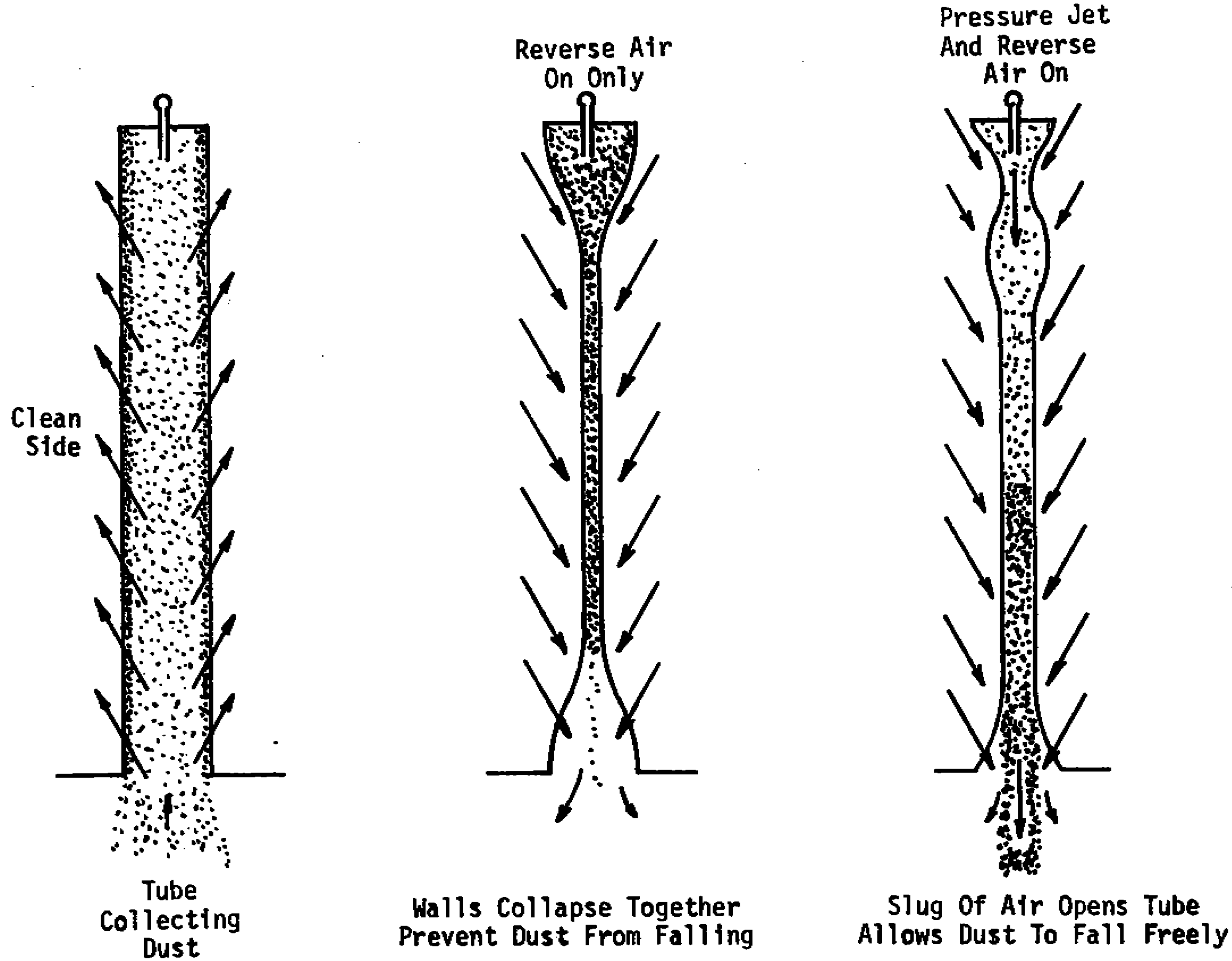


Figure 4-2. Baghouse cleaning methods (EPA, 1979).

Another method is to pulse air through a perforated ring that travels up and down the outside of each bag or sleeve. Air jets in the ring force the bag to collapse and reopen, thus breaking the filter cake apart.

Baghouses that draw dirty air from outside the fabric sleeve to the inside (thus collecting particles on the outside of the sleeve) often use a pulse jet cleaning system. In this system a blast of compressed air is forced down the inside of the fabric sleeve causing the sleeve to expand slightly breaking off the accumulated cake. This cleaning method can be used without isolating the bags being cleaned; however, sufficient space must be allowed between bags to avoid re-entraining dust.

The frequency of cleaning can be determined by a timed cycle. Alternatively, sensors can be installed which will start the cleaning cycle when a specified pressure drop across the system occurs because of the build up of the filter cake.

Materials available for bag construction include cotton, Teflon, Orlon, nylon, Dacron, wool, Dynel, and others. Temperature and other operating parameters must be considered in selecting fabric material. Most metallic mineral processes are at or near ambient conditions, therefore, temperature is usually not a significant concern in the industry. The most popular material in terms of wear and performance industry is Dacron felt. Felted materials are used most frequently on pulse jet units. Other parameters considered in the selection of fabrics and design of baghouses are the cleaning cycle frequency, cloth resistances to corrosion, and ore moisture (Danielson, 1973, p. 110-116).

The final major parameter considered is the air-to-cloth ratio or filter ratio. This parameter is defined as the ratio of air filtered (in cubic meters or cubic feet per minute) to the area of the filtering medium. This ratio reduces to meters (or feet) per minute. A filter ratio that is too high results in excessive pressure drop, reduced collection of particles, blinding, and rapid wear. Too low a filter ratio results in excessive expenditure for control equipment. The air-to-cloth ratio will vary with the type of baghouse. Reverse air and shaker baghouses typically require lower gross air-to-cloth ratios for continuous operations than pulse jet baghouses in part due to the necessity of closing off sections of the baghouse during reverse air or shaker cleaning. Typical ratios in the mineral processing industries are 2:1 to 4:1 for reverse air and shaker systems and 5:1 to 9:1 for pulse jet systems. The correct ratio for a particular type of baghouse depends on bag material and the particle size that is collected (Danielson, 1973, p. 116; Usis, 1978).

4.3 PERFORMANCE DATA FOR FABRIC FILTER BAGHOUSES

4.3.1 Particulate Emission Data

Particulate emissions were measured by EPA for 25 baghouses used to control emissions from crushing, screening, drying, and conveying operations at 13 mineral processing sites. Table 4-1 presents a summary of baghouse types and filter ratios (air-to-cloth) of the baghouses tested by EPA for which information was available.

Considerable care was given to choosing facilities that represent the range of conditions in the metallic mineral industry. The most adverse control conditions under which a facility could operate must be considered in the design of a test. For example, a facility is tested only when it is operating at 80 percent of capacity or greater.

The facilities chosen for testing were judged to be well designed, maintained and operated. Despite the effort made to coordinate testing with industry schedules and patterns and the efforts of industry representatives to ensure representative conditions, occasional equipment breakdown or other unanticipated malfunctions can hamper testing or result in completely nonrepresentative conditions. This may result in test data that are also nonrepresentative. Such cases were few in the testing program undertaken for the metallic mineral processing industry and provided the only conditions under which data were disregarded.

In most cases a single piece of control equipment collected emissions from several pieces of process equipment. In these cases attempts were made to measure the emission characteristics both before as well as after the wet scrubber. In the discussion below, the use of the term "combined inlet duct" in reference to inlet characteristics refers to actual measurements taken at a duct at a point beyond the junction of individual process ducts. In some cases it was not possible to measure

Table 4-1. BAGHOUSE UNITS TESTED BY EPA

Baghouse	Baghouse type	Filtering ratio	Process operations controlled
A1	NA	NA	Truck/railcar loadout and associated conveyor transfer point
F1	Pulse jet	7.4 to 1	Secondary and tertiary crushers and associated screens
F2	Pulse jet	7.1 to 1	Fine crushers to concentrator conveyor
F3	Pulse jet	6.5 to 1	Ore car dump
G1	Shaker	2.9 to 1	Primary crusher complex including two grizzly screens, primary crusher hood, and ore bins
G2	Shaker	2.9 to 1	Two truck dump stations
H1	Pulse jet	8 to 1	Ore storage bins
I1	Pulse jet	9.1 to 1	Primary, secondary and tertiary crushing, conveyor transfer point, and ore storage reclaim area
J1	Pulse jet	5.3 to 1	Primary impact crusher
J2	Pulse jet	7 to 1	Primary screen
J3	Pulse jet	7 to 1	Conveyor transfer point
J4	Pulse jet	5.2 to 1	Secondary cone crusher, screen

(continued)

Table 4-1. Concluded

Baghouse	Baghouse type	Filtering ratio	Process operations controlled
K1	Shaker	3.1 to 1	Primary impact crusher
K2	Shaker	2.1 to 1	Scalping screen, secondary cone crusher, two finishing screens, hammer mill, five storage bins, six conveyor transfer points
L1	Shaker	2.3 to 1	Primary jaw crusher, scalping screen, hammer mill
L2	Shaker	2.0 to 1	Two finishing screens, two conveyor transfer points
M1	Shaker	2.8 to 1	One scalping and two sizing screens, secondary cone crusher, two tertiary cone crushers, several conveyor transfer points
M2	Shaker	2.8 to 1	Finishing screen, several conveyor transfer points
N1	Pulse jet	5.2 to 1	Two sizing screens, four tertiary cone crushers; several conveyor transfer points
N2	Pulse jet	7.5 to 1	Five finishing screens, eight storage bins
O1	Reverse air	3.0 to 1	Pebble mill, bucket elevator, two conveyor transfer points, fine product loading
P1	Unknown	Unknown	Raymond impact mill
P2	Unknown	Unknown	Roller mill
Q1	Reverse air	6.0 to 1	Raymond roller mill, conveyor transfer points, vibrating screens
Q2	Reverse air	5.2 to 1	Fluid energy mill

a combined inlet duct; instead, a weighted average of individual inlet emission concentrations is given below to compare inlet and outlet concentrations. Figure 4-3 presents inlet loadings to the baghouses tested. These concentrations represent the particle levels at the inlet of the tested baghouses. Figures 4-4 and 4-5 present emission levels after baghouse control.

Particle size distribution data are reported below for most inlet and outlet streams. Typically, three tests were run for the inlet particle size distributions. Only one test was made of outlet particle size distribution because outlet size is not significant for the prediction of control equipment efficiency. The inlet particle size data are presented as the average of the runs unless the data varied significantly from run to run.

Plant A processes copper ore mined from low grade deposits (0.5 percent copper) into concentrate. This plant used a baghouse (A1) to control emissions from a railcar loading operation that handled copper ore concentrate. Use of baghouses under these conditions is fairly common because the valuable product captured by the baghouse can be returned directly to the operation. A weighted average of the truck loadout hood and the conveyor exhaust gave a calculated combined inlet concentration of 0.71 g/DNm^3 (0.31 gr/dscf). The baghouse outlet concentration averaged 0.03 g/DNm^3 (0.013 gr/dscf) as shown in Figure 4-4. Twenty percent of the inlet particles at both truck loadout hood and conveyor belt exhaust were smaller than 4 microns.

Plant F processes iron ore mined from an open pit operation. This plant was tested on two occasions, once in 1973 and again in 1978 after the wet scrubbers had been replaced by baghouses. The results of 1973 test will be reported in Section 4.5.

Baghouse F1 controlled the emissions from a secondary and tertiary crushing operation and associated screens. The outlet concentration averaged 0.008 g/DNm^3 (0.003 gr/dscf) and ranged from 0.007 to 0.009 g/DNm^3 (0.003 to 0.004 gr/dscf). No inlet measurements or particle size distributions were taken.

Baghouse F2 at Plant F controlled emissions from the system that conveyed ore from the fine crushers to the concentrator. The inlet concentration averaged 3.0 g/DNm^3 (1.31 gr/dscf) and the outlet average

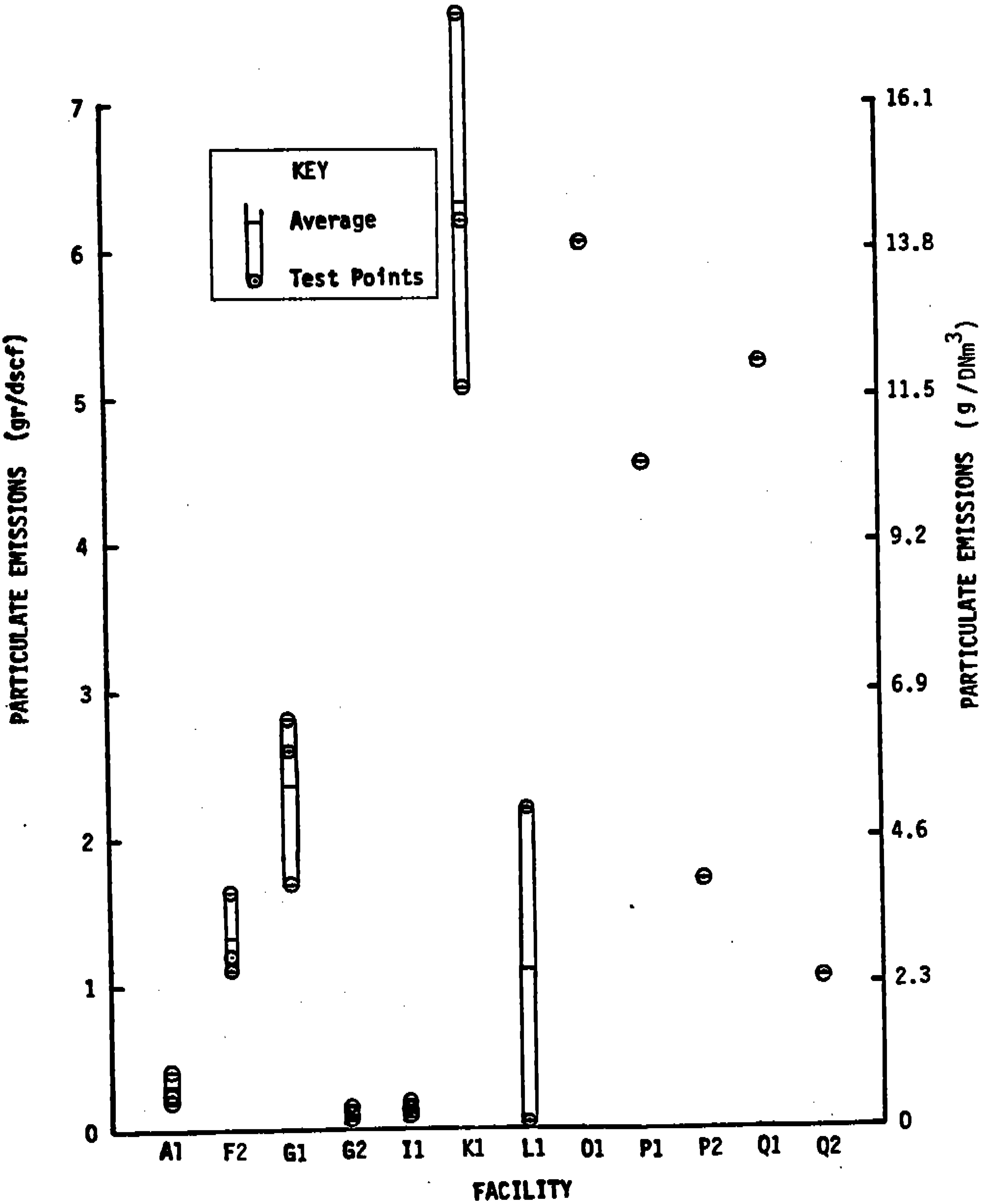


Figure 4-3. Inlet loadings to baghouses in the metallic and non-metallic minerals processing industries.

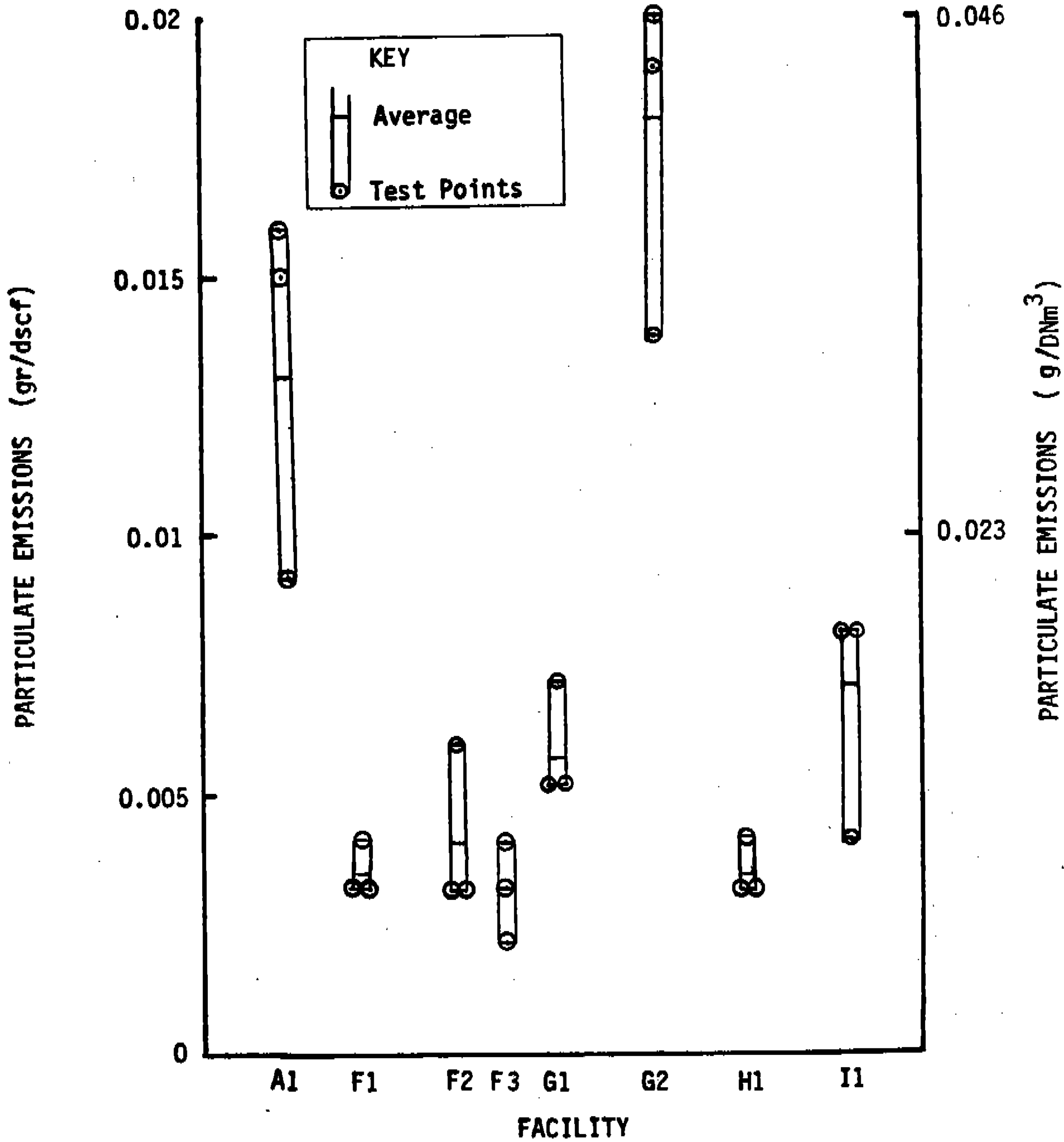


Figure 4-4. Particulate emissions from baghouses at metallic mineral processing operations.

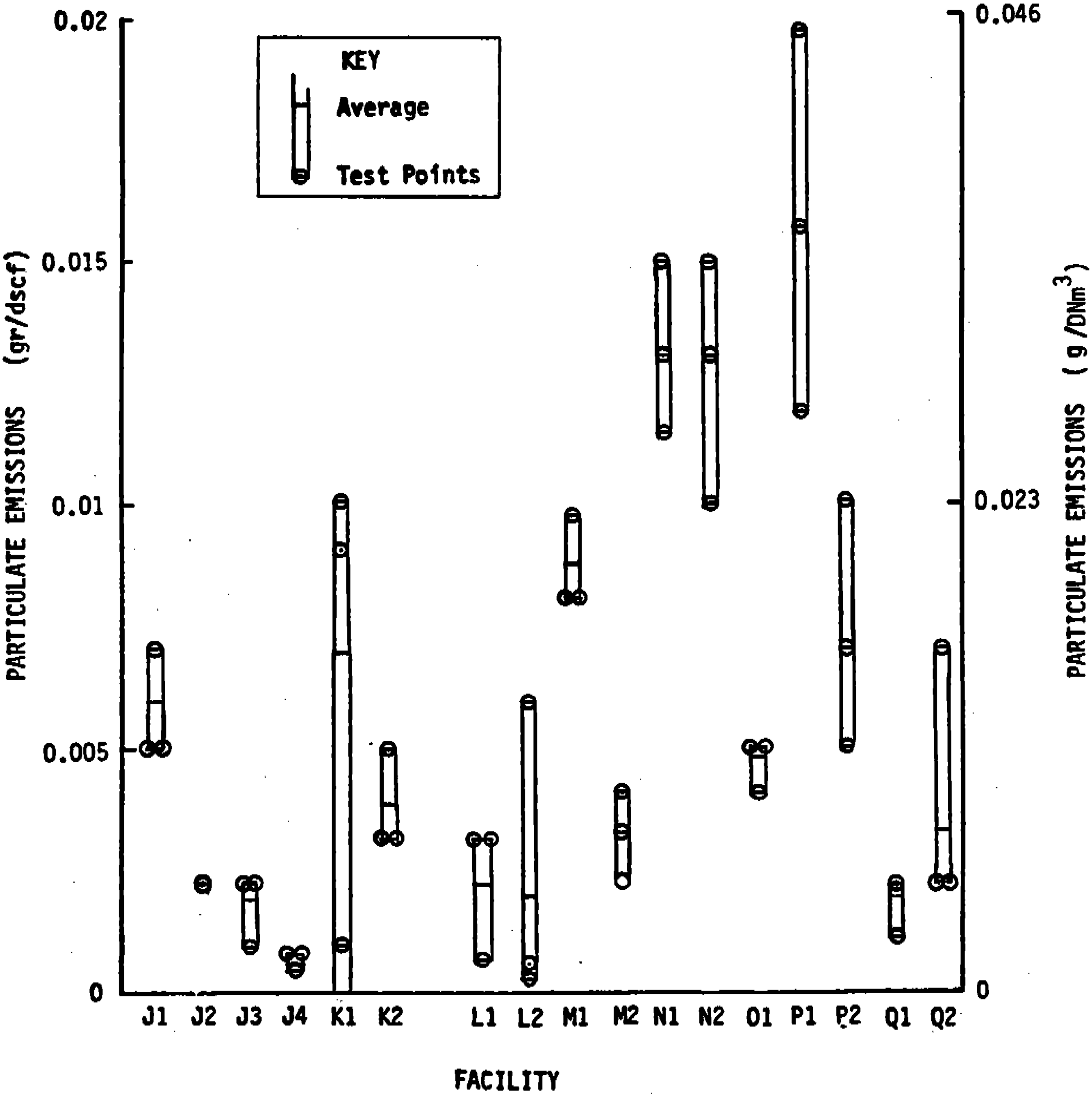


Figure 4-5. Particulate emissions from baghouses at non-metallic minerals processing operations.

0.009 g/DNm^3 (0.004 gr/dscf). No particle size data were taken at this facility.

Baghouse F3 controlled emissions from an ore car dump. The outlet concentration averaged 0.007 g/DNm^3 (0.003 gr/dscf). No inlet measurements or particle size distributions were taken.

Plant G processes copper ore from an open pit mine. Baghouse G1 controls emissions from a primary crusher complex including two grizzly screens, the primary crusher hood, and ore bins. As shown in Figure 4-3, the combined inlet duct concentration averaged 5.43 g/DNm^3 (2.37 gr/dscf) and the outlet averaged 0.013 g/DNm^3 (0.006 gr/dscf). Particle sizes of the combined inlet flow were relatively large. Ninety-five percent of the inlet particles were greater than 8 microns whereas 25 percent of the outlet particles were greater than 8 microns, as shown in Figure 4-6. The particle size distributions taken at the grizzly screen duct and the primary crusher hood duct were similar to the combined inlet duct.

Baghouse G2 controlled emissions from two truck dump stations from which ore was fed to the primary crusher. The combined inlet concentrations averaged 0.304 g/DNm^3 (0.133 gr/dscf) while the outlet averaged 0.041 g/DNm^3 (0.018 gr/dscf). As shown in Figure 4-7, 50 percent of the inlet particles were less than 4 microns while 20 percent of the outlet particle size distribution was below that level.

Plant H processed imported bauxite into alumina. One pulse jet baghouse controlling emissions from an ore bin complex was tested. The control equipment configuration prevented sampling of the inlet duct. The outlet from these ore bins averaged 0.007 g/DNm^3 (0.003 gr/dscf) and ranged from 0.007 to 0.009 g/DNm^3 (0.003 to 0.004 gr/dscf).

Plant I processed gold ore from an underground mining operation. The baghouse at the milling operation controlled emissions from the primary, secondary, and tertiary crushers, an ore storage inlet, and associated conveyor transfer operations. This baghouse had a design air-to-cloth ratio of 9.1:1 and operated with a pulse jet cleaning system.

During the testing of this baghouse, ore from 1500-1800 meters (5000-6000 feet) underground was being processed. This ore was

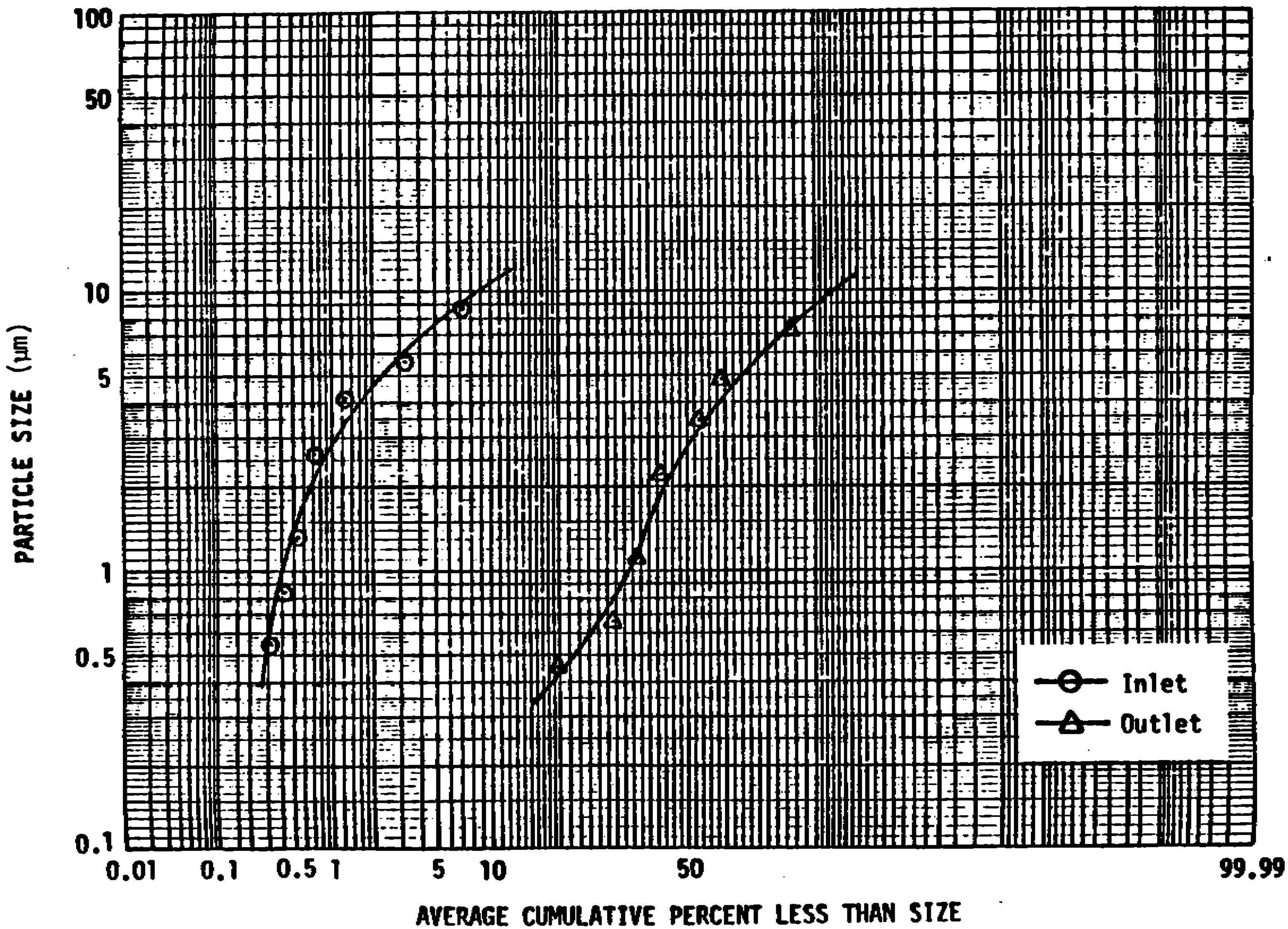


Figure 4-6. Particle size distribution for inlet and outlet streams for baghouse G1.

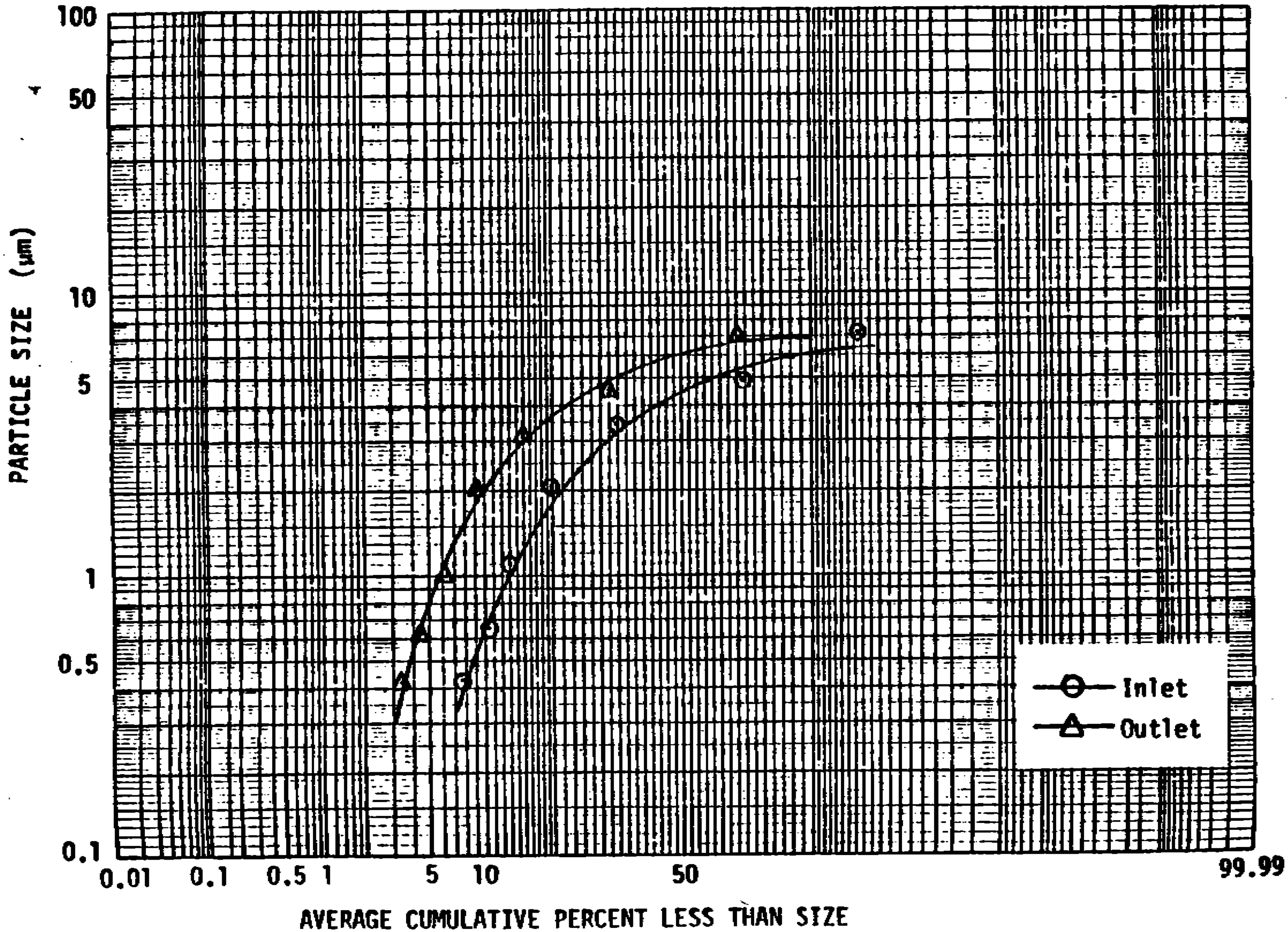


Figure 4-7. Particle size distributions for inlet and outlet streams at baghouse G2.

characterized by high levels of unbound water (4 to 5 percent) and warm temperatures (25 to 30°C (80° to 90°F)) due to the depths from which it was extracted. Because milling took place at the surface where the winter temperature was 0 to 7°C (30 to 45°F) condensation of moisture in the inlet ducts of the baghouse was very evident. The high moisture emissions combined with the relatively high air-to-cloth ratio caused blinding of the fabric filters rendering the pulse jet cleaning system ineffective. As a consequence, the pressure drop at the baghouse rose beyond design levels. To circumvent this problem, the filter bags were cleaned by manually air-lancing them before each test. The pressure drop at the baghouse was monitored closely during the tests. The implications of high moisture on the choice and performance of control equipment will be further discussed in Section 4.8.

The duct configuration of the baghouse prevented measurement of the combined inlet concentration. The weighted average of the crusher inlet, the conveyor transfer inlet, and the ore storage reclaim inlet resulted in a concentration of 0.39 g/DNm^3 (0.17 gr/dscf). The outlet concentration averaged 0.015 g/DNm^3 (0.007 gr/dscf). The particle size distribution at all three inlet ducts were similar. As shown in Figure 4-8, 30 to 40 percent of the particles were less than 10 microns in diameter.

Plant J processed limestone for the manufacturing of cement. Baghouse J1 controlled emissions from a primary crusher. As shown in Figure 4-5, the outlet concentration averaged 0.013 g/DNm^3 (0.006 gr/dscf). The inlet concentration was not measured; however, particle size at the inlet to the baghouse was measured. As shown in Figure 4-9, 98 percent of the particles were greater than 6 microns.

Baghouse J2 controlled emissions from the primary crusher screen. As shown in Figure 4-5, the outlet concentration averaged 0.005 g/DNm^3 (0.002 gr/dscf). Particle size at the primary screen was similar to that at the primary crusher, as shown in Figure 4-9. Baghouses J3 and J4 controlled emissions from a primary crusher transfer point and a secondary screen/crusher, respectively. Outlet concentrations averaged 0.004 and 0.002 g/DNm^3 (0.002 and 0.001 gr/dscf) at these two baghouses, respectively. No inlet measurements were taken.

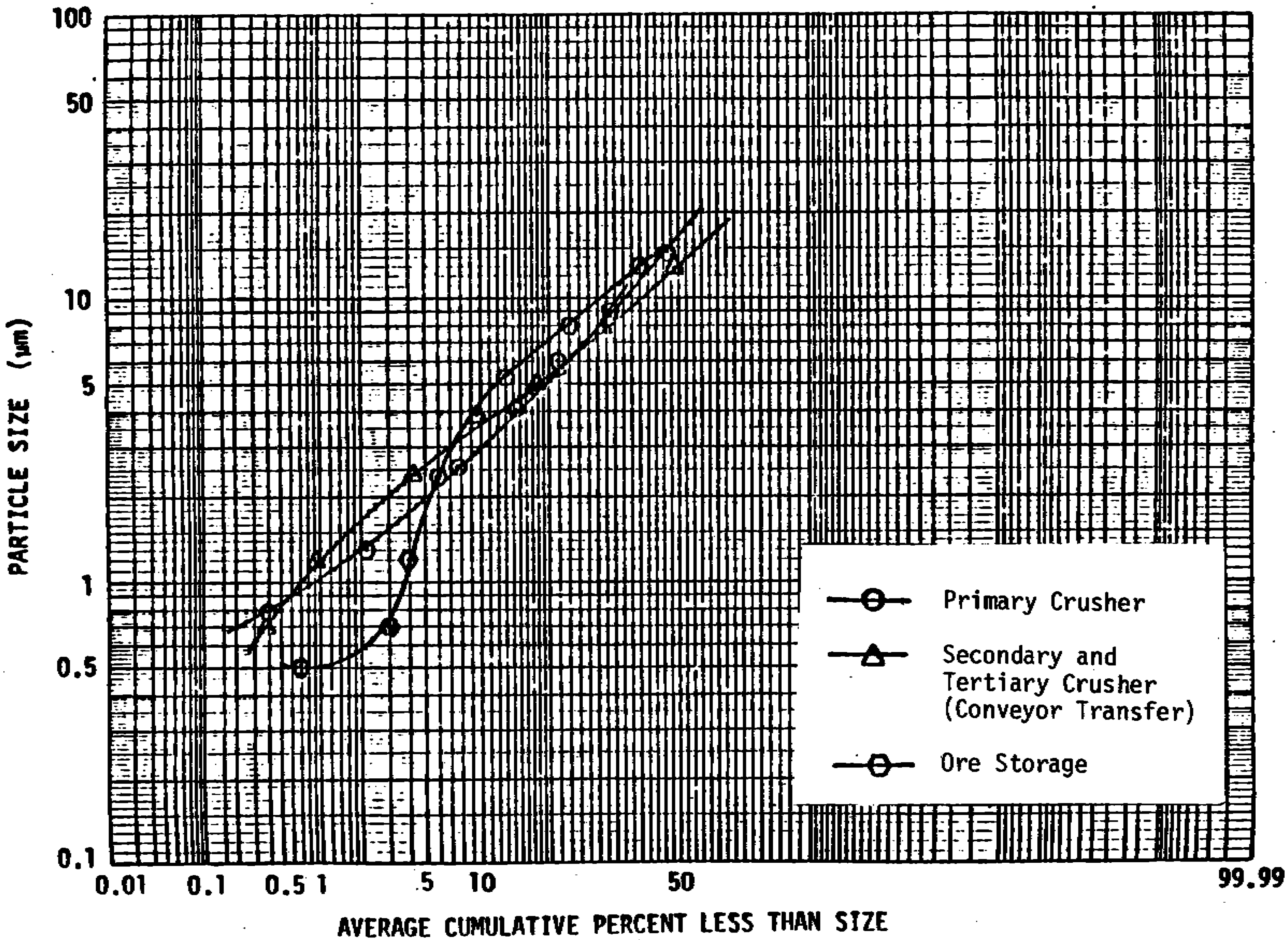


Figure 4-8. Particle size distribution for inlet streams to baghouse I1.

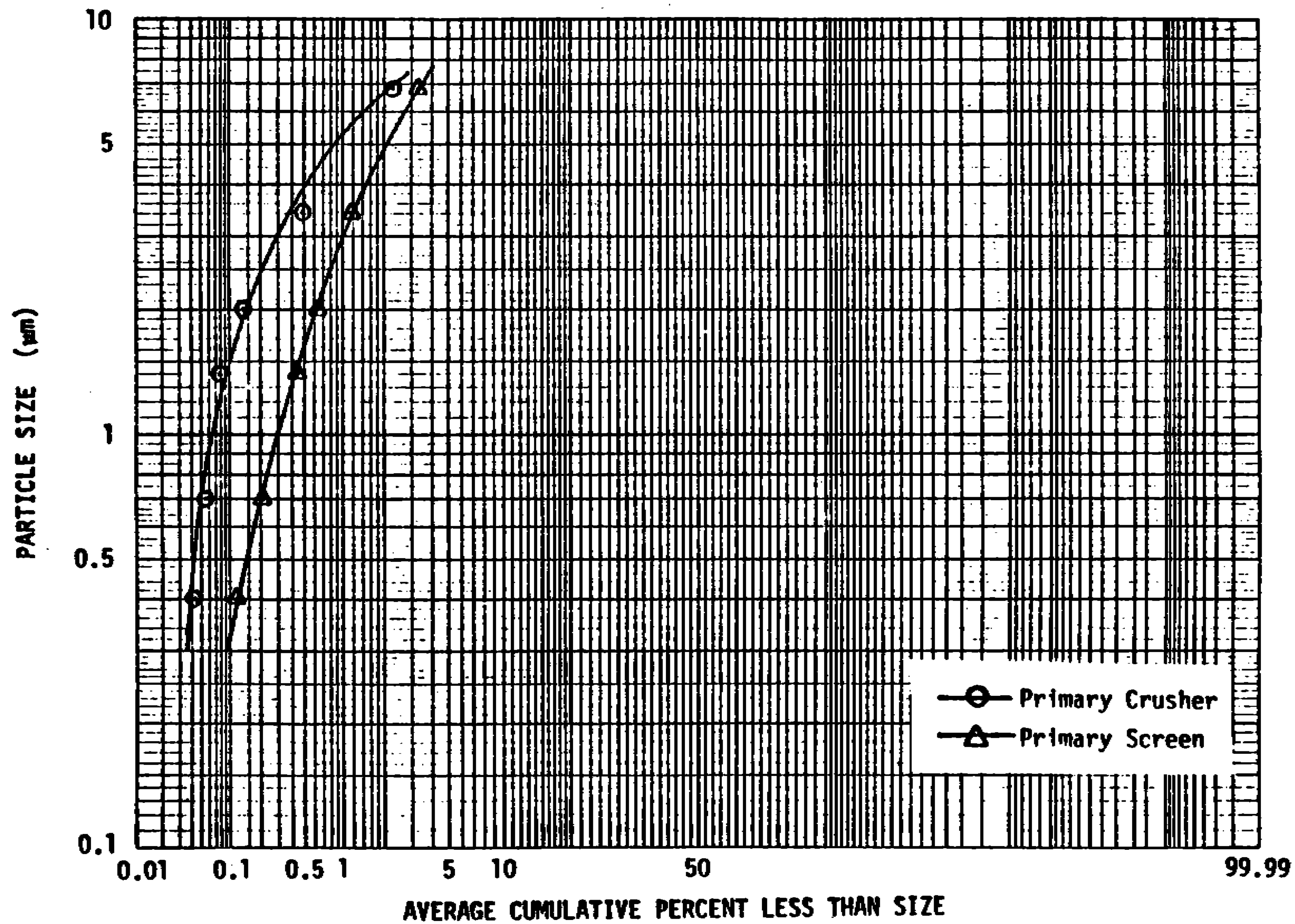


Figure 4-9. Particle size distribution for inlet streams at baghouse J1 (primary crusher) and J2 (primary screen).

Plant K produces crushed limestone and agricultural lime. Two baghouses were tested - one controlling emissions from a primary impact crusher, and the second controlling emissions from the secondary crusher complex including a scalping screen, a secondary cone crusher, a hammer mill, the top of both finishing screens, five product bins, and six conveyor transfer points. The inlet concentration at Baghouse K1 averaged 14.42 g/DNm^3 (6.30 gr/dscf) (Figure 4-3) while the outlet averaged 0.016 g/DNm^3 (0.007 gr/dscf) (Figure 4-5). The outlet of the secondary crusher complex (Baghouse K2) averaged 0.009 g/DNm^3 (0.004 gr/dscf). No inlet measurements were taken at Baghouse K2.

Plant L produced various sized aggregates and crushed stone from limestone. Two baghouses were tested at this plant. Baghouse L1 controlled emissions from a primary crusher, a scalping screen and a hammer mill. Baghouse L2 controlled emissions from two sizing screens and two conveyor transfer points.

A weighted average of the concentration in the duct from the primary crusher and the duct from the scalping screen and hammermill was calculated to be 2.5 g/DNm^3 (1.1 gr/dscf). The outlet of Baghouse L1 averaged 0.005 g/DNm^3 (0.002 gr/dscf). The outlet concentration of Baghouse L2 was again very low and averaged 0.005 g/DNm^3 (0.002 gr/dscf) (see Figure 4-5). No particle size testing was performed at either baghouse.

Plant M produced road base stone and various grades of bituminous aggregate from traprock. Traprock is a generic term for various dark colored, fine grained igneous rocks composed of ferromagnesian minerals and basic feldspars with little or no quartz. Of the two baghouses tested at this plant, M1 collected emissions from the secondary and tertiary crushers and associated screens and M2 collected emissions from the final sizing screens and associated transfer and discharge points. Baghouse 1 averaged 0.02 g/DNm^3 (0.009 gr/dscf) at its outlet while Baghouse 2 averaged 0.007 g/DNm^3 (0.003 gr/dscf). No measurements of particle size or concentration were taken at the inlet to these baghouses.

Plant N processes traprock into a variety of crushed stone aggregate products ranging from road base stone, concrete aggregate and bituminous aggregate. Baghouse N1 at this plant controlled emissions from four tertiary crushers and associated sizing screens and conveyor transfer points. Baghouses N2 controlled emissions from five finishing screens and eight conveyor transfer points. The outlets from Baghouse N1 and Baghouse N2 both averaged 0.030 g/DNm^3 (0.013 gr/dscf). No inlet measurements were taken.

Plant O is a feldspar crushing, grinding, and milling operation. The baghouse tested at this operation controlled emissions from a pebble mill (ball mill), bucket elevator, two conveyor transfer points, and a product loadout station. Two inlet ducts, which together represented the total flow to this baghouse, were tested. A weighted average of the concentrations at these ducts gave a total inlet concentration of 13.85 g/DNm^3 (6.05 gr/dscf). The outlet from this baghouse averaged 0.011 g/DNm^3 (0.005 gr/dscf). The particle size distributions at the two inlet ducts were similar. A weighted average of the particle size distribution was taken and the median particle size was 25 microns as shown in Figure 4-10.

Plant P processed kaolin for use in the stoneware industry. Baghouse P1 at this plant controlled emissions from a Raymond impact mill. The inlet concentration measured 10.36 g/DNm^3 (4.53 gr/dscf) while the outlet averaged 0.037 g/DNm^3 (0.016 gr/dscf). The particle size distribution of emissions from this impact mill represents a relatively difficult control condition. As shown in Figure 4-11, 50 percent of the particles were less than 3.8 microns and 10 percent were less than 1.7 microns.

Baghouse P2 controlled emissions from a roller mill. The inlet concentration measured 4.03 g/DNm^3 (1.76 gr/dscf) while the outlet averaged 0.016 g/DNm^3 (0.007 gr/dscf). The particle sizes at the duct from this process were similar to those for Baghouse P1. As shown in Figure 4-12, 50 percent of the particles were less than 3.5 microns and 10 percent were less than 1.5 microns.

Plant Q processed fuller's earth from attapulgite-type clay deposits. Baghouse Q1 controlled emissions from a roller mill. The inlet concentration to this baghouse was 11.99 g/DNm^3 (5.24 gr/dscf) while the outlet averaged 0.005 g/DNm^3 (0.002 gr/dscf). Particle size data taken at the inlet to this baghouse indicate a normal distribution (in the statistical sense) rather than the more typically seen skewed

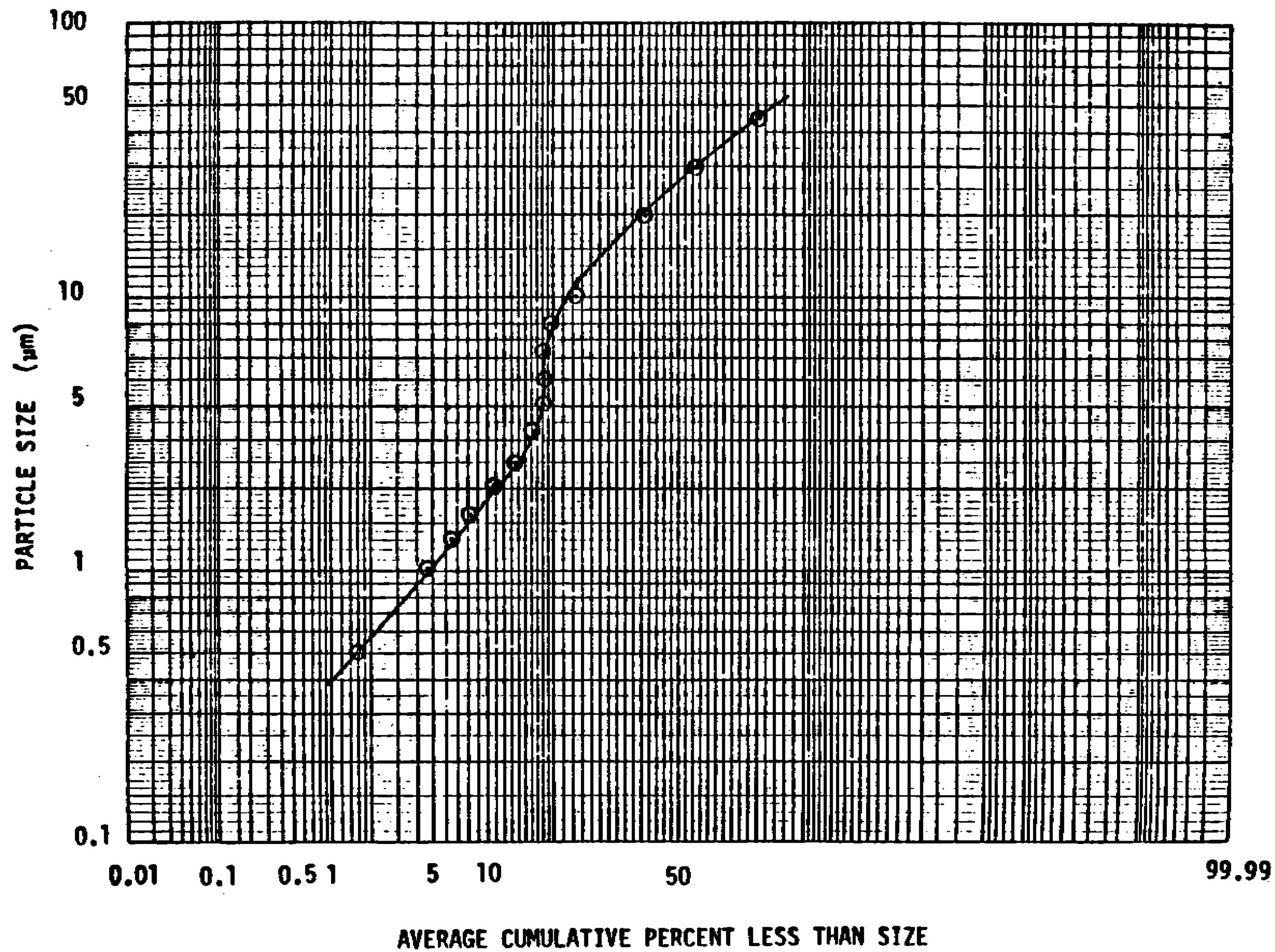


Figure 4-10. Particle size distribution for inlet stream to baghouse 01.

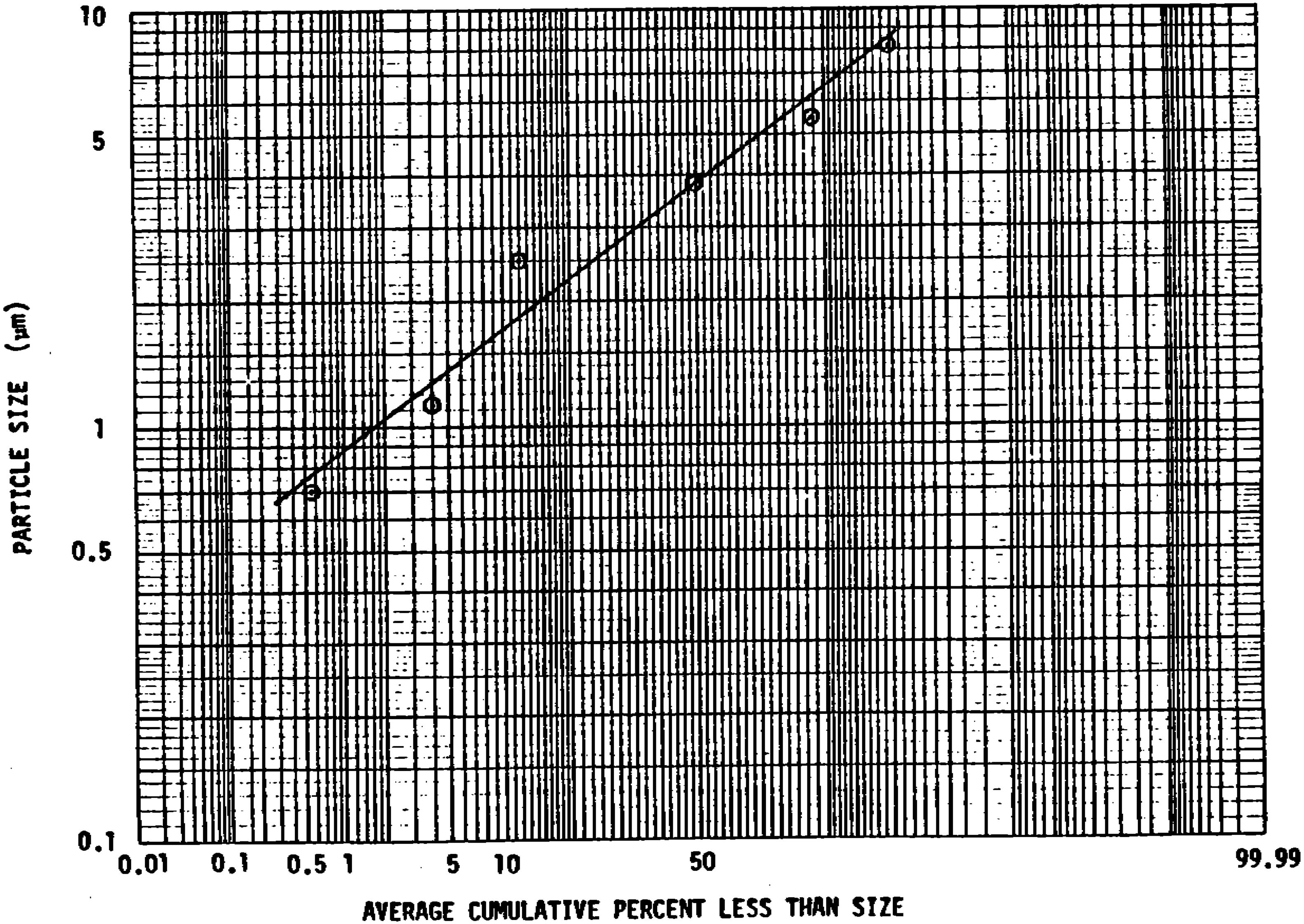


Figure 4-11. Particle size distribution for inlet stream to baghouse P1.

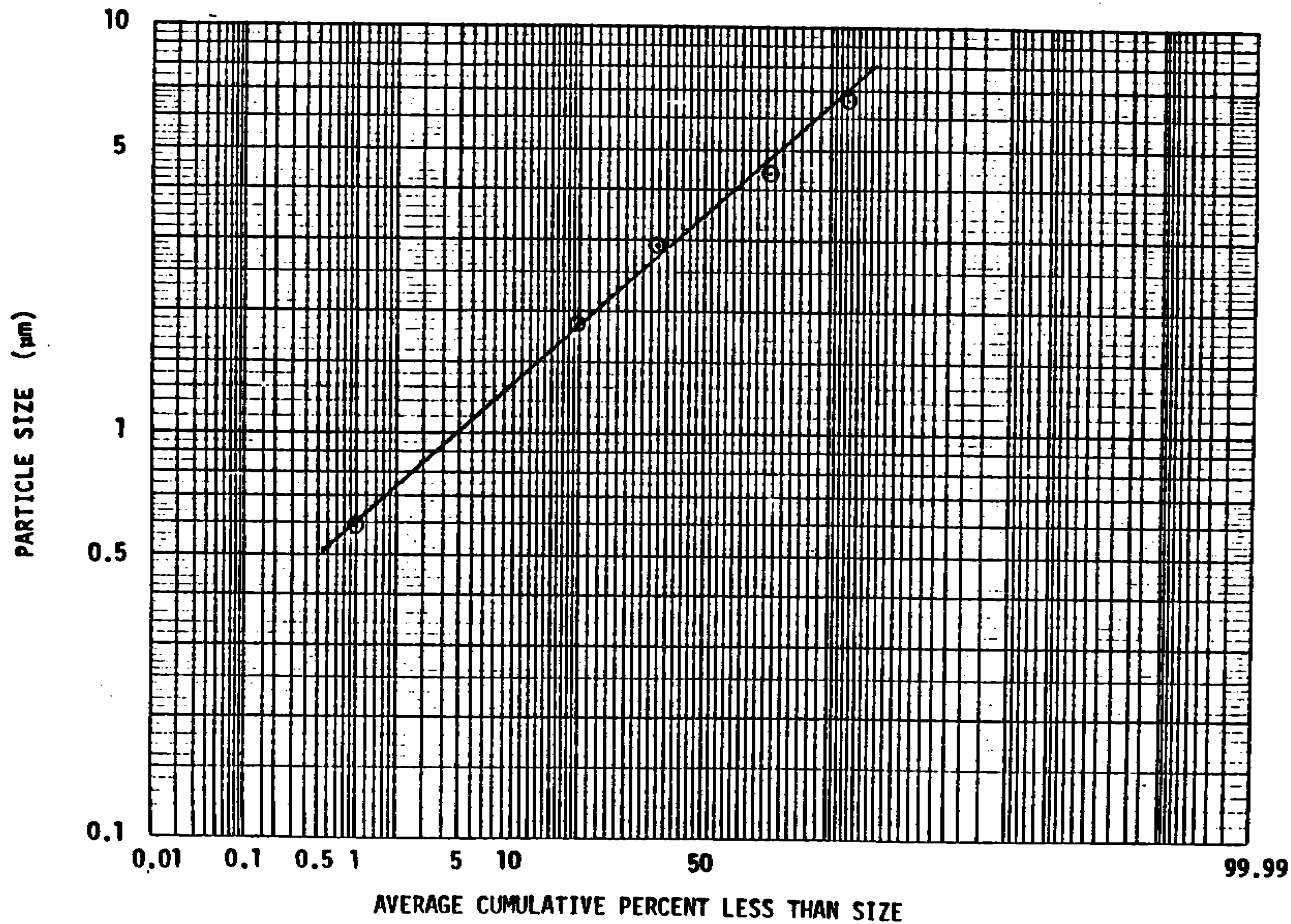


Figure 4-12. Particle size distribution for inlet stream to baghouse P2.

distribution. As shown in Figure 4-13, the particles at this test point were relatively small with 57 percent of the particles between 3.5 and 8 microns in diameter.

The emissions ducted to Baghouse Q2 presented the most difficult control conditions encountered at any metallic or non-metallic facility due to extremely small sized particles coupled with a relatively high uncontrolled emission rate. This baghouse controlled emissions from a fluid energy mill that reduces particles to 1 to 20 microns in size (see Section 3.2.1.5 for a more complete description). Simultaneously the mill pneumatically classifies material by size by allowing the smaller particles to escape with the vent exhaust. After the bulk of the sized material is removed from the airstream, exhaust from the fluid energy mill at Plant Q is vented to a baghouse. The particle size distribution taken at the inlet to the baghouse reflects the size reduction of the mineral in the fluid energy mill. Fifty percent of the particles were less than 1.5 microns and 20 percent of the particles were less than 0.7 microns, as shown in Figure 4-14. The inlet concentration measured 2.38 g/DNm^3 (1.04 gr/dscf) while the outlet averaged a very low level of 0.007 g/DNm^3 (0.003 gr/dscf).

4.3.2 Visible Emission Data

Visible emission observations were also made during the emission tests described above. The opacity of the exhaust from each of the baghouses was observed in accordance with EPA Method 9 procedures (Appendix A 40 CFR Part 60). Method 9 measures emissions in terms of percent opacity ranging from 0 percent, representing no interference with transmission of light, to 100 percent, representing complete interference with light transmission. Readings are taken at 15 second intervals and averaged over 6-minute periods.

As shown in Table 4-2, 21 of 24 baghouses showed zero emissions during all observation periods. The highest 6-minute average recorded at Plant K was 1 percent opacity. The highest 6-minute average for Baghouse 1 at Plant G was 1-percent opacity and for Baghouse 2, the highest reading was 6-percent opacity.

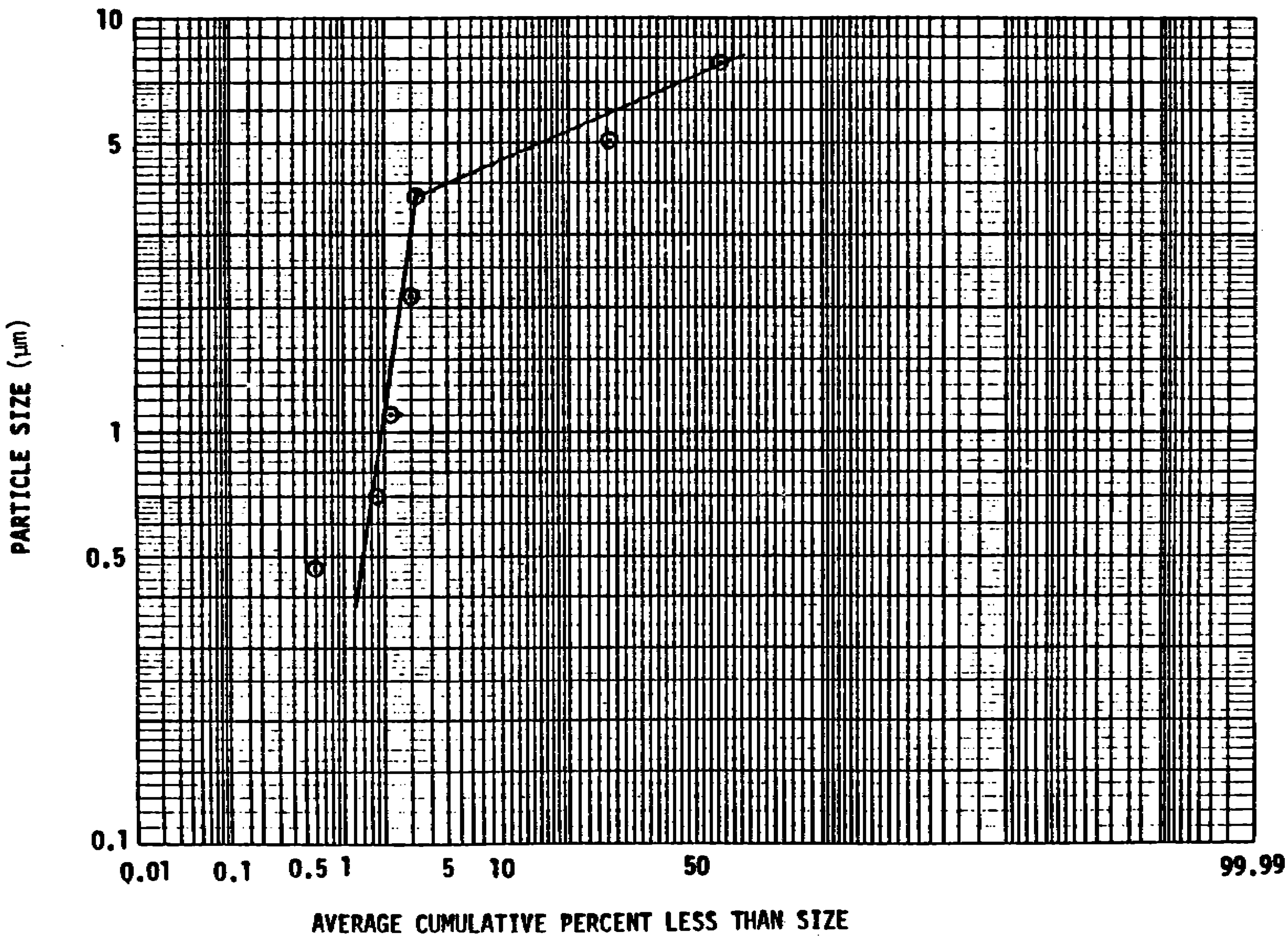


Figure 4-13. Particle size distribution for the inlet stream to baghouse Q1.

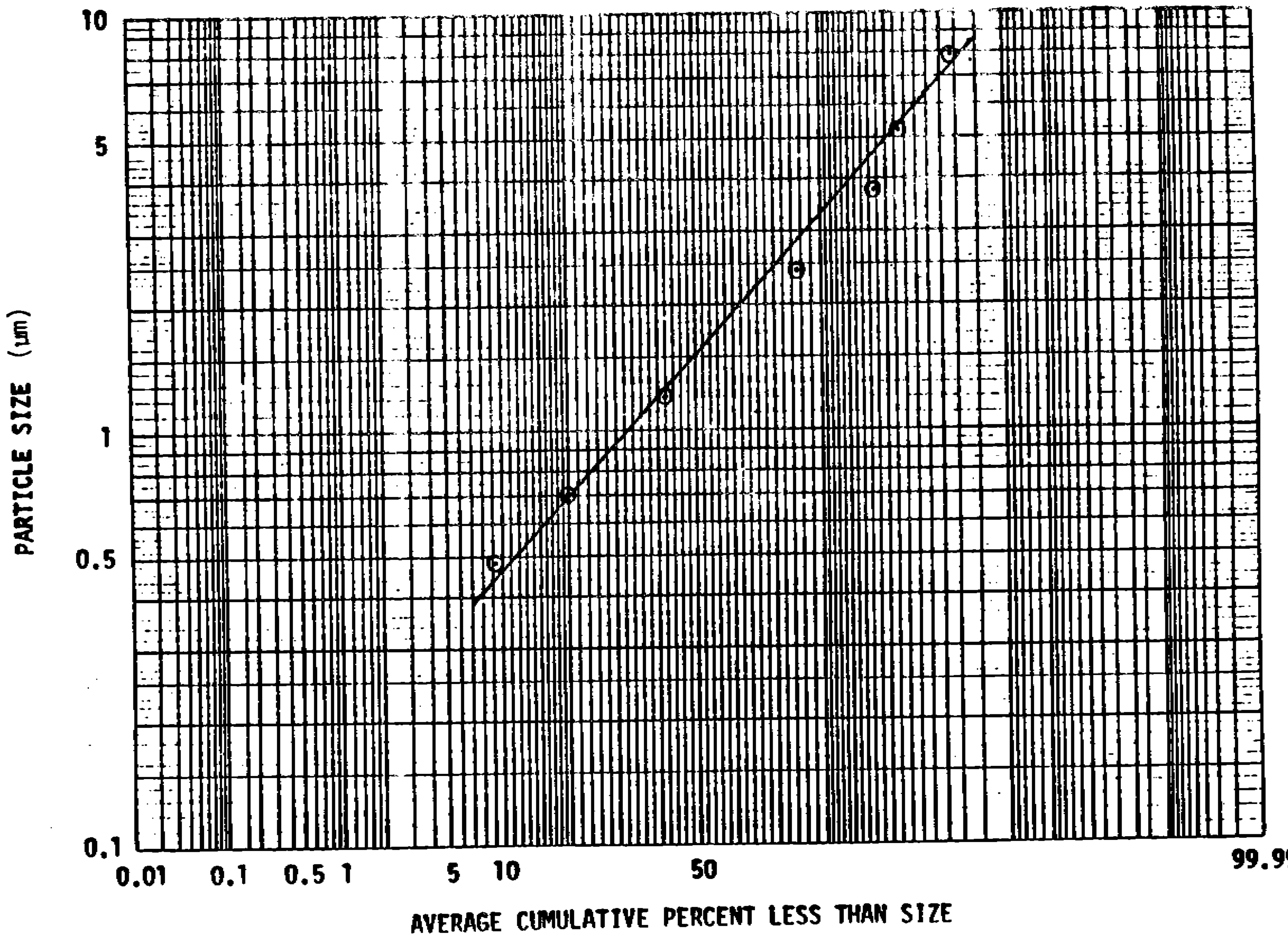


Figure 4-14. Particle size distribution for the inlet stream to baghouse Q2.

Table 4-2. OPACITY MEASUREMENTS FROM BAGHOUSE EXHAUST STACKS

Baghouse	Processes controlled	Mean opacity (percent)	Highest 6 minute average opacity (percent)	Lowest 6 minute average opacity (percent)
A1	Product loading including truck dump hopper, and railcar loading.	0	0	0
F1	Secondary and tertiary crushing operations and associated screens.	0	0	0
F2	Conveyor transfer points.	0	0	0
F3	Ore car dump.	0	0	0
G1	Primary crusher complex including grizzly screens, primary crusher hood, and ore bins.	0	1	0
G2	Truck dump hopper.	1	6	0
H1	Ore storage bin.	0	0	0
I1	Primary, secondary, and tertiary crushers, ore storage, and conveyor transfer points.	0	0	0
J1	Primary crusher.	0	0	0
J2	Primary crusher screen.	0	0	0
J3	Primary crusher transfer point.	0	0	0
J4	Secondary crusher and screen.	0	0	0
K1	Primary crusher.	0	1	0
K2	Secondary crusher complex.	0	1	0
L1	Primary crusher and hammer mill.	0	0	0
L2	Screens and conveyor transfer points	0	0	0
M1	Secondary and tertiary crushers and screens.	0	0	0
M2	Screens and transfer points.	0	0	0
N1	Tertiary crushers and screens.	0	0	0
N2	Screens and conveyor transfer points.	0	0	0
O1	Pebble mill, bucket elevator, transfer points, and product loadout.	0	0	0
P1	Impact mill.	0	0	0
P2	Roller mill.	0	0	0
Q1	Roller mill.	0	0	0
Q2	Fluid energy mill.	0	0	0

Data on fugitive emissions at hoods, pickup points and other capture systems used in conjunction with baghouses are presented in Section 4.8.

4.4 SCRUBBERS

Information gathered from industry under authority of Section 114 of the Clean Air Act indicates that wet scrubbers with pressure drops of 1.2 to 2.0 kPa (5- to 8-inches water gauge (w.g.)) are the most commonly used emission control devices in the metallic mineral processing industry. The numerous types of wet scrubbers cannot be conveniently represented by one design; however, all wet scrubbers follow the same principle of bringing contaminated air into contact with a liquid and subsequently separating the particle-contaminated liquid from the airstream. The actual mechanism for effecting this contact varies with design as discussed below.

The most important parameters to be considered in the application of wet scrubbers include the energy imparted in the liquid-gas mixing process (measured as pressure drop), the amount of scrubber water used per volume of gas (liquid-to-gas ratio), inlet particle size and concentration, and the emission limits to be achieved. Generally, higher pressure drops across a wet scrubber increase the likelihood of contact between the scrubbing liquid and individual particles. Higher removal efficiencies thus require higher energy input.

The difficulty of removing particulate material increases markedly with decreased particle size. As particle size decreases, the surface area-to-mass ratio increases so that surface properties can dominate over mass properties. As this happens, higher velocities and more acute changes in direction are required to separate the particle from the gas stream. A typical 1.5 kPa (6 inch) wet scrubber exhibits removal efficiencies of 80 to 99 percent for particles in a range of 1 to 10 microns in diameter. High-energy wet scrubbers with pressure drops of 7.5 kPa (30 inches) can achieve efficiencies of 99.0 to 99.9 percent for particles in the 1 to 10 micron range and 95 to 99 percent for particles from 0.2 to 1 micron (Theodore and Buonicore, 1978, p. 5-33).

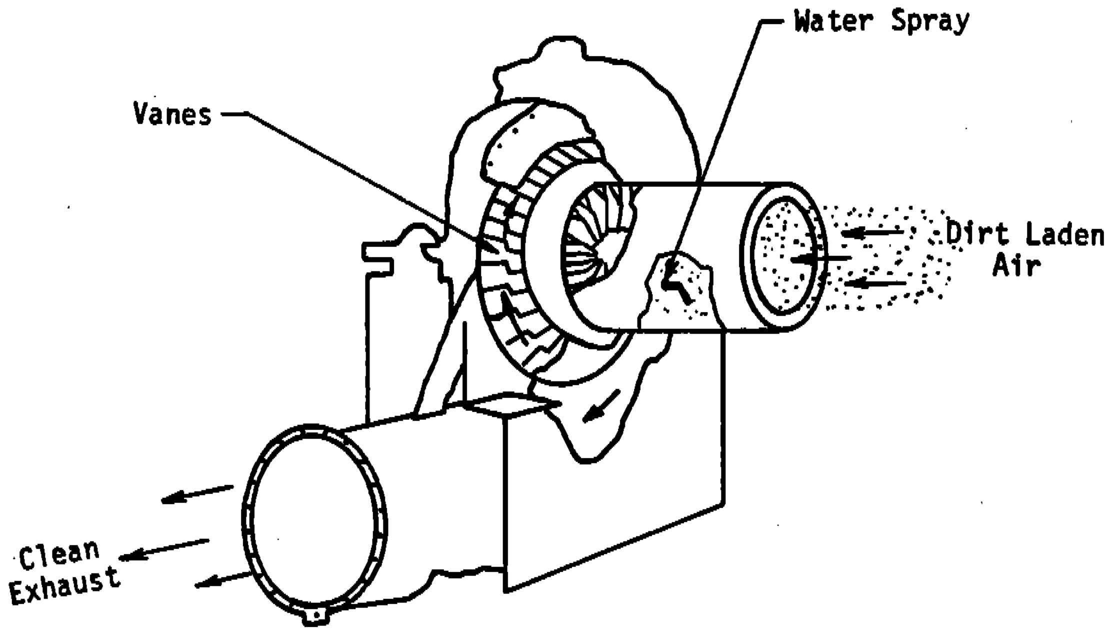
Given a scrubber collection efficiency reflecting a pressure drop, liquid-to-gas ratio, and particle size distribution, the emission level will be a function of the inlet concentration. Over normal operating ranges emission levels are a relatively constant percentage of inlet loading.

Several wet scrubber designs are popular in the metallic mineral industry. One common type is the dynamic or mechanically aided scrubber, as shown in Figure 4-15. In this type of collector the scrubber liquid is introduced just prior to the fan. The fan acts as a propeller of the gas stream, a mixer for the gas and liquid streams, and an impingment surface for particles and contaminated liquid. Water is typically added at a rate of 75 to 150 liters per 1000 cubic meters (0.5 to 1 gallon per 1000 cubic feet) of gas.

Several manufacturers offer improvements on the dynamic scrubber design by adding preconditioning sections to the scrubber. These preconditioning sections utilize cyclonic flows and liquid additions to provide an initial mixing of the scrubber liquid and the gas stream.

High energy scrubbers are most commonly designed as venturi scrubbers. High collection efficiency is achieved by increasing the relative velocity of the scrubber liquid and the gas stream, thereby increasing the particle droplet impaction rate. In a venturi scrubber the gas velocity is increased to 4,000 to 8,000 meters per minute (219 to 437 feet per second) through a constricting throat (see Figure 4-16). The scrubbing liquid is introduced slightly ahead of the throat and is atomized by the high velocity gas. Water is typically added at a rate of 800 to 1340 liters per 1000 cubic meters (6 to 10 gallons per 1,000 cubic feet) of gas. The energy used by a venturi scrubber is primarily a function of the pressure drop across the venturi throat. Pressure drops of 1.5 to 14.9 kPa (6 to 60 inches) are possible.

After the thorough mixing of gas and liquid, the particulate-contaminated droplets are separated from the gas stream. This separation typically occurs in a separator adjoining the venturi throat as shown in Figure 4-16. The increased size and inertia of the droplet-particle combination forces it to the side of the cyclone and the clean air exits through the cyclone top.



4-15. Generalized depiction of a dynamic or mechanically-aided wet scrubber.

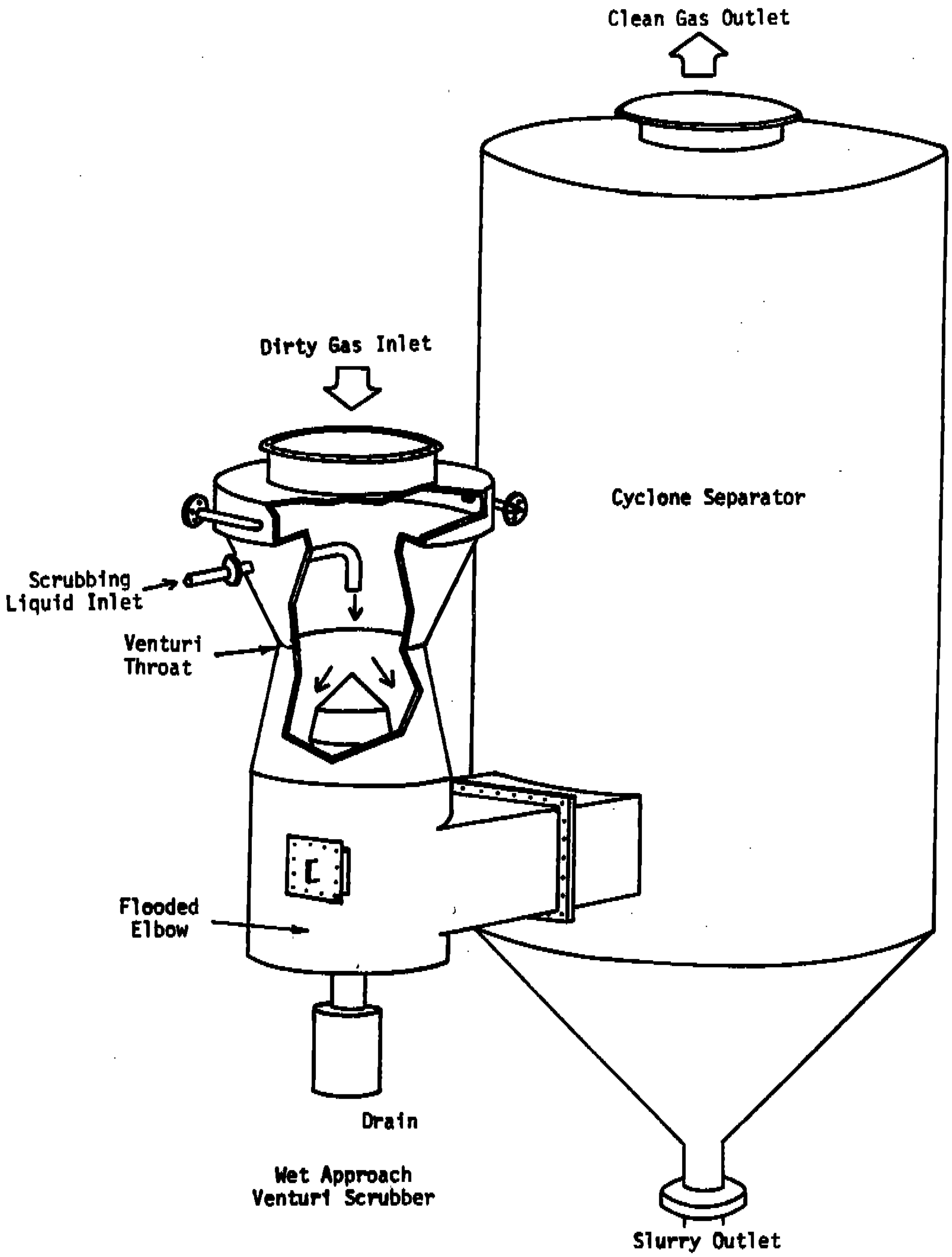


Figure 4-16. Generalized depiction of a venturi scrubber.

Wet scrubbers used in the metallic mineral industries are most often constructed of carbon steel with the option of plastic or resinous coating. Under corrosive or acidic conditions the use of stainless steel and the buffering of scrubber liquids are options.

4.5 PERFORMANCE DATA FOR WET SCRUBBERS

4.5.1 Particulate Emission Data

Particulate emission measurements were conducted by EPA on 13 wet scrubbers used to control emissions from crushing, screening, drying, and conveying operations at 7 metallic mineral processing sites. As with baghouses, one wet scrubber often controls the emissions from several process steps. The term "combined inlet duct" will be used in the same context described in Section 4.3 (Performance Data for Baghouses). Figures 4-17 and 4-18 present the inlet data for the wet scrubbers tested.

As noted in Section 4-4, 1.5- to 2.0-kPa (6- to 8-inch) pressure drop wet scrubbers are widely used in the industry. The test data reported below reflect the current industry practice. These test data demonstrate two general sets of conditions in the industry. First there is a midrange of conditions at a large number of plants that can be effectively controlled with equipment similar to that currently used in the industry. On the other hand, the inlet test data presented in this section and in the section on baghouse performance indicate the possibility that worse conditions may occur that are not suited to control techniques currently used in the industry. Although baghouses are well suited to small particle size, high concentration emissions, high moisture conditions may preclude their use in some cases. High energy wet scrubbers may be better suited to the worst cases which involve a combination of relatively small particle size, high emission levels, and high moisture conditions. Because few wet scrubbers above 2.5-kPa (10-inch) pressure drop are available for testing in this industry, Section 4.6 is devoted to mathematical modelling of the performance of high energy wet scrubbers.

Plant A processed copper ore mined from low grade ore deposits (0.5 percent copper) from an open pit mine in Arizona. Two wet scrubbers were tested at this operation. Wet scrubber A1 (1.5-kPa (6-inch) pressure

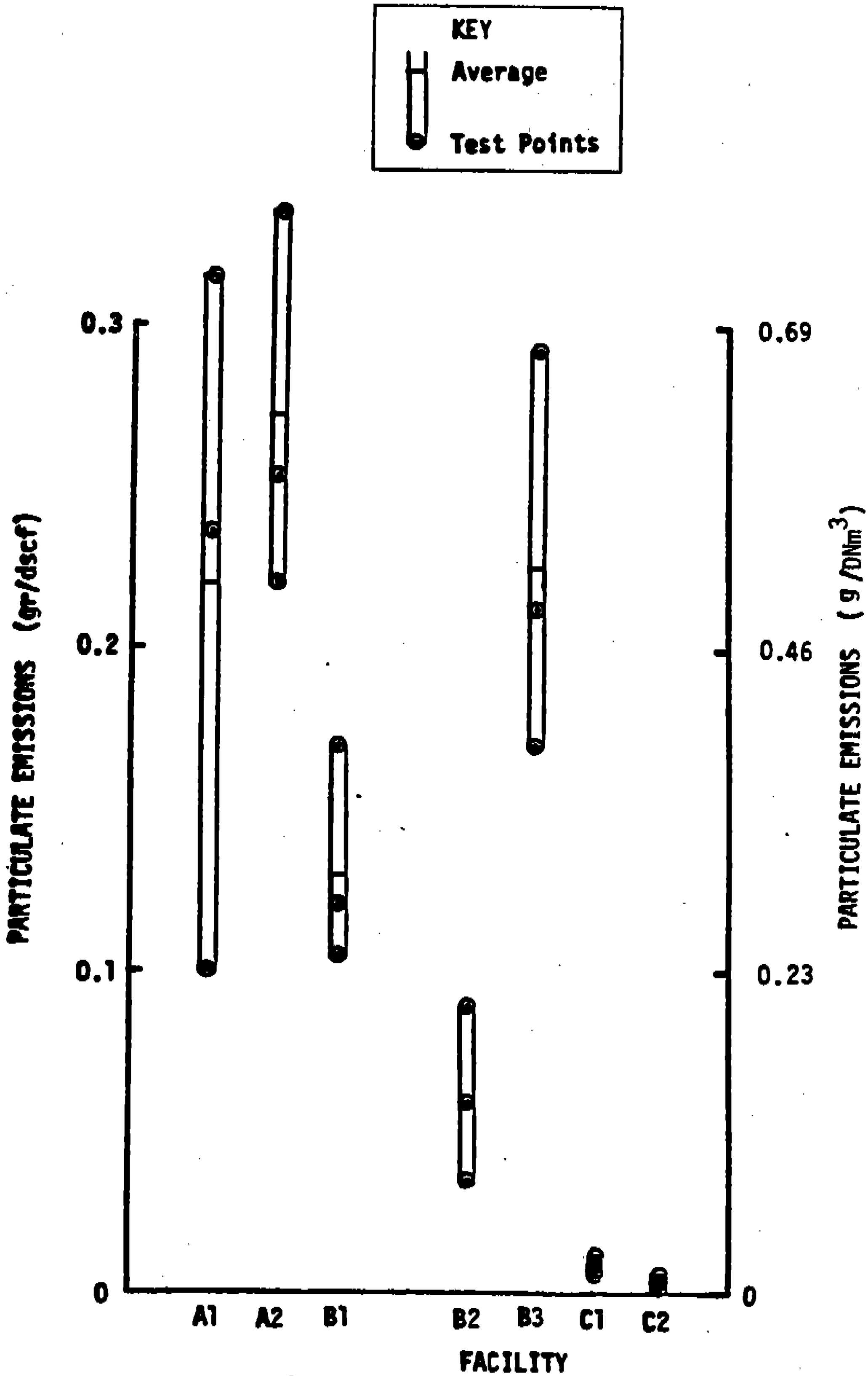


Figure 4-17. Inlet loadings to wet scrubbers A1 through C2 in the metallic minerals processing industry.

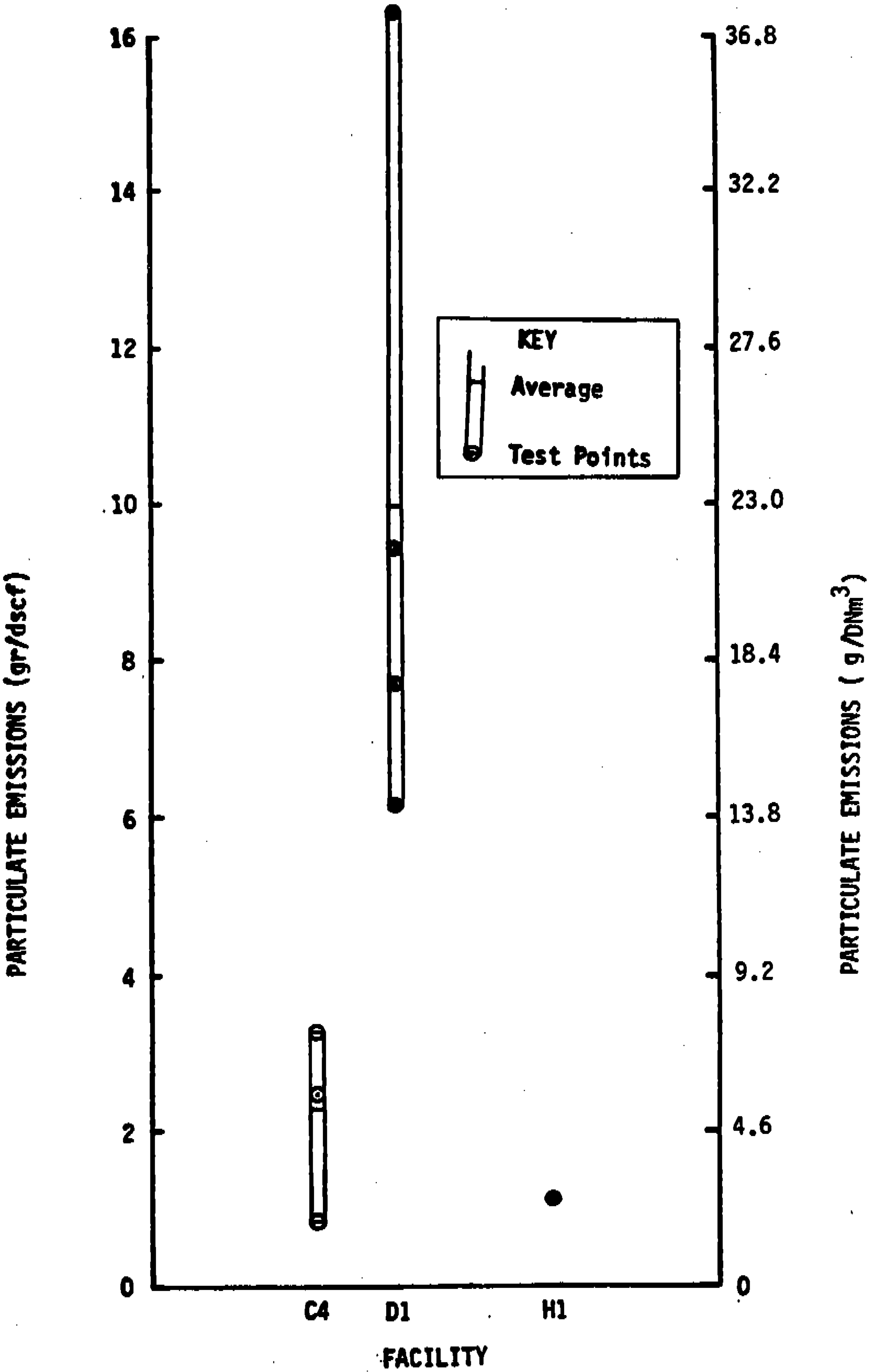


Figure 4-18. Inlet loadings to wet scrubbers C4 through H1 in the metallic minerals processing industry (note scale change from Figure 4-23).

drop) controlled emissions from the primary crusher surge bin and associated conveyor transfer points. As shown in Figure 4-17, the combined inlet duct concentration averaged 0.501 grams per dry normal cubic meter (g/DNm^3) (0.219 grains per dry standard cubic foot (gr/dscf)) and outlet concentration averaged 0.025 g/DNm^3 (0.011 gr/dscf) as shown in Figure 4-19. Figure 4-20 presents the average particle size distribution for the combined inlet duct and the outlet duct. Approximately 60 percent of both the inlet and outlet particles were greater than 7 microns though the outlet showed a higher percentage of submicron particles. By comparison with the combined inlet, the particle size distribution of primary crusher surge bin showed 97 percent of the particles greater than 7 microns. The conveyer inlet duct was closer to the combined inlet distribution with 65 percent of the particles greater than 7 microns. A third inlet duct to the total scrubber inlet was not tested for particle size distribution.

Wet scrubber A2 (1.5-kPa (6-inch) pressure drop) at Plant A controlled emissions from a secondary crushing operation and an ore reclaim operation. Reclaiming refers to the process of withdrawing ore from a storage area and conveying it to a processing operation. As shown in Figure 4-17, the combined inlet concentration averaged 0.622 g/DNm^3 (0.272 gr/dscf) and as shown in Figure 4-19, the outlet concentration averaged 0.041 g/DNm^3 (0.018 gr/dscf). Figure 4-21 presents the average particle size distribution for both the combined inlet and the outlet particulate emissions. Approximately 70 percent of the combined inlet particles were greater than 7 microns while 85 percent of the outlet particles were greater than 7 microns. Theoretically the outlet particles should show a smaller size distribution because the wet scrubber preferentially collects larger particles. The larger outlet particles may represent the agglomeration of smaller particles that occurs under the high moisture conditions following the scrubber.

Based on an average of 3 runs as shown in Figure 4-21, 78 percent of the particles from the secondary crusher alone were greater than 7 microns compared with 95 percent from the primary crusher. In principle, one might expect smaller particle sizes from finer crushing

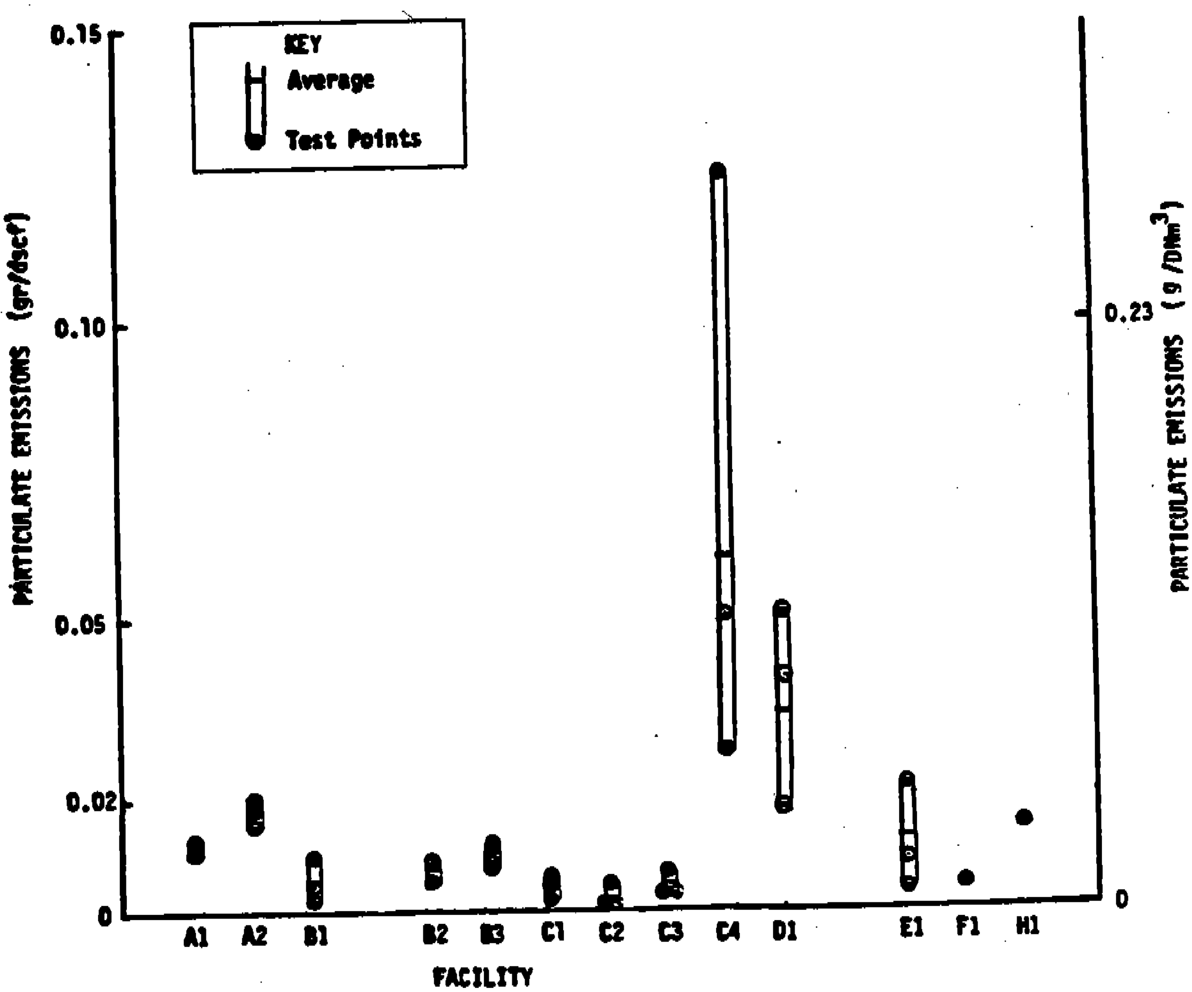


Figure 4-19. Particulate emissions from low energy wet scrubbers at metallic minerals processing operations (see Section 4.6 for high energy wet scrubber performance).

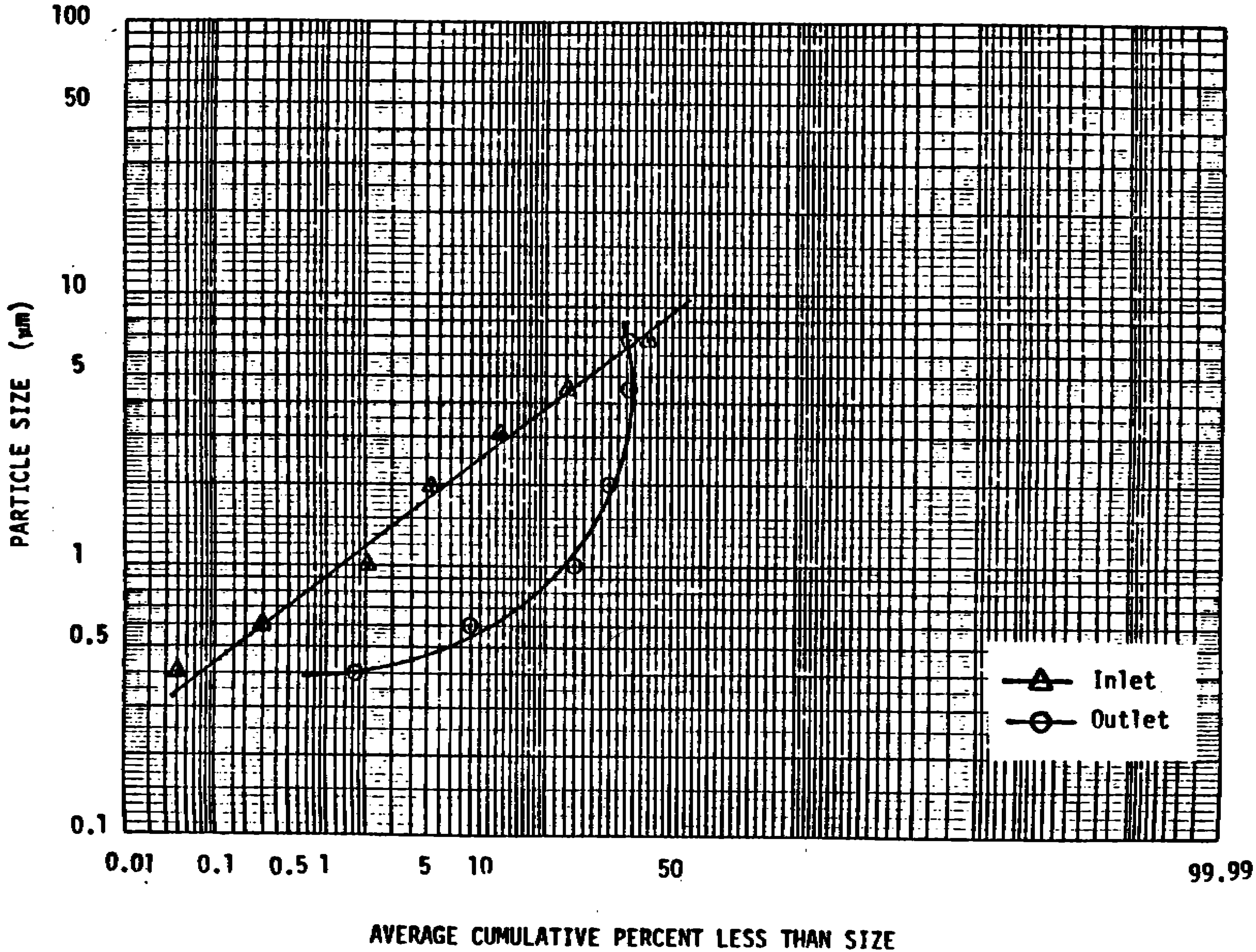


Figure 4-20. Particle size distribution for inlet and outlet streams at wet scrubber A1.

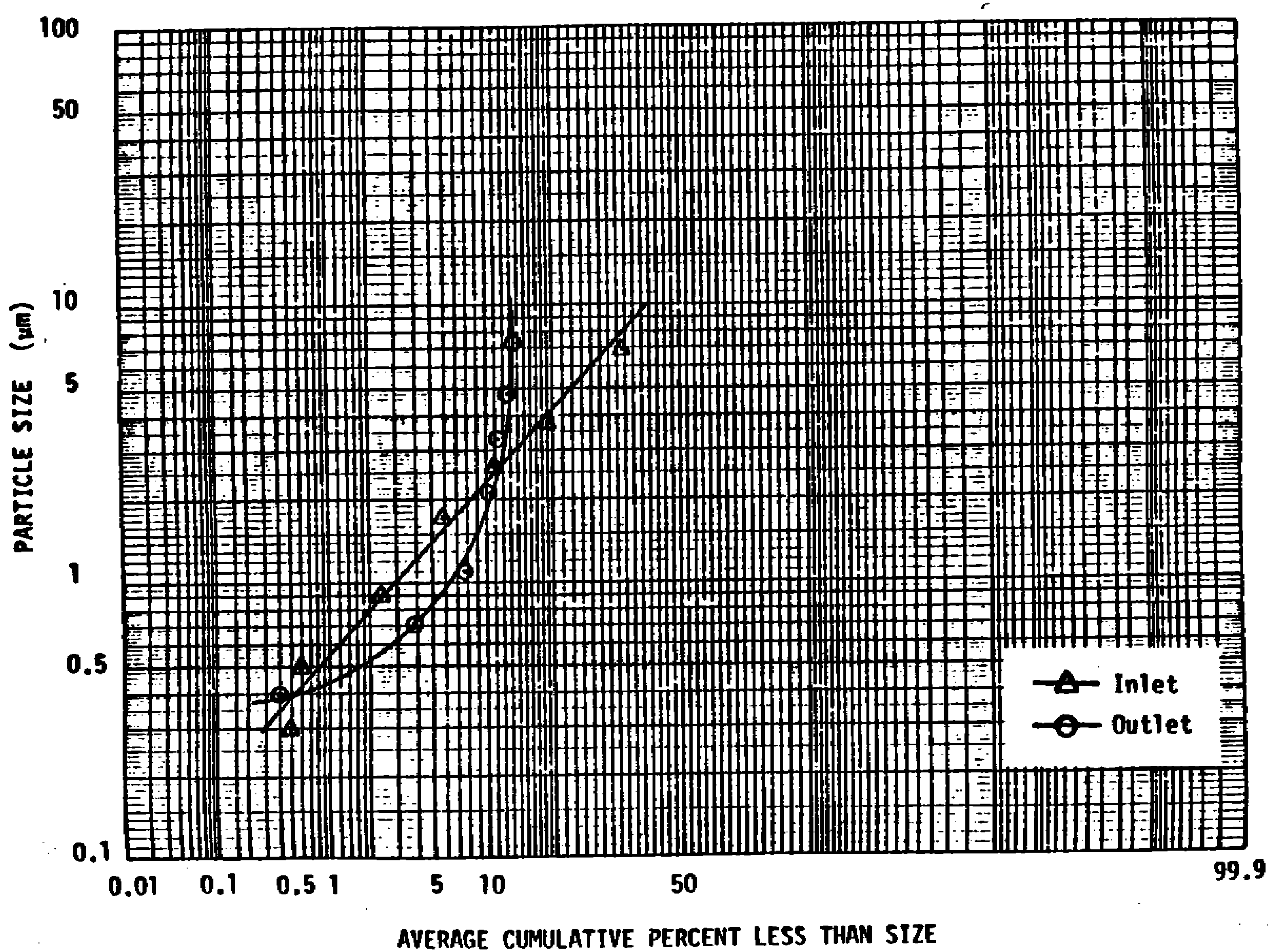


Figure 4-21. Particle size distribution for inlet and outlet streams at wet scrubber A2.

operations, although in this case the difference between primary and secondary crushing operations may be an artifact of the data. In the case of the secondary crusher 2 runs showed 93 percent of the particles greater than 7 microns, and the third run showed 50 percent greater than 7 microns.

Plant B processes molybdenum from ore mined from an underground deposit in Colorado. Three wet scrubbers were tested at this plant. All three scrubbers operated with a 1.5- to 2.0-kPa (6- to 8-inch) pressure drop.

Scrubber B1 controls emissions from a primary crusher pit, apron feeder, and a conveyor transfer point. In addition to controlling emissions from the primary crusher by ducting emissions through a wet scrubber, Plant B also uses a wet suppression spray system at the crusher pit.

Measurements of the combined inlet duct at this scrubber were not possible. Therefore, a weighted average of the concentrations measured at the crusher pit inlet duct and the combined apron feeder duct and conveyor duct was taken to determine the total inlet concentration. As shown in Figure 4-17, the combined inlet concentration, as calculated, averaged 0.302 g/DNm^3 (0.132 gr/dscf). The outlet concentrations were low with an average of 0.012 g/DNm^3 (0.005 gr/dscf) as shown in Figure 4-19. Between 33 and 42 percent of the particles from the transfer point and the crusher pit were less than 8 microns as shown in Figure 4-22. The scrubber exhaust outlet showed 75 percent of the particles to be less than 8 microns (Figure 4-23).

Wet scrubber B2 controlled emissions from a pebble milling operation. Emissions were collected from the screening operation before the mill and a bucket elevator transfer point. The combined inlet concentration averaged 0.137 g/DNm^3 (0.060 gr/dscf) while the outlet concentration averaged 0.016 g/DNm^3 (0.007 gr/dscf) as shown in Figures 4-17 and 4-19 respectively. Approximately 30 percent of the combined inlet particles were less than 8 microns while 83 percent of the outlet particles were less than 8 microns as shown in Figure 4-24. Approximately 50 percent of the particles from bucket elevator duct and 50 percent of the particles from the mill screen duct were less than 8 microns.

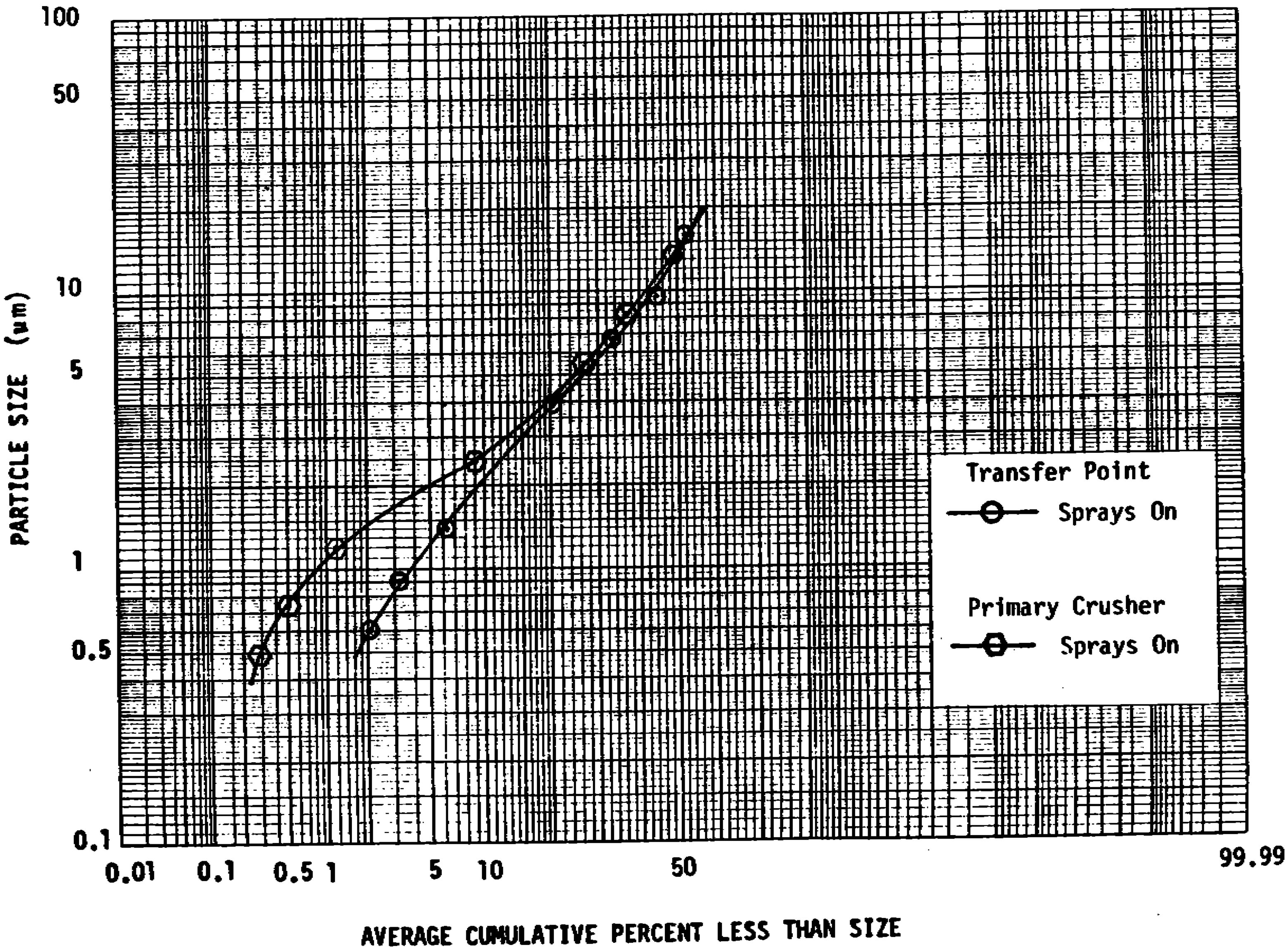


Figure 4-22. Particle size distribution for the inlet streams to wet scrubber B1 with and without wet suppression.

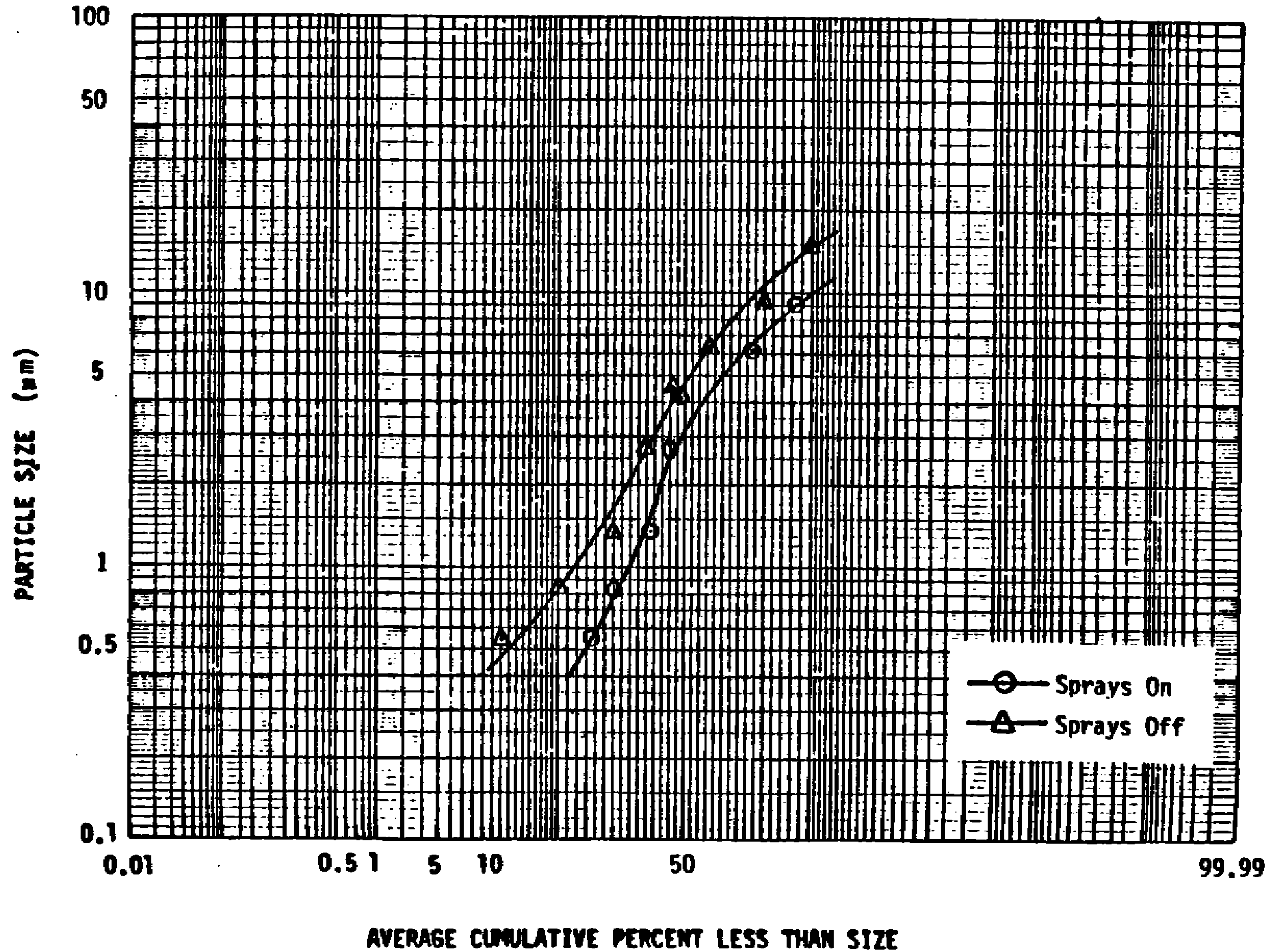


Figure 4-23. Particle size distribution for the outlet stream from wet scrubber B1.

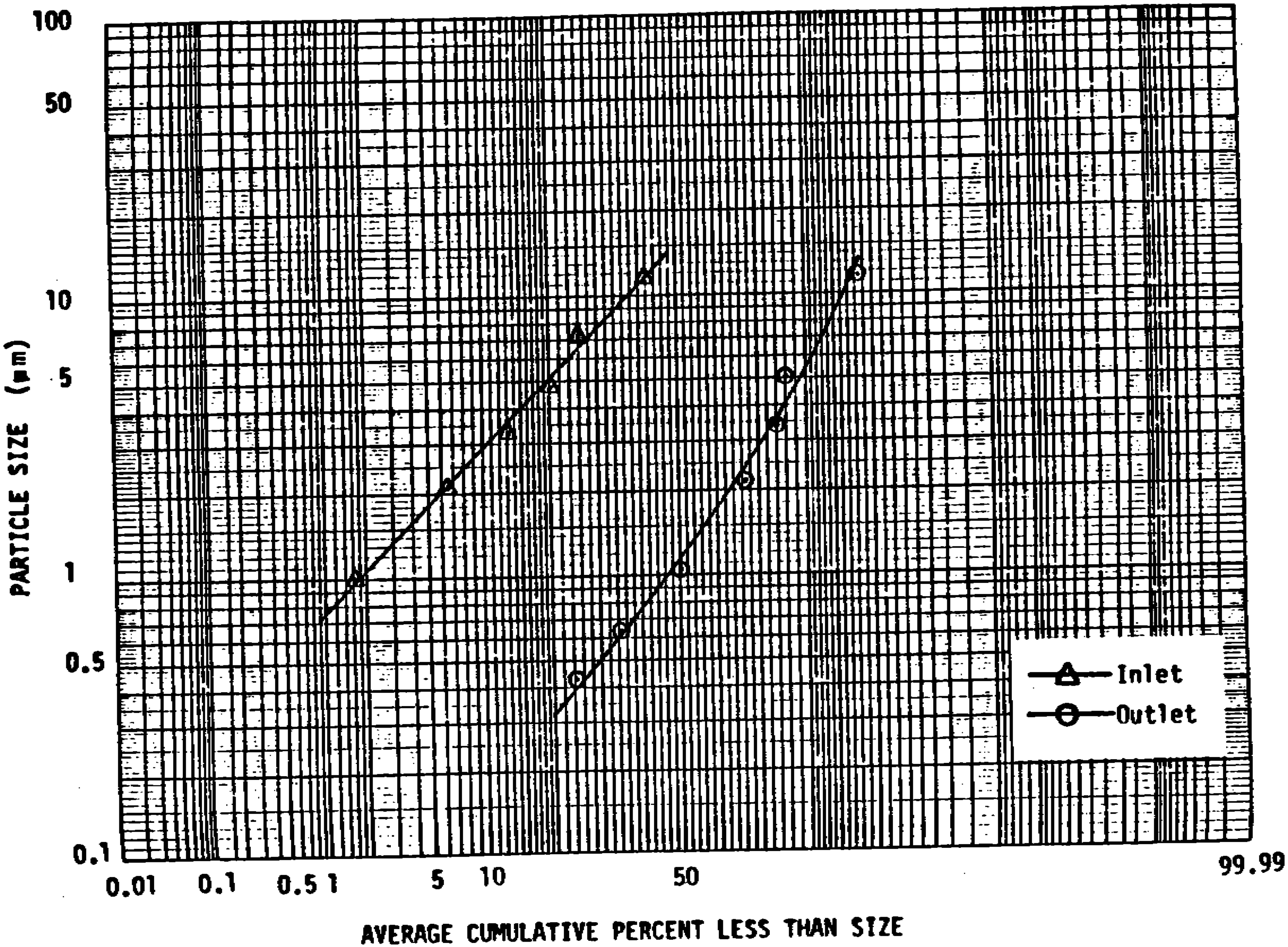


Figure 4-24. Particle size distribution for inlet and outlet streams at wet scrubber B2.

The wet scrubber B3 controlled emissions from ore concentrate dryers. As shown in Figure 4-17, the combined inlet from the dryers averaged 0.51 g/DNm^3 (0.224 gr/dscf) while the scrubber outlet averaged 0.020 g/DNm^3 (0.009 gr/dscf) as shown in Figure 4-19. Particle sizes were significantly smaller than with the other operations. As shown in Figure 4-25, 90 percent of the particles were less than 8 microns and 45 percent of the particles were less than 2 microns. The outlet particle size distribution was similar with 96 percent of the particles less than 8 microns.

Plant C processes uranium from ore deposits extracted from an underground mine in Wyoming. Four scrubbers were tested at Plant C. Wet scrubber C1 (8-inch pressure drop) controlled emissions from a primary crusher complex including the crusher and vibrating grizzly exhaust duct and the conveyor transfer point exhaust system. The contribution of a third duct system exhausting a second set of conveyors was not tested directly.

The inlet concentrations were very low from this operation; in fact, the uncontrolled emission rates at this plant compare favorably with the controlled emission rates at other plants tested. As shown in Figure 4-17, combined inlet concentration averaged 0.021 g/DNm^3 (0.009 gr/dscf) while the outlet averaged 0.008 g/DNm^3 (0.004 gr/dscf) as shown in Figure 4-19.

Wet scrubber C2 (1.5-kPa (6-inch) pressure drop) controls the emissions from the fine ore bins and associated transfer points. Uncontrolled inlet emissions were again very low, averaging 0.010 g/DNm^3 (0.004 gr/dscf) as shown in Figure 4-17. The outlet concentration averaged 0.005 g/DNm^3 (0.002 gr/dscf) (see Figure 4-19).

The particle size distributions of the combined inlets to both C1 and C2 indicated a high percentage of submicron particles as shown in Figure 4-26. Extrapolation of these distributions to conditions with higher uncontrolled emission rates would not be reliable because of the bias in the very low uncontrolled emission rates. By comparison the uncontrolled emissions from the dryer (see C4 below) had a median particle size of 6 microns and a concentration of 5.15 g/DNm^3 (2.25 gr/dscf).

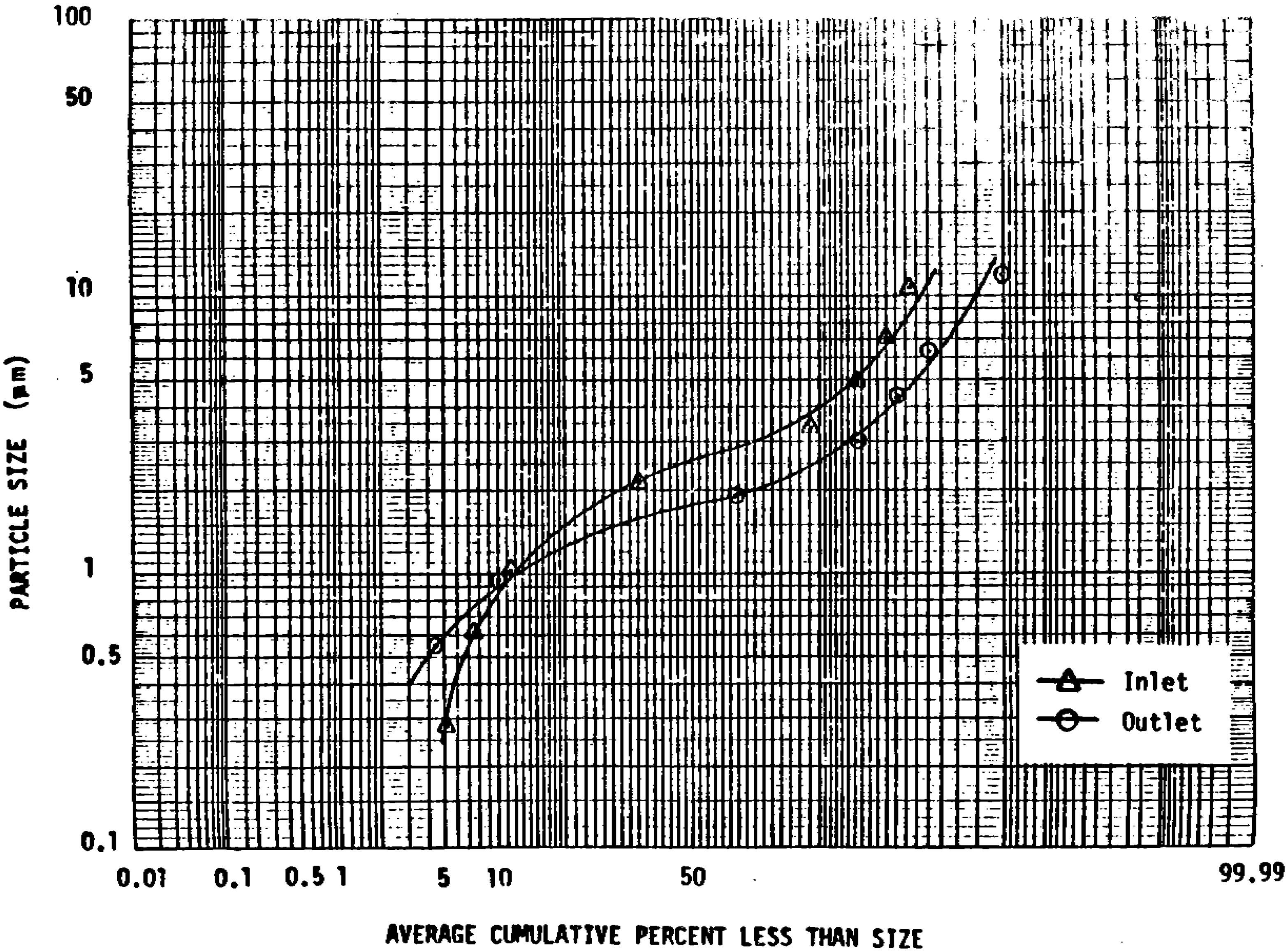


Figure 4-25. Particle size distribution for the inlet and outlet streams at wet scrubber B3.

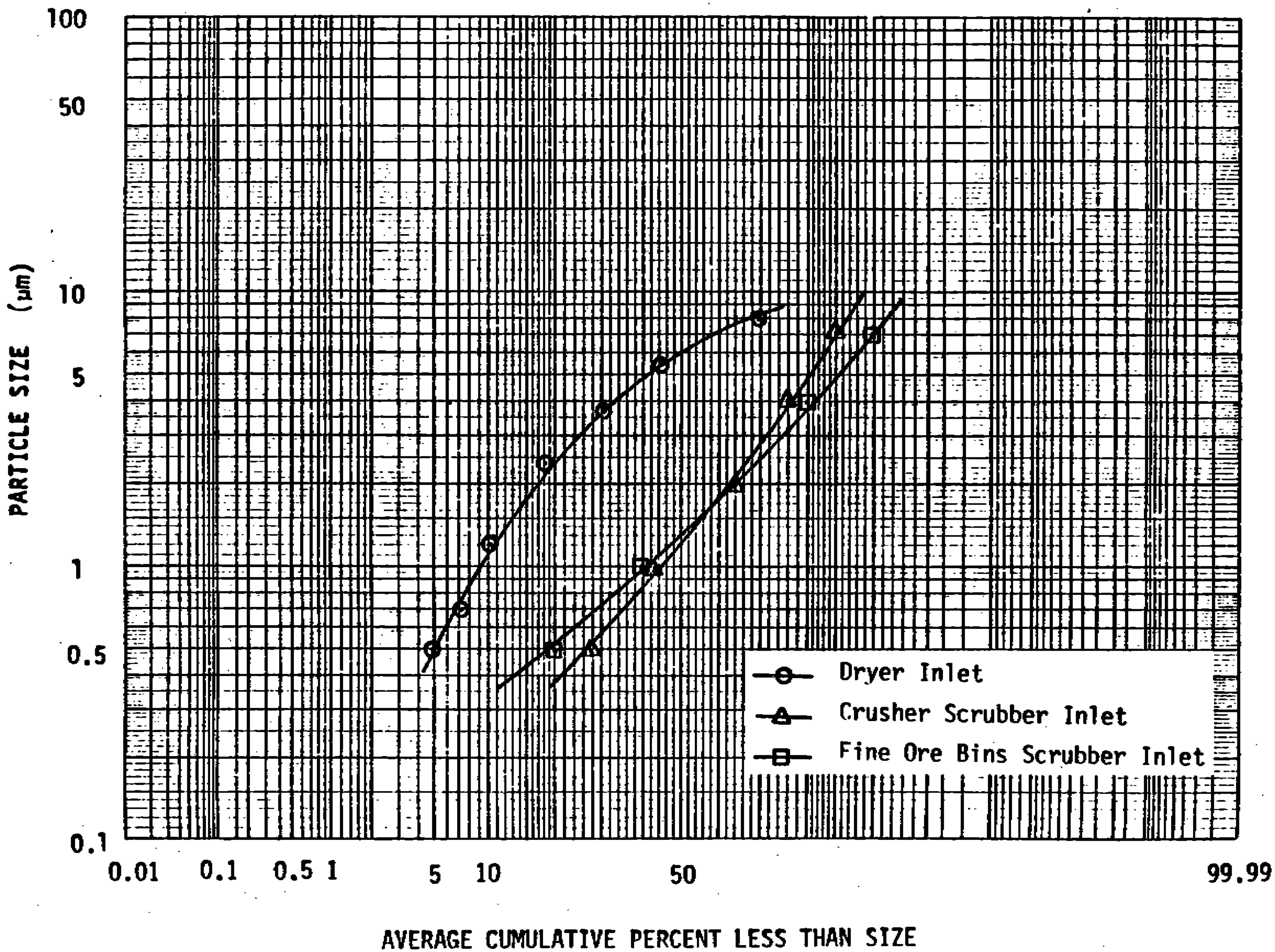


Figure 4-26. Particle size distribution for the inlet streams at wet scrubbers C1, C2, and C4.

Wet scrubbers C3 and C4 control emissions from operations that occur after the beneficiation of uranium ore. As discussed in Chapter 3, the environmental, energy, and economic impacts of the control of these operations will not be covered in Chapters 6, 7, and 8 of this document. Because the radioactive composition of these emissions should not affect the control of total particulate emissions, test results from these scrubbers are included because of their relevance to the control of emissions from drying and product loadout operations.

Wet scrubber C3 controlled emissions from the yellowcake packing area. The outlet concentration averaged 0.010 g/DNm^3 (0.004 gr/dscf), as shown in Figure 4-19. Uncontrolled emissions from this packaging process were not tested. The outlet duct from scrubber C3 is joined with the inlet duct to wet scrubber C4. The emissions from the packaging operation are thus treated by two scrubbers in series.

Wet scrubber C4 (1.5-kPa (6-inch) pressure drop) also controls emissions from a yellowcake drying operation. Uncontrolled emissions from this drying process were considerably higher than at the other facilities at Plant C and averaged 5.157 g/DNm^3 (2.254 gr/dscf). The total inlet concentration to scrubber C4 was taken as a weighted average of the dryer duct and the packaging operation duct. This inlet concentration averaged 2.06 g/DNm^3 (0.90 gr/dscf) while the outlet averaged 0.156 g/DNm^3 (0.068 gr/dscf), as shown in Figure 4-18 and 4-19 respectively. Figure 4-26 shows an average of 18 percent of the particles from the dryer inlet to the wet scrubber are below 2 microns and 40 percent are less than 5 microns. Seventy percent of the outlet particles were less than five microns. The particle size distribution found at the dryer exhaust is more indicative of the range of particle sizes that would occur if this material was processed under drier conditions with consequently higher uncontrolled emission rates.

Plant D processes vanadium from ore and slag. Vanadium ores are extracted from an open pit operation. Wet scrubber D1 controls emissions from a coarse ore dryer and transfer points. Emissions from these points are ducted through two separate dry cyclones before treatment by a single wet scrubber. A weighted average of the emissions from the two dry cyclones was taken to represent the total inlet flow to the wet scrubber because no direct measure of the combined inlet was possible. Total calculated inlet concentration averaged 22.2 g/DNm^3 (9.7 gr/dscf) (Figure 4-18) while the outlet averaged 0.088 g/DNm^3 (0.039 gr/dscf) (Figure 4-18). As shown in Figure 4-27, 30 percent of the inlet particles were less than 6 microns and 4 percent less than 2 microns. No data were taken on scrubber outlet particle size. The larger particle sizes in the uncontrolled emissions from this dryer, in comparison with the dryers at Plants B and C, reflects the size distribution of the coarse ore fed to it. The dryer at Plant D dried the ore before a final grinding process, whereas the dryers at B and C were the final process of the concentration step.

Plant E processes iron ore mined from an open pit operation. Processing at Plant E involves the crushing, concentrating, and pelletizing of the iron ore (hematite and magnetite combination). The plant uses wet scrubbers (2.5-kPa (10-inch) pressure drop) to control emissions from crushing and pelletizing operations. A wet scrubber controlling emissions from the secondary crusher, secondary ore bin, vibrating screen and screen undersize, and a conveyor for ore to the tertiary ore bin was tested by EPA. As shown in Figure 4-19, the emissions from this scrubber averaged 0.026 g/DNm^3 (0.011 gr/dscf). Uncontrolled emissions and particle size distributions in the combined or individual inlet ducts were not measured.

Plant F also processes iron ore mined from an open pit operation. This plant was tested on two occasions, once in 1973 and again in 1978 after the wet scrubbers had been replaced by baghouses. The 1973 test measured emissions from a wet scrubber (pressure drop unknown) controlling secondary and tertiary crushing operations. Emissions from the wet scrubber, tested in 1973, were 0.011 g/DNm^3 (0.005 gr/dscf). Only one replicate was run, and no measurement of inlet particle size or concentration were taken.

Plant H processed bauxite imported from Jamaica during the test period. Wet scrubber H1 controlled emissions from a transfer point at a ship unloading facility. Only one inlet and outlet concentration

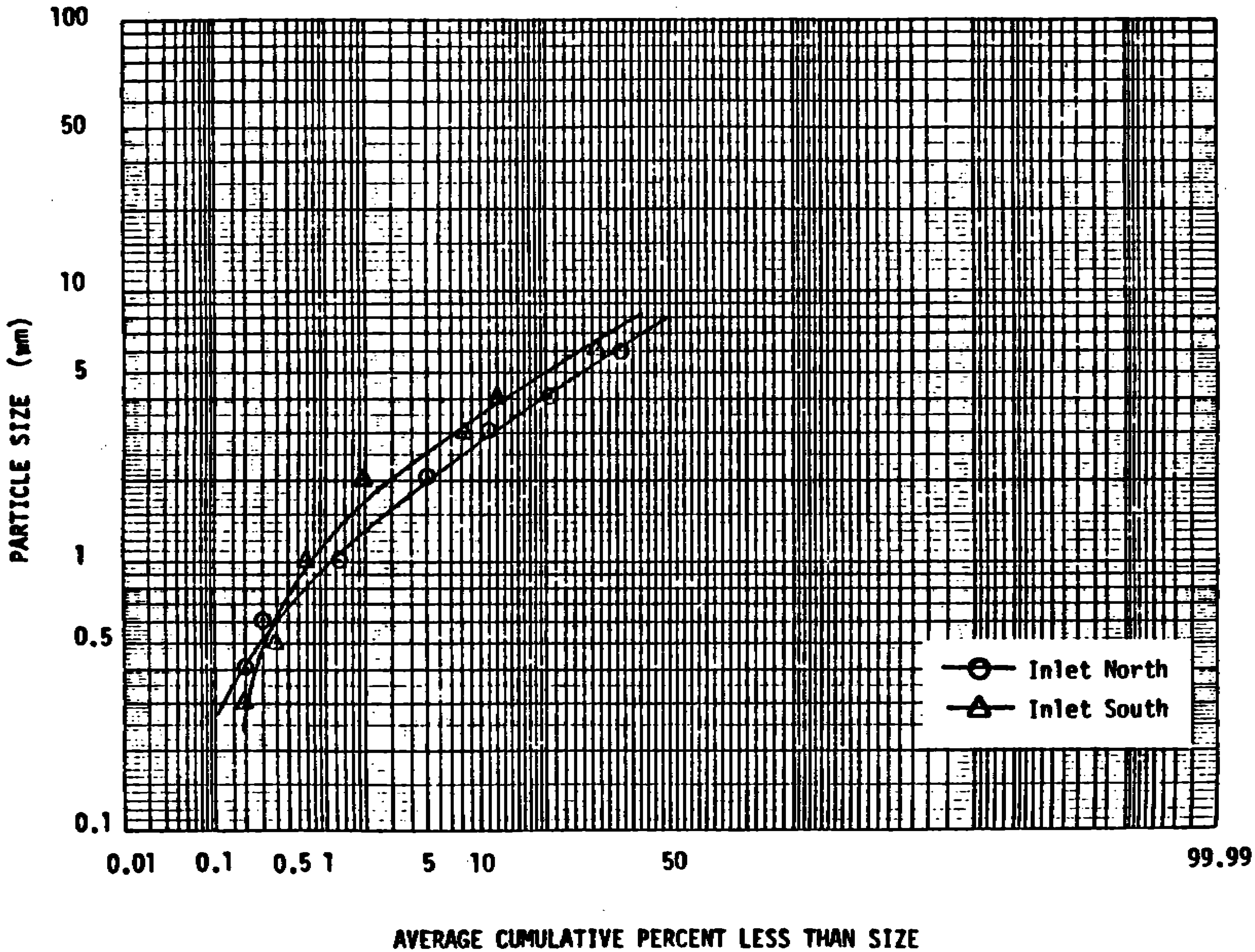


Figure 4-27. Particle size distribution for the inlet streams to wet scrubber D1.

measurement was taken. Values were 2.61 and 0.039 g/DNm^3 (1.14 and 0.017 gr/dscf), as shown in Figures 4-24 and 4-25, respectively.

As noted in the text above and shown in Figure 4-19, the emissions from dryers at Plants C and D were considerably higher than from all other scrubbers tested. Because the scrubbers tested at these dryers were relatively low pressure drop scrubbers, the performance of higher energy wet scrubbers was modeled upon the characteristics of dryer exhausts at Plants B, C, and D. The rationale for this modelling is consistent with the method of applying worst case conditions as discussed in the introduction to this section; the results are presented in Section 4.6.

4.5.2 Visible Emissions Data: Wet Scrubbers

In addition to particulate concentration measurements taken in accordance with EPA Method 5 procedures, visible emission observations were also made during the emissions tests described above. Table 4-3 presents a summary of EPA Method 9 data. There is no direct relationship between the opacity data shown for the various wet scrubbers and the outlet emission concentrations. For example, scrubber B3 averaged outlet concentrations of 0.02 g/DNm^3 (0.009 gr/dscf) and opacity readings as high as 24 percent while scrubber C4 averaged outlet concentrations of 0.16 g/DNm^3 (0.067 gr/dscf) with opacity readings ranging from 0 to 5 percent.

Section 4.8 will present visible emission data for fugitive emissions at hoods and other pickup points at metallic and non-metallic minerals plants.

4.6 MATHEMATICAL MODELLING OF VENTURI SCRUBBER EFFICIENCY

Although fabric filter baghouses will most often show superior performance in removing small size particles, there are worst-case scenarios possible as discussed in Sections 4.4 and 4.5 where a high pressure drop wet scrubber may be the preferred type of control equipment. When high moisture ore is processed, the resulting emissions may blind the fabric filter in the baghouse resulting in increased pressure drop and decreased performance due to incomplete cleaning of the bags. Both Plant C and Plant I process high moisture ore though only Plant I uses a

Table 4-3. OPACITY MEASUREMENTS FROM WET SCRUBBER EXHAUST STACKS

Wet scrubber	Processes controlled	Mean opacity (percent)	Highest 6-minute average opacity (percent)	Lowest 6-minute average opacity (percent)
A1	Primary crusher; surge bin; conveyor transfer points	7	10	1
A2	Secondary crusher; ore reclaim	0	0	0
B1	Primary crusher; apron feeder; conveyor transfer points (sprays on)	6	10	5
B2	Pebble mill; screen; buck elevator transfer point	0	0	0
B3	Dryer	15	24	5
C1	Primary crusher; grizzly screen; conveyor transfer	0	0	0
C2	Fine Ore Bins	0	0	0
C3	Packaging area	No measurements possible		
C4	Dryer	2	5	0

(continued)

Table 4-3. Concluded

Facility	Facilities controlled	Mean opacity (percent)	Highest 6-minute Average Opacity (percent)	Lowest 6-minute Average Opacity (percent)
D1	Dryer	1	5	0
E1	Secondary crusher, screens; conveyors	0	2	0
F1	Secondary and tertiary crusher		No measurements taken	
H1	Ship unloading transfer point	19	20	18

baghouse to control emissions. During testing at Plant I, the fabric filter bags required manual air-lancing between test runs in order to keep the pressure drop within acceptable levels. This rapid "blinding" of the bags which prevented proper cleaning by the pulse jet system presumably occurred as a result of the condensation of moisture from the warm, wet ore.

A second effect of high moisture conditions is the suppression of emissions from ore processing operations. As was pointed out in Section 4.4.1, the high moisture conditions under which Plant C operates suppressed uncontrolled emissions to levels comparable to controlled emissions at other metallic mineral plants. Measurements at Plant I also indicated low inlet concentrations.

Because high pressure drop venturi scrubbers were not available for testing in the metallic mineral processing industry, it was decided to compare the performance of 1.5-kPa (6-inch), 3.7-kPa (15-inch), and 7.5-kPa (30-inch) venturi scrubbers utilizing a modelling program developed by Sparks (1978). The predictions of this model have been compared to the performance of actual scrubbers controlling fly ash particles of various types. This model predicts particle penetration to within ±10 percent of actual values (95 percent confidence interval) (Sparks, 1981). Performance of the venturi scrubber was modelled under two sets of circumstances. The first set of conditions involved the use of the particle size data and uncontrolled particulate emission concentration as measured from a secondary crusher at Plant I. The particle size data at Plant I are typical of values found in the metallic mineral industry.

The second set of conditions involved the use of particle size data and uncontrolled emission concentrations taken at Plant Q. The particle sizes measured at Baghouse Q2 were the smallest measured at any site with a comparable level of emissions in either the metallic or non-metallic industry. There is good reason to expect this to have been the case. The fluid energy mill tested at Plant Q is a dry size-reduction operation that reduces material to an approximate diameter of 1 to 20 microns, a smaller diameter than is typically required in the metallic mineral processing industry. Because the fluid energy mill pneumatically classifies material, the exhaust stream from this operation would be expected to contain a significantly higher percentage of submicron material than an exhaust stream from a typical crushing operation. The combination of uncontrolled emission concentrations and small particle size at Baghouse Q2 provide the most difficult control case tested in the non-metallics industry and reflect conditions worse than any likely to occur in the future in the metallic minerals industry.

The parameters used in modelling the performance of venturi scrubbers are presented in Appendix C. Where more than one particle size test was run at a facility, the distribution showing the lowest median particle size was used. Appendix C also presents a verification of this model against known conditions and performance data for the metallic mineral industry.

Table 4-4 summarizes the results of this modelling. As expected the control efficiency (defined in the program used as 100 (1-p) where p is the proportional particle penetration integrated over the particle size distribution) is directly related to pressure drop. At any given pressure drop the control efficiency is greater for Plant I than for Plant Q. Under worst-case conditions represented by Plant Q, a 1.5-kPa (6 inch) venturi scrubber could achieve emission levels of 0.34 g/DNm^3 (0.15 gr/dscf); a 3.7-kPa (15 inch) venturi scrubber could achieve 0.14 g/DNm^3 (0.06 gr/dscf). Under more typical industry conditions represented by Plant I, the venturi scrubber would provide more effective control both in terms of the percent reduced and the absolute levels achieved. The baghouse at Q2 provided considerably better performance under dry conditions than that predicted for a 7.5-kPa (30-inch) venturi scrubber.

Because the dryers used in the metallic mineral industry might have similar problems with high moisture and because no data were available on the use of high pressure drop scrubbers on dryers, a separate set of modelling exercises as undertaken for dryers at Plant B, C, and D. The modelling parameters are detailed in Appendix C and the results are summarized in Table 4-5. As shown in this table, all the dryers would average emissions of 0.05 g/DNm^3 (0.02 gr/dscf) or less with a 7.5-kPa (30-inch) venturi scrubber.

Table 4-4. EMISSION CONCENTRATIONS POSSIBLE WITH VENTURI SCRUBBERS GIVEN WORST- AND MOIST-CASE CONDITIONS

Facility	Efficiency of a 1.5-kPa (6") wet scrubber	Emissions concentration for a 1.5-kPa (6") wet scrubber using tested inlet concentration		Efficiency of a 3.7-kPa (15") wet scrubber	Emissions concentration for a 3.7-kPa (15") wet scrubber using tested inlet concentration		Efficiency of a 7.5-kPa (30") wet scrubber	Emissions concentration for a 7.5-kPa (30") wet scrubber using tested inlet concentration	
	(percent)	g/DNm^3	(gr/dscf)	(percent)	g/DNm^3	(gr/dscf)	(percent)	g/DNm^3	(gr/dscf)
Q2[1]	85.4	0.34	(0.15)	94.2	0.14	(0.06)	97.9	0.05	(0.02)
I1[2]	98.4	0.011	(0.005)	99.38	0.004	(0.0019)	99.81	0.001	(0.0006)

[1]Worst case particle size distribution.

[2]Actual high moisture case.

Table 4-5. MODELLING OF VENTURI SCRUBBER PERFORMANCE WITH DRYER EXHAUST CHARACTERISTICS

Process unit	Plant	Δp kPa (in. W.G.)	Test data: Inlet g/DNm^3	Test data: Inlet (gr/dscf)	Test data: Outlet g/DNm^3	Test data: Outlet (gr/dscf)	Modelling outlet data: 3.7-kPa (15") Venturi scrubber g/DNm^3	3.7-kPa (15") Venturi scrubber (gr/dscf)	7.5-kPa (30") Venturi scrubber g/DNm^3	7.5-kPa (30") Venturi scrubber (gr/dscf)
Dryer	D	2.5 (10")	21.7	(9.5)	0.11	(0.05)	0.050	(0.021)	0.007	(0.003)
			17.2	(7.5)	0.05	(0.02)	0.039	(0.017)	0.005	(0.002)
			14.2	(6.2)	0.09	(0.04)	0.033	(0.014)	0.004	(0.002)
			36.04	(15.75)		--*	0.083	(0.036)	0.011	(0.005)
Dryer	C	1.5 (6")	2.29	(1.001)	0.286	(0.125)	0.041	(0.018)	0.0015	(0.007)
			3.04	(1.33)	0.117	(0.051)	0.055	(0.024)	0.0020	(0.009)
			0.82	(0.357)	0.062	(0.027)	0.015	(0.006)	0.0005	(0.002)
Dryer	B	1.5 (6")	0.48	(0.212)	0.029	(0.013)	0.003	(0.001)	0.0003	(0.0002)
			0.38	(0.168)	0.013	(0.006)	0.002	(0.001)	0.0003	(0.0001)
			0.67	(0.293)	0.017	(0.007)	0.004	(0.002)	0.0005	(0.0002)

*Outlet was not tested.

4.7 EXHAUST SYSTEMS AND DUCTING

The efficient and effective control of particulate emissions requires the capture of these emissions at the source of generation. Capture requires the proper design of a hood and ducting system. Such a system usually consists of a close-fitting hood surrounding the point at which particle-laden air is discharged into a ducting system and carried to a collection device by one or more exhaust fans.

Design of an exhaust system requires careful planning in order to ensure that air flow is sufficient to pick up all emissions and convey them to the collector. On the other hand, excessive air flow rate will overburden the system and increase capital and operating costs. Recommended exhaust requirements for several of the operations involved in metallic minerals processing are presented in Table 4-6.

The hood should be designed so that the process machinery can be easily reached. This can usually be achieved by installing doors in sheet metal hoods. Other enclosures that consist of of heavy rubber matting or other pliable material provide fewer problems for access. These materials, however, are not suitable where the hood or enclosure is to be an integral, free standing structure.

Dust must move through ductwork with sufficient velocity to avoid settling. Recommended minimum duct velocities have been published and are given in Table 4-7. The system must be as compact as possible to minimize friction and branching losses and to reduce operating (power) costs. For this reason, the collection devices should be placed as close as possible to the sources of emissions. Care must be taken to ensure that the ducts are designed with a balanced duct or static pressure. This means choosing duct sizes that result in a static pressure balance at each junction, achieving the desired air volume in each branch duct.

The following sections describe several of the process emission sources and how they can be enclosed and exhausted. Various guidelines for the design of the exhaust and ducting systems are also mentioned.

4.7.1 <u>Conveyor Belt Dust Control</u>

Dust generation occurs primarily at the point where ore is transferred from one conveyor to another especially where a drop is involved

Table 4-6. EXHAUST REQUIREMENTS FOR METALLIC MINERAL PROCESSING OPERATIONS[a]

Operation	Exhaust arrangement	Remarks
Conveyor belts	Hoods at transfer points enclosed as much as possible	For belt speeds less than 1 m/sec (200 ft/min), gas flow (Q) should be 0.5 m^3/sec for each meter of belt width (350 ft^3/min for each ft of belt width) with at least 0.75 m/sec (150 ft/min) gas velocity through openings. For belt speeds greater than 1 m/sec (200 ft/min), Q = 0.7 m^3/sec for each meter of belt width (500 ft^3/min per each foot of belt width) with at least 1 m/sec (200 ft/min) gas velocity through remaining openings. Also note the additional exhaust requirements on Figure 4-28 for material drops greater than 1 meter (3 feet).
Bucket elevator	Tight casing	For 0.05 m^3/sec for each square meter (100 ft^3/min per square foot) of elevator casing cross section (exhaust near elevator top and also vent at bottom if over 10.7 m (35 ft) high).
Grinders, crushers	Enclosure	Gas velocity of 1 m/sec (200 ft/min) to 2.5 m/sec through openings.

[a]Danielson (1973, p. 31).

Table 4-7. RECOMMENDED MINIMUM DUCT VELOCITIES[a]

Nature of contaminant	Examples	Dust velocity m/sec	(ft/min)
Gases, vapors, smokes fumes, and very light dusts	All gases, vapors, and smokes; zinc and aluminum oxide fumes; wood, flour, and cotton lint	10	(2000)
Medium-density dry dust	Buffing lint; sawdust; grain, rubber, and plastic dust	15	(3000)
Average industrial dust	Sandblast and grinding dust, wood shavings, cement dust	20	(4000)
Heavy dusts	Lead, and foundry shakeout dusts; metal turnings	25	(5000)

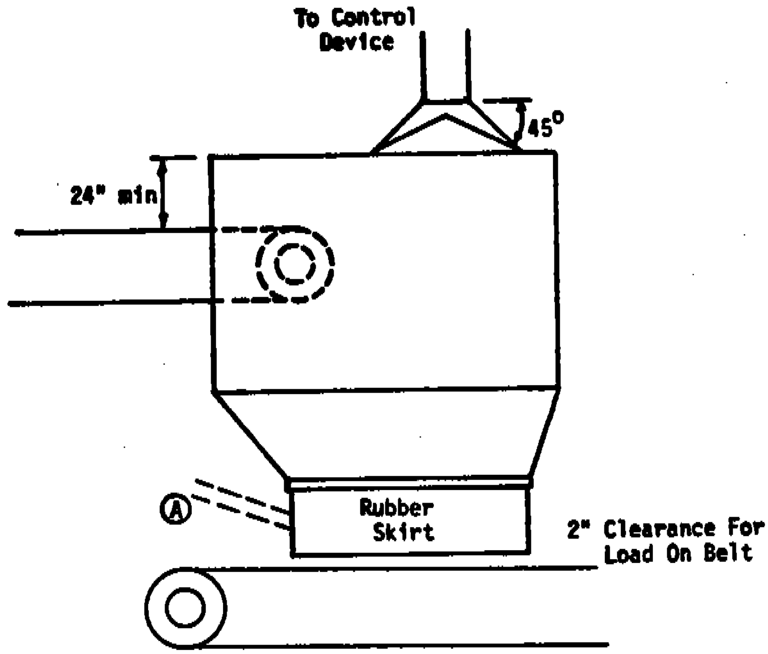
[a]Danielson (1973, p. 50).

which allows falling dust to become airborne. Ideally, the area including the head pulley of the feeding conveyor and the tail pulley of the receiving conveyor are enclosed. Two schematics of proposed enclosures with hooding points are represented in Figure 4-28 (American Conference of Governmental Industrial Hygenists (ACGIH), 1976, p. 5-33). One system is designed for less than a 1 m (3 ft) drop between the belts, the other designed for greater than a 1 m drop. The first of the two is seen most frequently in the industry. Ore is discharged into a small bin which feeds the pickup belt below. A hood located over the bin recovers any discharge created in the process of transferring the ore. The receiving belt is placed just below the outlet of the bin so that it, in effect, "drags" the ore into it. In addition, a rubber skirt is usually fitted at the belt opening where discharge from the bin occurs. The skirt narrows the opening through which particles can escape, in effect causing the crushed ore in the hopper discharge to act as a curtain that traps dust. Ideally, the open area at the bin discharge should be reduced to 0.16 m^2/m (0.2 ft^2/ft) of belt width.

These transfer points should be designed so that a minimum indraft of 0.75 to 1 m/sec (150 to 200 fpm) is provided at all openings when conveyor belt speeds of under 1 m/sec (200 fpm) are encountered. Because conveyor belts carrying ore act much like a fan, as conveyor belt speeds increase it is good practice to design air velocities into openings of conveyor enclosures at least equal to belt speeds (Laird, 1980). Minimum volumetric flow should be 0.5 $m^3/sec/m$ (350 cfm/ft) of belt width for belt speeds under 1 m/sec (200 ft/min) or 0.7 $m^3/sec/m$ (500 cfm/ft) of belt width for belt speeds over 1 m/sec (200 ft/min). Duct minimum velocity should be 18 m/sec (3,500 ft/min) (ACGIH, 1976, p. 5-33).

4.7.2 <u>Crushers and Dry Grinders</u>

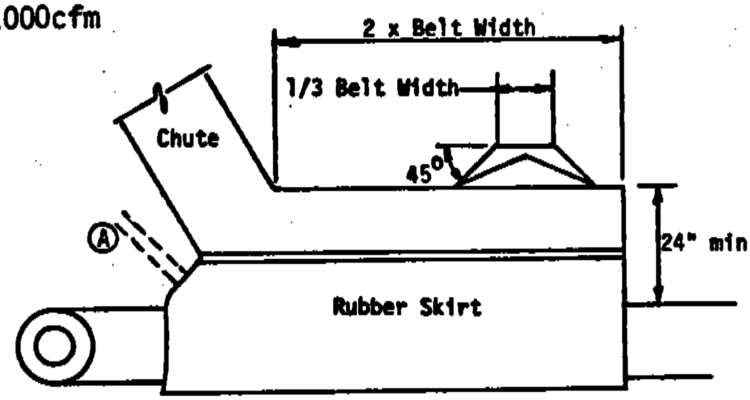
Crushing equipment generates a significant amount of dust emissions in the mineral processing industry. The wide range of sizes and types of crushing equipment and the variability of dust emissions require design specifications for exhaust systems that vary from plant to plant. Though dry grinding also constitutes a significant emission source at a few plants, dry grinding operations are not expected at future



Conveyor Transfer

Greater than 3' fall use additional control exhaust as shown Ⓐ at following rates:

Belt Width	Exhaust
12"-36"	Q= 700 cfm
above 36"	Q= 1000cfm



Chute to Belt Transfer

Figure 4-28. Methods of hooding conveyor transfer points (ACGIH,1976).

metallic mineral processing operations. Indraft velocities associated with the hooding around these crushers and dry grinders should be 1 m/sec (200 ft/ min) (Danielson, 1973).

For underground mining operations, primary crushing often takes place below ground. The ore is crushed sufficiently to allow loading into skips for elevation to the surface. In some mines, the rock breaks naturally into fragments small enough to allow direct loading into the skips with primary crushing occurring at the surface.

Surface primary crushers often have no hoods at the inlet but usually are hooded at the outlet. The crusher is often located in a pit at the surface that is ventilated to the control equipment (see Figure 4-29). The pits are maintained at negative pressure. A truck dump over or near the primary crusher, as depicted in Figure 4-29, is often enclosed in a building. The truck dump area of the building can then be exhausted to a collection device.

In controlling crushers, the objective is to enclose the source as well as possible. In secondary and tertiary crushers, this is performed by completely enclosing the inlet to the crushers with hoods fitted with maintenance doors. The outlet of the crusher has an apron feeder which is enclosed and ducted to a collection device. Figure 4-30 is a typical exhaust system for a secondary or tertiary crusher.

Ductwork follows the general design guidelines for other process equipment ducting. For impact crushers or grinders, exhaust volumes may range from 1.9 to 3.8 m^3/sec (4,000 to 8,000 cfm). For compression type crushers, an exhaust rate of 0.7 m^3/sec per meter (500 cfm/ft) of discharge opening is sufficient (ACGIH, 1976, p. 10-1 to 11-28). The width of the discharge opening will approximate the width of the receiving conveyor. For either type of crusher, pickup should be applied downstream of the crusher for a distance of at least 3.5 times the width of the receiving conveyor (Environmental Protection Agency, 1979).

4.7.3 Screens

In controlling dust emissions from screens, the best technique is to fully enclose the screens and undersize hopper with a hood. The screen discharge is then ducted to one or more control devices. Often, screening takes place immediately prior to a crushing operation and the screens are enclosed by the crusher's dust hood.

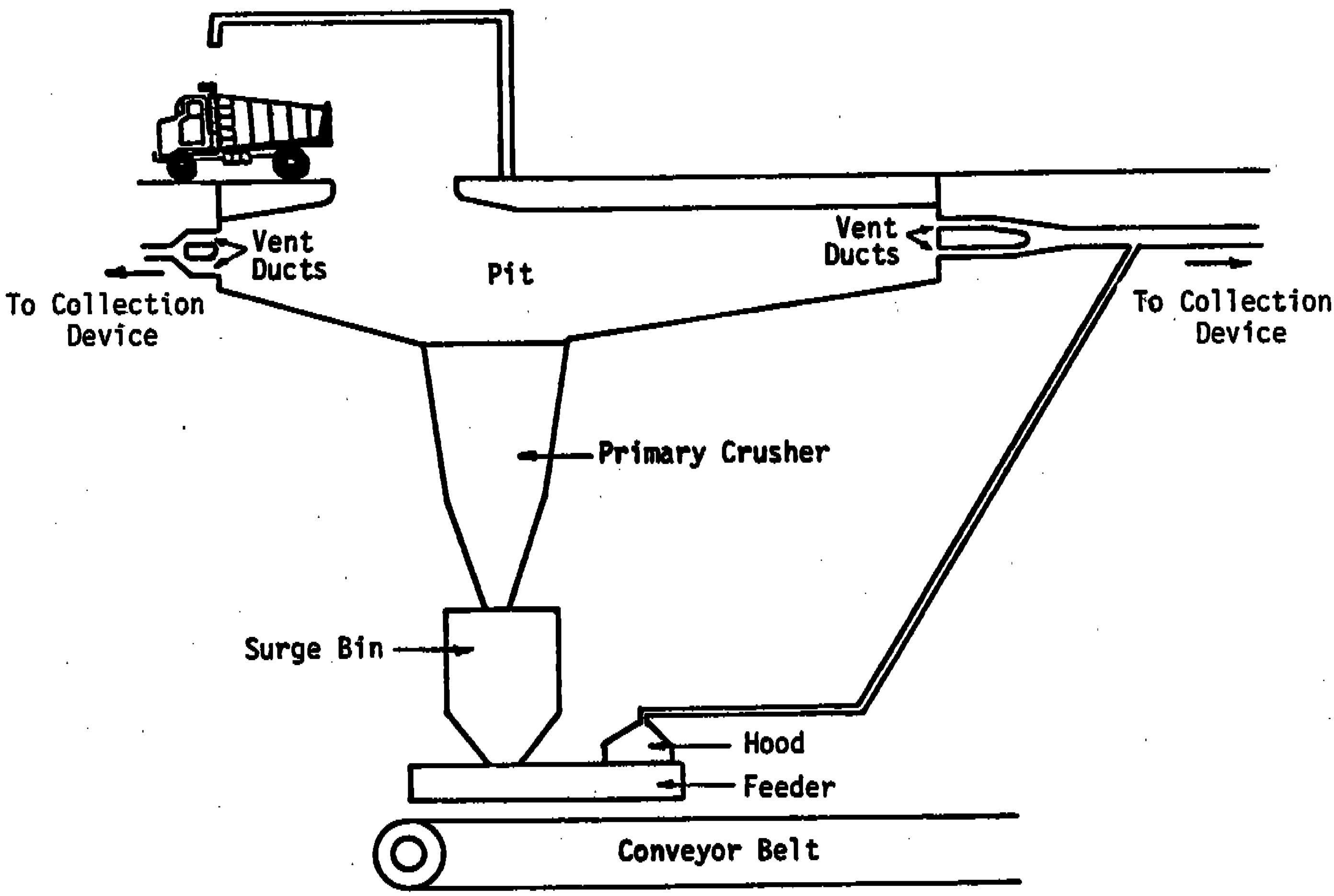


Figure 4-29. Typical exhaust system for a primary crusher.

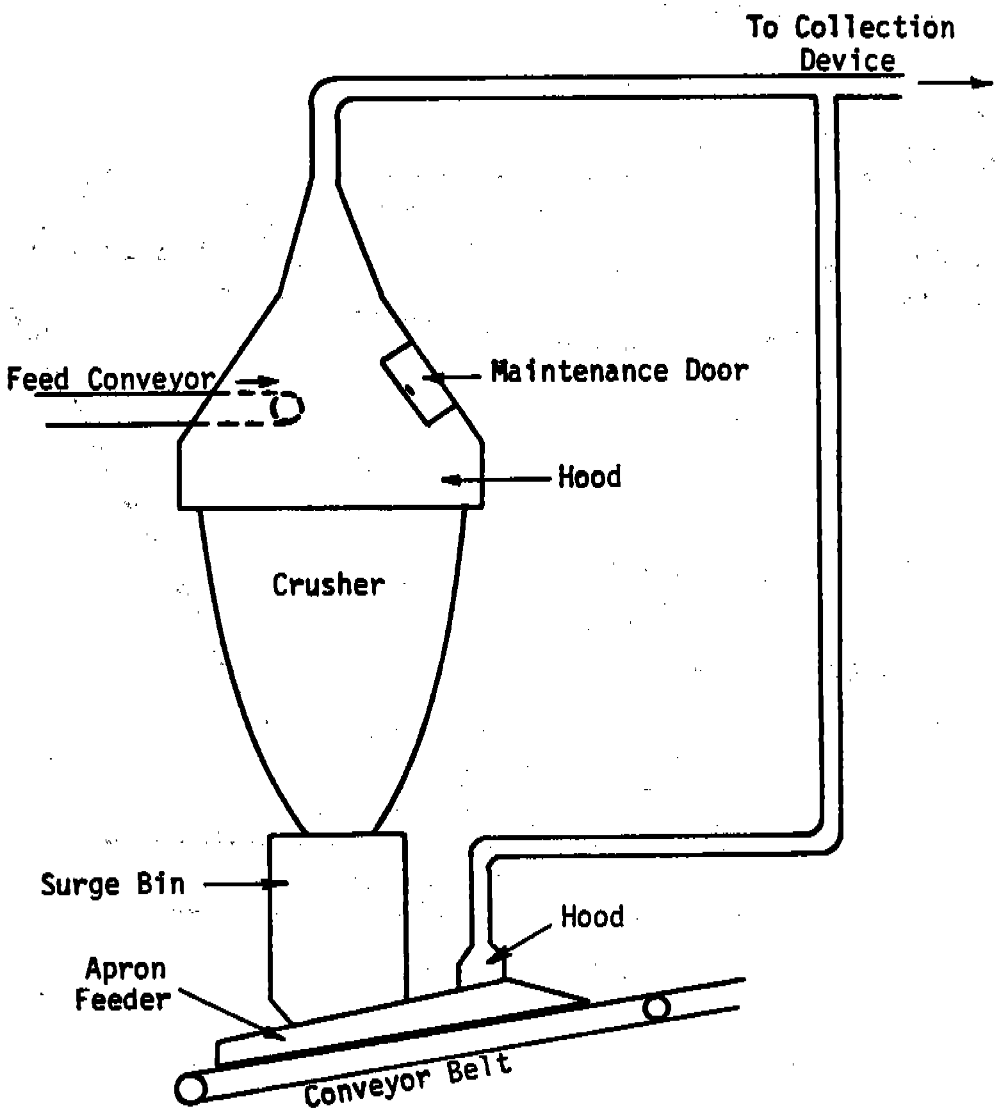


Figure 4-30. Typical exhaust system for a secondary or tertiary crusher.

Flat deck and cylindrical screens (the two most common types), with their associated exhaust systems, are depicted in Figure 4-31. Exhaust flow rates vary with the surface area of the screen and a common value is 0.2 $(m^3/sec)/m^2$ (50 cfm/ft^2) of screen area (ACGIH, 1976, p. 5-34). No change in this figure is associated with multiple decks. In exhaust systems for flat deck screens, a flow rate of 1.0 $m^3/sec/m^2$ (200 cfm/ft^2) of hood opening and a duct velocity minimum of 17.8 m/sec (3,500 ft/min) is common. In cylindrical screens flow rates of 0.5 $m^3/sec/m^2$ (100 cfm/ft^2) of circular cross section of screen and duct velocity of 17.8 m/sec (3,500 ft/min) are common (ACGIH, 1976, p. 5-34).

4.7.4 Raw Materials and Product Storage in Bins

Materials at intermediate stages of processing often are stored in bins or silos. An enclosure with a hood is located as far from the entrance to the bin as possible. Figure 4-32 is a representation of common methods of exhausting dust from entrances of storage facilities.

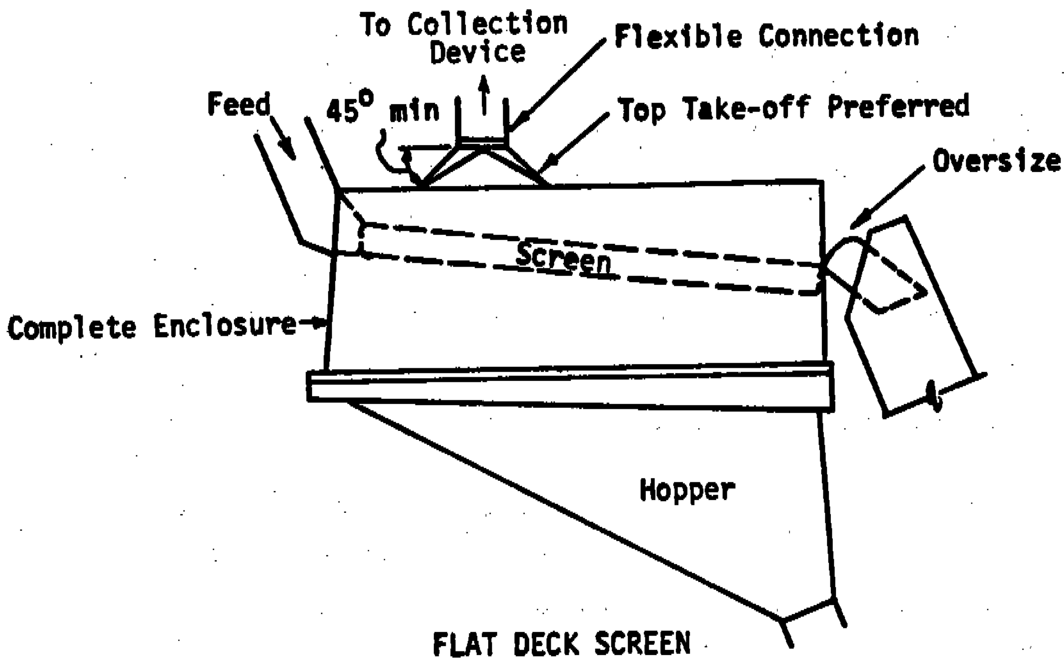
As with most other process equipment exhaust systems, minimum indraft velocity is 1.0 $m^3/sec/m^2$ (200 cfm/ft^2) for all open areas. A duct velocity of 17.8 m/sec (3,500 ft/min) minimum is also the rule (ACGIH, 1976, p. 5-31). Induced drafts as a function of conveyor belt speeds must also be considered as noted in Section 4.7.4. Handling of dry and dusty material may also increase air flow requirements.

Volumetric flow rates with respect to belt speed are:

- 0.5 $m^3/sec/m$ (350 cfm/ft) of belt width for belt speeds of less than 1 m/sec (200 ft/min)
- 0.7 $m^3/sec/m$ (500 cfm/ft) of belt width for belt speeds of more than 1 m/sec (200 ft/min).

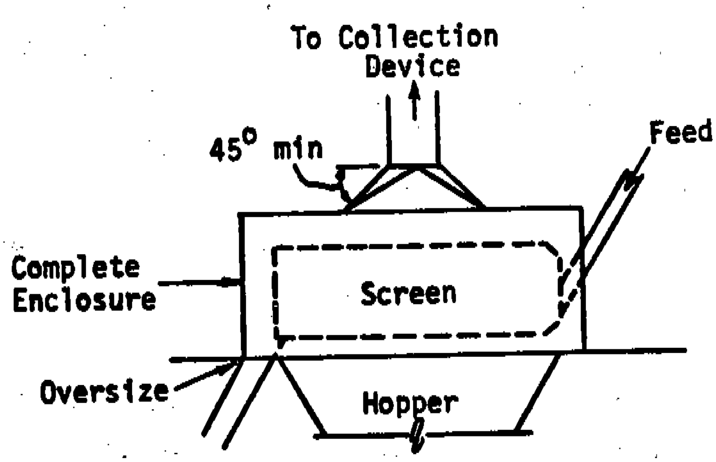
4.7.5 Product Handling

Dust suppression and collection devices are used to control dust generated by product handling operations. Often, concentrate is loaded as filter cake which contains sufficient moisture to suppress dust during this operation. Where dry, dusty products are handled, baghouses are commonly used and not only provide particulate control but also recover valuable product.



FLAT DECK SCREEN

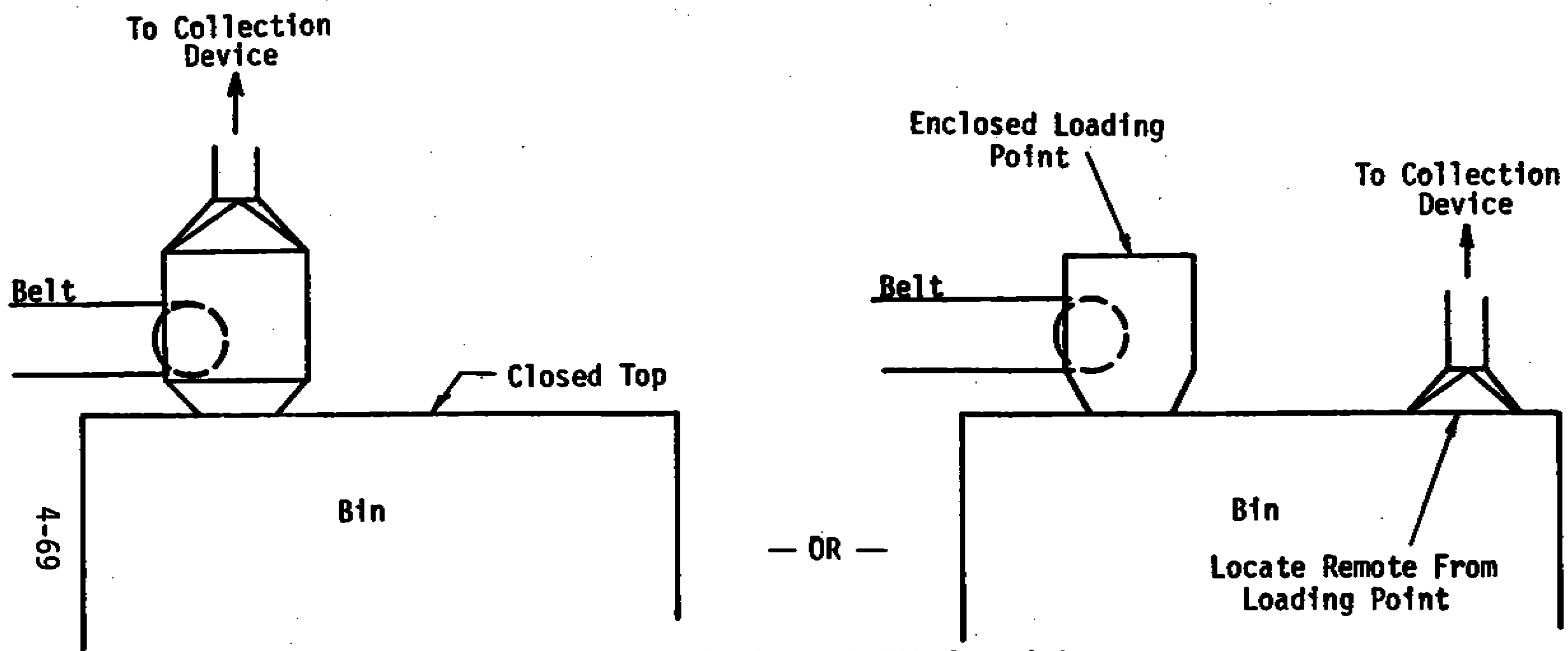
Flow Rate (Q) = 200 cfm/ft^2 through hood openings, but not less than 50 cfm/ft^2 screen area. No increase for multiple decks. Duct velocity = 3,500 fpm minimum.



CYLINDRICAL SCREEN

Q = 100 cfm/ft^2 circular cross section of screen; at least 400 cfm/ft^2 of enclosure opening. Duct velocity = 3,500 fpm minimum.

Figure 4-31. Screening exhaust systems.



Duct Velocity = 3,500 fpm minimum
$Q = 200\ cfm/ft^2$ Of All Open Area

Mechanical Loading*

*Belt Speed	Volume
Less Than 200 fpm	350 cfm/ft of Belt Width Not Less Than 150 cfm/ft of Opening
Over 200 fpm	500 cfm/ft of Belt Width Not Less Than 200 cfm/ft of Opening

Figure 4-32. Storage area exhaust systems (ACGIH, 1976).

Particulate emissions from truck and railcar loading of coarse material can be minimized by reducing the open space from the silo or bin to the shipping vehicle that the material must fall through. Shrouds, telescoping feed tubes, and windbreaks can further reduce the fugitive emissions from this intermittent source. Particulate emissions from loading of fine material into either trucks or railroad car can be controlled by an exhaust system vented to an emissions control system. The system is similar to the system described above for controlling bin or hopper transfer points (see Figure 4-32). The material is fed through one of the vehicle's openings and the exhaust connection is normally at another opening. The system should be designed with a minimum amount of open area around the periphery of the feed chute and the exhaust duct. The system can also be exhausted through a double concentric tube with material fed through the inner tube and air exhausted through the outer tube.

Where product is being loaded into open railcars or trucks other emission control arrangements are necessary. Figure 4-33 is a representation of such a system currently in use in Arizona. Trucks unload concentrate into a hopper that is enclosed and exhausted to a control device. The concentrate is then fed via a conveyor belt to a telescoping chute. The conveyor belt and chute are also ducted to the same collection device as the truck hopper.

4.7.6 Drying of Product

Product is dried to reduce the moisture content of the filter cake or concentrate. Concentrate dryers usually involve direct contact between the drying material and the heating source. Dust generated in the drying process passes directly into a duct located at the exit of the dryer and is then removed from the airstream by a control device. The flow rates through the duct work range from 1.8 to 7.1 m^3/sec (4,000 to 15,000 cfm) at plants that were visited. In some systems product released into the exhaust stream from the dryer is returned to the process after collection by dry cyclones and/or wet scrubbers.

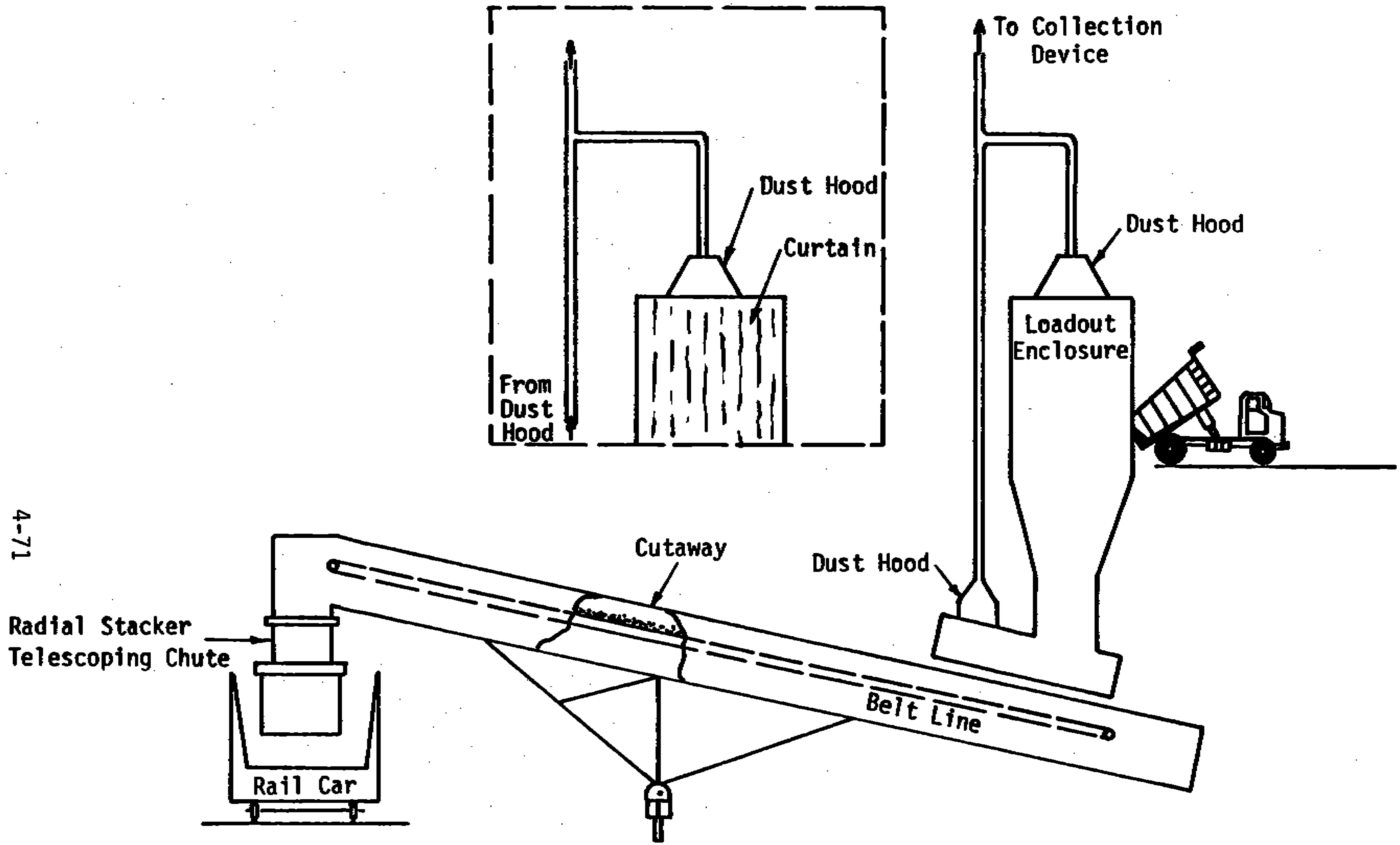


Figure 4-33. Product loadout facility exhaust system.

4.8 Performance Data for Exhaust Systems

Concurrently with most of the tests of wet scrubber and baghouse performance, the effectiveness of exhaust systems, hoods, and other capture devices was tested. After analysis of air flow rates taken during the Method 5 tests, it became apparent that some hood systems were not meeting the minimum design criteria outlined above for air velocities at hood openings or emission null points. In most cases these problems could be avoided in new facilities by proper positioning of the hood or the more complete enclosure of a source rather than increasing the actual flow rate. Data are not reported for points with design deficiences.

Effectiveness of exhaust systems is measured in terms of opacity of visible emissions escaping capture at the crucial junction between the process equipment and the inlet to the ducting system (the pickup point) by EPA Method 9. Method 9, described in Section 4.3.2, measures opacity at 15-second intervals on a scale from 0 to 100. Readings are then averaged over 6-minute periods.

Table 4-8 presents results of the tests by Method 9 for emission sources controlled by wet scrubbers and baghouses in both the metallic and non-metallic mineral industry. Three additional plants (R, S, T) are listed in Table 4-8. These plants were observed as part of EPA's test program for non-metallic minerals. Plant R processed gypsum; Plant S, mica; and Plant T, talc. Test sites from the non-metallic mineral processing industry are included here because the techniques for capturing emissions from operations in the metallic and non-metallic industry are similar.

In most instances, essentially no visible emissions were observed at adequately hooded or enclosed process facilities. The data indicate that properly designed facilities can meet visible emission limits of 10 percent opacity calculated as a 6-minute average.

4-9. ELECTROSTATIC PRECIPITATORS

As noted in the introduction to this chapter, the use of electrostatic precipitators (ESP's) in the metallic mineral industries has been confined to high temperature, high flow exhaust streams from calcining and pelletizing operations. The use of ESP's is probably not necessary for

Table 4-8. SUMMARY OF VISIBLE EMISSIONS MEASUREMENTS AT HOODS (PICKUP POINTS) AT METALLIC AND NON-METALLIC FACILITIES

Facility	Date of test	Pickup points	Mean opacity (percent)	Highest 6-minute average opacity (percent)	Lowest 6-minute average opacity (percent)
A	11/13/79	Secondary crusher tunnel outlet	0	0	0
	thru	Secondary crusher reclaims feeder hood	0	5	0
	11/15/79	Truck dump hopper hood	1	2	0
		Railroad car loading chute	3	5	0
B	8/27/79	Transfer point (sprays on)	0	0	0
	thru	Rail car unloading (sprays on)	0	1	0
	8/29/79	Crusher building (sprays on)	0	0	0
		Bucket elevator hood	0	0	0
		Screen hood	0	0	0
		Dryer area	0	0	0
C	9/28/79	Grizzly hood and crusher entrance	0	0	0
	thru	Crusher transfer point	0	0	0
	10/01/79	Crusher grizzly	0	0	0
		Fine ore bin hopper exhaust	0	0	0
		Barreling enclosure area	0	0	0
		Fine ore transfer point	0	0	0
D	12/06/79	Dryer conveyor transfer point	0	0	0
	thru	Grinder conveyor inlet	0	0	0
	12/08/79				
G	10/25/80	East grizzly screen	0	3	0
	thru	West grizzly screen	0	8	0
	10/26/80	Coarse ore transfer point	0	0	0
I	1/15/80	Secondary crusher inlet	0	1	0
		Conveyor transfer inlet	0	0	0
		Grizzly screen area	0	1	0
		Crusher building	0	0	0

(continued)

Table 4-8. Continued

Facility	Date of test	Pickup points	Mean opacity (percent)	Highest 6-minute average opacity (percent)	Lowest 6-minute average opacity (percent)
J	7/09/75	Primary impact crusher discharge	0	4*	0
		Conveyor transfer point	0	3*	0
K	7/01/75	Scalping screen	1	4	0
		Surge bin	0	0	0
		Secondary cone crusher No. 1	0	2	0
		Secondary cone crusher No. 2	0	0	0
		Secondary cone crusher No. 3	0	0	0
		Hammer mill	0	0	0
		3-deck finishing screen (L)	0	1	0
		3-deck finishing screen (R)	0	0	0
M	7/08/75	No. 1 tertiary gyrasphere cone crusher	0	0	0
		No. 2 tertiary gyrasphere cone crusher	0	0	0
		Secondary standard cone crusher	0	0	0
		Scalping screen	0	0	0
		Secondary (2-deck) sizing screen	0	0	0
		Secondary (3-deck) sizing screen	0	0	0
O	9/27/76	Ball mill (feed end)	0	0	0
		Ball mill (discharge end)	0	0	0
		Indoor transfer point No. 1	0	0	0
		Indoor transfer point No. 2	0	0	0
		Truck loading	0	0	0
		Rail car loading	1	2	0
R	10/27/80	Hammer mill	0	1	0
S	9/30/76	Bagging operation	0	0	0

(continued)

Table 4-8. Concluded

Facility	Date of test	Pickup points	Mean opacity (percent)	Highest 6-minute average opacity (percent)	Lowest 6-minute average opacity (percent)
T	10/21/76	Vertical mill	0	0	0
		Secondary crusher	0	1	0
		Bagger	1	9	0
		Pebble mill	0	2	0

*Sequential 6-minute average data not available. These data are calculated as a maximum 6-minute average opacity assuming all visible emissions occured in one 6-minute period.

the types of operations discussed in this document and their performance can be duplicated with less expensive devices. However, because ESP's are highly effective particulate emission control devices, their use is possible with the emissions from metallic mineral processes and a brief description is thus provided.

ESP's operate by electrically charging incoming particles by bombarding them with gaseous ions or electrons formed by high voltage corona discharge. An electrostatic field attracts the ions to oppositely charged plates or collection electrodes. This process can take place in one, two, or multiple-stage operations. A two-stage ESP is depicted in Figure 4-34.

ESP's operate with very low pressure drops, and high volumetric flow rates and temperatures. ESP's also have no moving parts and, theoretically, have no lower limit on the size of particles that can be collected. Collection efficiencies of 99+ percent for 0.1 to 3 micron particles can be readily achieved.

Operating conditions for electrostatic precipitators are as follows (Hesketh, 1974):

- Gas flow - 1 cfm to 2 x 10^6 cfm (.03-57,000 m^3/min)
- Gas temperature - up to 1200°F (650°C)
- Gas pressure - up to 150 psi (1000 kPa)
- Gas velocity - 3 to 15 ft/sec (up to 50 ft/sec in special units) (1 to 5 m/sec (up to 15 m/sec))
- Pressure drop - 0.1 to 0.5 in. of water per section (0.02-0.1 kPa)
- Particles removed - 0.1 to 200 microns
- Particle inlet concentration - 0.15 x 10^{-3} to 15 lb/1,000 ft^3 (2.3 x 10^{-3} to 2.3 x 10^2 gram/DNm^3)
- Treatment sequence - 1 to 10 sections in series
- Power supply - 50,000 to 70,000 Vdc (up to 100,000 V in some units)
- Discharge electrodes - up to 0.109 in. (0.025 mm) diameter coppered steel wires

There are several drawbacks to electrostatic precipitation, including high initial cost and necessity for frequent maintenance. The initial cost is the highest in the air pollution control equipment market.

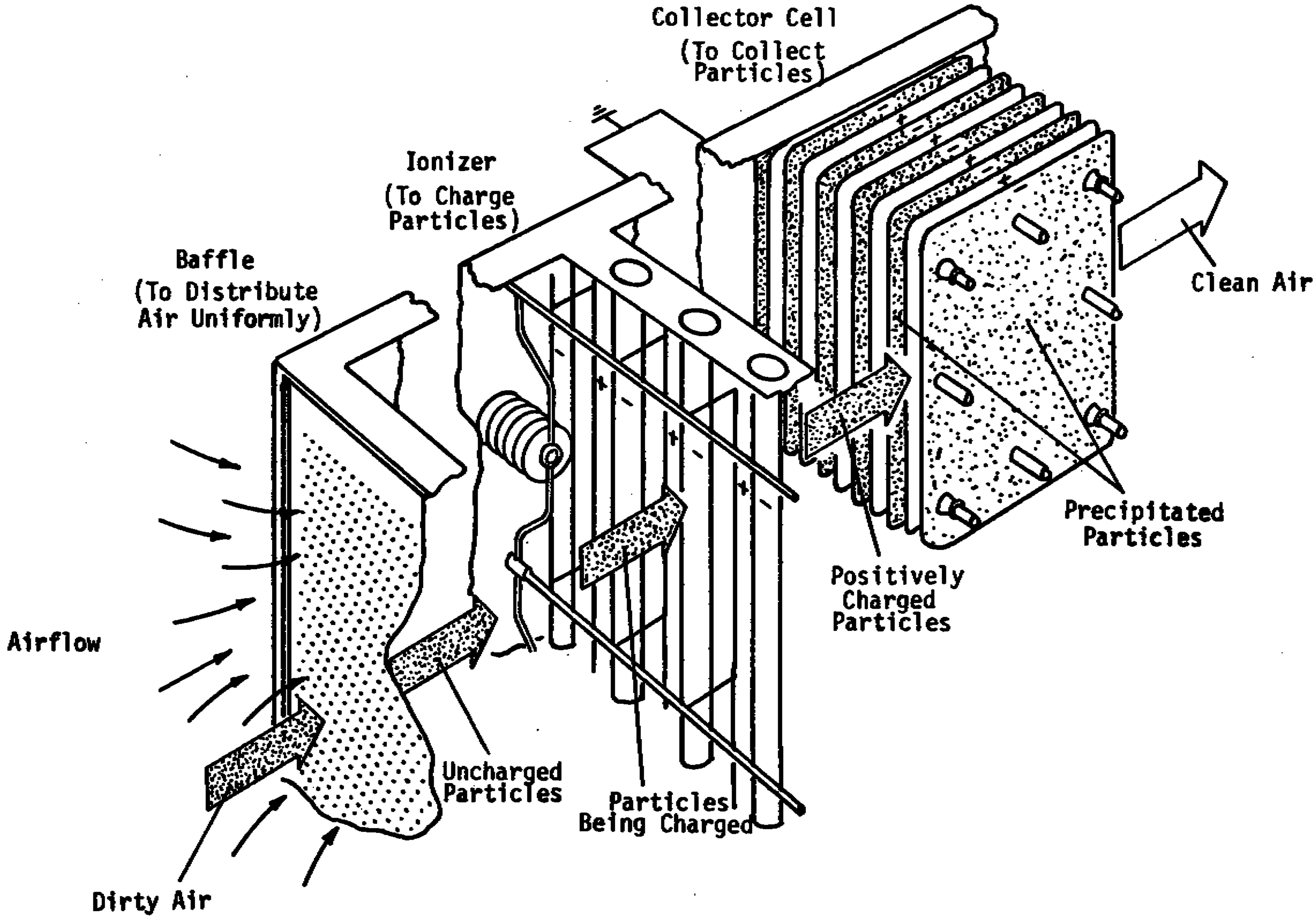


Figure 4-34. Standard two-stage precipitator.

4.10 CONCLUSIONS FROM TEST AND MODELLING DATA

Several conclusions are justified after a review of the test data in this chapter. A comparison of particle sizes ranges for the metallic and non-metallic facilities indicates similar distributions. Table 4-9 includes data on the percentage of particles under 5 microns at all processes tested. This figure ranged from 2 to 92 percent with an average of 36 percent for metallic mineral processes. Excluding the particle size data from facilities C1, C2, and C3, which are of minimal significance because of the very low uncontrolled emission rates, the range for the metallic facilities was from 2 to 87 percent with an average of 28 percent. In either case the particle size range for non-metallic facilities indicated smaller particles at these facilities. The percentage of particles below 5 microns ranged from 10 to 92 percent and averaged 48 percent.

Engineering specifications for control equipment for use in the metallic mineral industry typically assume uncontrolled emission rates of 11.4 to 22.9 g/DNm^3 (5 to 10 gr/dscf). This range of values is significantly in excess of most of the concentrations measured in this study. Table 4-9 summarizes all the uncontrolled emission rates from both single and combined unit processes or processing steps measured in the studies described. Of the points measured only four exceeded 11.4 g/DNm^3 (5 gr/dscf). These points included the dryer at Plant D, the primary crusher at Plant K, the pebble mill at Plant O and a roller mill at Plant Q. Over one half of the points tested showed concentrations below 2.3 g/DNm^3 (1.0 gr/dscf).

The overall average of the uncontrolled emission concentration measured at ducts venting individual process steps in the metallic minerals industry (as marked in Table 4-8) was 1.99 g/DNm^3 (0.87 gr/dscf). When breaking out emission data by emission source type, certain patterns were noted. Dryers showed the highest uncontrolled emission levels with an average concentration of 9.38 g/DNm^3 (4.10 gr/dscf). Crushers showed an average uncontrolled emission concentration of 2.04 g/DNm^3 (0.89 gr/dscf). Transfer points and product loadout operations showed similar emission levels of 0.66 and 0.55 g/DNm^3 (0.29 and 0.24 gr/dscf),

Table 4-9. AVERAGE UNCONTROLLED EMISSIONS LEVELS FROM ALL PROCESSES TESTED BY EPA IN THE METALLIC AND NON-METALLIC MINERAL PROCESSING INDUSTRIES

Plant	Baghouse (BH) or Scrubber (S)	Facility	Average concentration g/DNm^3	(gr/dscf)	Percentage of particles less than 5 microns
A	S1	Primary crusher conveyor	0.167	(0.073)[a]	25
		Primary crusher surge bin	1.899	(0.830)[a]	3
		Total scrubber inlet	0.501	(0.219)	25
	S2[b]	Secondary crusher exhaust	2.741	(1.198)[a]	15
		Total scrubber inlet	0.622	(0.272)	25
	BH1	Truck loadout conveyor exhaust	1.597	(0.698)[a]	30
		Truck loadout hood exhaust	0.071	(0.031)[a]	30
B	S1	Transfer points exhaust ducts[c] sprays on	0.399	(0.174)[a]	26
		Crusher pit exhaust duct sprays on	0.237	(0.104)[a]	24
		Transfer points exhaust ducts sprays off	0.387	(0.269)	23
		Crusher pit exhaust ducts sprays off	0.154	(0.067)	33
	S2	Pebble screening and milling, screen exhaust duct	0.018	(0.008)[a]	35
		Pebble screening and milling, bucket elevator exhaust duct	0.146	(0.064)[a]	31
		Total scrubber inlet	0.137	(0.060)	17
	S3	Total scrubber inlet (from dryer)	0.513	(0.224)[a]	87

(continued)

Table 4-9. Continued

Plant	Baghouse (BH) or Scrubber (S)	Facility	Average concentration g/DNm^3	Average concentration (gr/dscf)	Percentage of particles less than 5 microns
C	S1	Crusher transfer point exhaust	0.014	(0.006)[a]	75
		Grizzley exhaust duct	0.023	(0.010)[a]	70
		Crusher scrubber inlet[d]	0.021	(0.009)	79
	S2	Fine ore bins hopper exhaust	0.007	(0.003)[a]	91
		Fine ore bins, scrubber inlet[e]	0.009	(0.004)	73
	S3	Dryer scrubber inlet	5.157	(2.254)[a]	43
		Packaging area exhaust duct[f]	0.009	(0.004)[a]	-
		Total scrubber inlet	2.050	(0.896)	-
D	S1	Dryer scrubber inlet (north)	17.79	(7.77)	25
		Dryer scrubber inlet (south)	26.86	(11.74)	22
		Total dryer scrubber inlet	22.10	(9.88)[a]	-
F	BH2	Fine crusher conveyor, baghouse inlet	2.99	(1.31)	-
G	BH1	Crusher baghouse No. 1-2 inlet	5.42	(2.37)[a]	2
		Crusher grizzley east duct	0.194	(0.085)[a]	28
		Crusher hood duct	3.07	(1.34)	22
	BH2	Truck dump baghouse No. 3-4 inlet	0.304	(0.133)[a]	67
H	S1	Ship unloading scrubber inlet	2.61	(1.14)[a]	-

(continued)

Table 4-9. Continued

Plant	Baghouse (BH) or Scrubber (S)	Facility	Average concentration g/DNm^3	(gr/dscf)	Percentage of particles less than 5 microns
I	BH1	Secondary crusher inlet	0.71	(0.31)[a]	17
		Conveyor transfer inlet	0.75	(0.33)[a]	21
		Ore storage reclaim operations	0.10	(0.04)[a]	12
		Total baghouse inlet	0.39	(0.17)	-
K	BH1	Primary crusher, baghouse inlet	14.42	(6.30)[g]	-
L	BH1	Primary crusher	0.491	(0.215)[g]	-
		Scalping scrren, hammer mill, etc.	2.84	(1.24)	-
		Total inlet to baghouse	2.47	(1.08)	-
O	BH1	#2 mill baghouse, north inlet	29.6	(12.9)	15
		#2 mill baghouse, south inlet	2.26	(0.989)	25
		#2 mill baghouse, total inlet	13.8	(6.05)[g]	-
P	BH1	Raymond mill baghouse inlet	10.36	(4.53)[g]	70
	BH2	Roller mill, baghouse inlet	4.03	(1.76)[g]	70

(continued)

Table 4-9. Concluded

Plant	Baghouse (BH) or Scrubber (S)	Facility	Average concentration g/DNm^3	(gr/dscf)	Percentage of particles less than 5 microns
Q	BH1	#2 Raymond mill, baghouse inlet	11.99	(5.24)[g]	18
	BH2	#2 Fluid energy mill, baghouse inlet	2.38	(1.04)[g]	92

[a]Test points used to determine the average uncontrolled emission level from metallic mineral facilities.

[b]Also controls ore reclaim operation.

[c]Transfer points include apron feeder and conveyor to stockpile.

[d]This also includes a third duct from a second set of conveyors that was not tested separately.

[e]This also includes transfer points.

[f]This point is actually an inlet to dryer scrubber.

[g]Test points used to determine the average uncontrolled emission level from non-metallic mineral facilities.

respectively. Finally, screens and fine ore bins showed very low emission rates of 0.11 and 0.007 g/DNm^3 (0.05 and 0.003 gr/dscf), respectively.

These low uncontrolled emission levels might be interpreted as evidence that some sites are unnecessarily diluting process emissions. However, it must be recognized that air flow requirements are most often determined by the necessity to maintain minimum air velocities and flow rates at the hoods or pickup points as required by MSHA regulations. Careful attention should be paid to the design of hoods in order to maximize the efficient enclosure of the point of emissions and to minimize the air flow requirements and consequent energy use.

In contrast to the metallic minerals facilities, non-metallic facilities averaged an uncontrolled emission of 8.2 g/DNm^3 (3.6 gr/dscf). This higher emission level coupled with the generally smaller particle sizes as exemplified in Plant P and Q again support the introductory comment that the non-metallic facilities provided more difficult control conditions than those encountered in the metallic minerals industry.

In general a review of the data presented in this chapter indicates that a wide variety of conditions were sampled in these tests. Uncontrolled emission rates ranged from almost immeasurably low, as in the case of some operations at Plant C, to close to the maximum design levels, as in the case of the dryer at Plant D. Mean particle size ranged from less than 2 microns to greater than 20 microns. Because of the range of possible conditions, control equipment should be applied to a specific facility with an understanding of the emission characteristics of the operation that may require actual testing of this facility.

The approach in this chapter and throughout this document is to present the worst case conditions and to judge the effectiveness of various approaches in that light. The necessity of finding performance levels that are achievable in the widest possible range of circumstances in the industry compel us to view the entire industry in terms of worst case conditions. This approach, however, should not obscure the fact that much of the industry may operate under less adverse circumstances and thus may properly apply a variety of techniques to achieve prescribed goals. The purpose of this chapter is to outline achievable levels of performance, but not to dictate the methods for achieving these levels.

A review of the tests of baghouses at metallic and non-metallic facilities demonstrates that baghouses can easily attain emission levels of 0.05 g/DNm^3 (0.02 gr/dscf) under a wide variety of circumstances. Manufacturers of baghouses routinely guarantee performance of properly designed baghouses to meet emission standards of 0.05 g/DNm^3 (0.02 gr/dscf) (Adams, 1980; and Skalos, 1980).

The tests of wet scrubbers at metallic minerals facilities indicate that, at many operations tested, wet scrubbers with pressure drops as low as 1.5 kPa (6 inches) could meet emission levels below 0.05 g/DNm^3 (0.02 gr/dscf). Exceptions are the dryers at Plants C and D. Because these facilities use relatively low-energy wet scrubbers, modelling exercises were undertaken to predict the performance of higher pressure drop venturi scrubbers given the uncontrolled emission characteristics at these facilities. These modelling exercises show that these facilities could meet 0.05 g/DNm^3 (0.02 gr/dscf) with a 7.5-kPa (30-inch) venturi scrubber.

Given the potential problems with moisture condensation in dryer exhaust, wet scrubbers may be preferred to baghouses for the control of emissions under these circumstances. In addition, in situations where warm moist ore extracted from underground mines is processed at surface temperatures significantly below mine temperatures, moisture condensation may preclude the use of baghouses. Modelling of the performance of venturi scrubbers given the emission characteristics at Plant I (which processed high moisture ore from underground mines) was reported in this chapter. These results showed that both 1.5- and 3.7-kPa (6- and 15-inch) wet scrubbers could meet a 0.05 g/DNm^3 (0.02 gr/dscf) emission level.

Modelling of the performance of venturi scrubbers given worst case conditions was performed and reported in this chapter. Worst case conditions as observed at Plant Q were determined on the basis of particle size distribution and uncontrolled emission rate. The emission particle sizes from the fluid energy mill at Plant Q would be smaller than typically encountered in the metallic mineral industry because this operation processes material to a smaller size than do dry operations in the metallic mineral industry. Given these worst case conditions, a 1.5-kPa (6-inch) wet scrubber will allow an emission level of 0.34 g/DNm^3

(0.15 gr/dscf). A 3.7-kPa (15-inch) venturi scrubber would allow emission levels of 0.14 g/DNm^3 (0.06 gr/dscf). As indicated by the test results at this facility, a baghouse can attain the emission levels below 0.05 g/DNm^3 (0.02 gr/dscf).

This raises the following hypothetical question: What if the particle size distribution found at the fluid energy mill occurred under high moisture conditions which precluded use of a baghouse? Given the conditions present at Plant Q, modelling of the performance of 7.5-kPa (30-inch) venturi scrubbers indicated that it would give an emission level of 0.05 g/DNm^3 (0.02 gr/dscf). Because high moisture conditions would suppress uncontrolled emission levels as shown in Plants I and C, uncontrolled emission rates as high as those at Plant Q would not be expected and, in turn, wet scrubber emissions would be lower.

In conclusion, though the metallic mineral processing industry encompasses a wide variety of processes and ore types, the fundamental parameters of uncontrolled emission rate and particle size distribution (as demonstrated by the tests in this chapter) indicate conditions amenable to commonly available methods of particulate emission control.

4.9 REFERENCES FOR CHAPTER 4

Adams, J., American Air Filter Company. 1980. Telephone conversation with E. Monnig, TRW. September 26. Emission limit guarantees for baghouse performance.

American Conference of Governmental Industrial Hygienists (ACGIH). 1976. Industrial Ventilation - A Manual of Recommended Practice. Lansing, Michigan. pp. 4-1-4-21; 5-29-5-34.

Danielson, J. A., 1973. Air Pollution Engineering Manual (AP-40), Environmental Protection Agency, Research Triangle Park, North Carolina. p. 31.

Ducon Inc. 1978. Dynamic Gas Scrubber, Type UW-4, Model IV. No. W-7578. Mineola, New York. 8p.

Environmental Protection Agency (EPA), 1979 (March). Non-Metallic Mineral Processing Plants - Background Information for Proposed Emission Standards. Draft Document. Research Triangle Park, North Carolina. p. 4-1 to 4-5.

Hesketh, H.E.. 1974. Understanding and Controlling Air Pollution. Ann Arbor Science Publications. Ann Arbor, Michigan.

Laird, F. J., Anaconda Copper Company, 1980. Letter to S. T. Cuffe, Environmental Protection Agency. December 23. Comments on emission control techniques in the metallic mineral industries.

Skalos, C., Dravo Corporation. 1980. Telephone conversation with E. Monnig, TRW. September 26. Emission limit guarantees for baghouse performance.

Sparks, L. E., 1978. SR-52 Programmable Calculator Programs for Venturi Scrubbers and Electrostatic Precipitators. EPA/600/7-78-026. Environmental Protection Agency. Research Triangle Park, North Carolina. pp. 3-28.

Sparks, L.E., Environmental Protection Agency. 1981. Telephone conversation with E. Monnig, TRW. February 18. Precision of scrubber model.

Theodore, L. and A. J. Buonicore, 1978. Control of Particulate Emissions. Environmental Protection Agency, Research Triangle Park, North Carolina. p. 5-19.

Usis, A., W. W. Sly Manufacturing Co. 1978. Telephone conversation with R. Greenberg, GCA. June 16. Air-to-cloth ratio for baghouses.

5. MODIFICATIONS AND RECONSTRUCTIONS

5.1 MODIFICATION

A metallic mineral processing plant is composed of combinations of crushers, grinding mills, screens, dryers, conveyor transfer points, ore storage areas, and product handling operations. For a change to be termed a modification, it must result in an increase in emissions from any one of these process operations.

As defined in 40 CFR 60.14, the following physical or operational changes are not considered modifications to existing metallic mineral processing plants irrespective of any change in the emission rate:

A. Changes determined to be routine maintenance, repair or replacement.

B. An increase in the production rate if that increase can be accomplished without a capital expenditure exceeding the existing facility's IRS Annual Asset Guideline repair allowance of 6.5 percent per year.

C. An increase in the hours of operation.

D. Use of an alternative raw material if the existing facility was designed to accomodate such material. Because process equipment (crushers, screens, conveyors, etc.) are designed to accomodate a variety of rock types, any change in raw material feed would probably not be considered a modification.

E. The addition or use of any air pollution control system except when a system is removed or replaced with a system considered to be less effective.

F. The relocation or change in ownership of an existing facility.

The expected impact of the modification provision on existing metallic mineral processing facilities should be very slight. No condition is currently foreseen that would allow an existing metallic mineral processing facility to be modified under this definition. Whether a change is a modification or not shall be determined by the Division of Stationary Source Enforcement (DSSE) and the appropriate EPA Regional Office.

When expansions at existing plants take place, usually a completely new crushing/grinding line is added (with the possible exception of the primary crusher). Such an increase in production would not be considered a modification but rather a series of new sources. Primary crushing operations at metallic mineral plants usually operate below 100 percent capacity and are capable of handling increased throughput without additional equipment. Under (B) above, an increase in production at the primary crusher would not be considered a modification.

5.2 RECONSTRUCTION

The reconstruction provision is applicable only where replacement of components of an existing facility exceeds 50 percent of the fixed capital cost that would be required to construct a similar new facility and air pollution control systems are shown to be technologically and economically feasible. For the metallic mineral industries, replacement or refurbishing of equipment parts subject to high abrasion and impact such as crushing surfaces, screening surfaces, and conveyor belts are performed on a regular basis and could be considered routine maintenance. The cumulative cost of these repairs to any one piece of equipment over a period of time could exceed 50 percent of the fixed capital cost of entirely new equipment. Whether such actions constitute reconstructions shall be determined by DSSE and the appropriate Regional office.

6. MODEL PLANTS AND REGULATORY OPTIONS

6.1 INTRODUCTION

Chapter 4 presented various technologies available for the control of particulate emissions. These control technologies form the basis for the regulatory alternatives available for the proposed new source performance standards. In order to evaluate the environmental and economic impacts of the regulatory alternatives, an analysis of "model plants" has been used. Model plants have been selected for each of the ten metallic ore processing industries that are expected to show growth in processing capacity in the next 5 years. These model plants are representative of the expected population of new or expanded metallic mineral processing plants that will be subject to the standards.

6.2 MODEL PLANTS

Although there are variations in the processes used for the different minerals, there are operations that are common to various aspects of the metallic mineral processing industries. An all-inclusive model facility can be depicted which includes all the particle-emitting processes common to the industry. All other model plants are subsets of this all-inclusive facility. It should be stressed that it is highly unlikely that any new metallic mineral processing facility will look exactly like this all-inclusive facility or its subsets. In general, these models overestimate the actual impacts. As noted in Chapter 3, increased use of wet grinding processes is possible in the future which would reduce the application of control technology at metallic mineral plants. However, all new metallic mineral facilities will contain at least some of the facilities described in this model.

6.2.1 Inclusive Model Facility

The inclusive model facility includes all of the usual processing equipment and procedures that produce particulate emissions. All the sources of particle emissions can be classified and assigned an emission point number. In a single process line there are a total of 23 emission points at the inclusive model facility. Larger plants may run several parallel lines and will contain more than 23 emission points. Figure 6-1 presents a diagram of the model including all 23 labelled emission points. These numbers will remain constant throughout the discussion of model plants for each emission point.

The number and size of individual processing equipment units at each emission point can be adjusted to represent the range of total facility production capacities found in the industry. Eight different production capacity facilities have been selected to represent the range of production capacities found in the industry. The eight capacities are 23 Mg/hr (25 TPH), 45 Mg/hr (50 TPH), 68 Mg/hr (75 TPH), 140 Mg/hr (150 TPH), 270 Mg/hr (300 TPH), 540 Mg/hr (600 TPH), 1,100 Mg/hr (1,200 TPH), and 2,200 Mg/hr (2,400 TPH). The range of all ten individual industries are covered by these eight capacities. Table 6-1 presents the eight capacities for the inclusive model facility and indicates the size and number of process units at each emission point, as well as the gas volumes.

6.2.2 Process Units

As noted previously, there are a total of 23 emission points common to the metallic mineral processing industries. Although it is conceivable that each of these emission sources could have one emission control system, current industry practice indicates that several associated emission points are ducted to a common control device. For purposes of analyzing the environmental, economic and energy impacts, the process equipment at the inclusive model facility have been grouped to form the following process units.

A. Crushing unit – defined as a crusher and its associated dumping station, grizzly, screens, coarse ore storage bins, and conveyor belt transfer points.

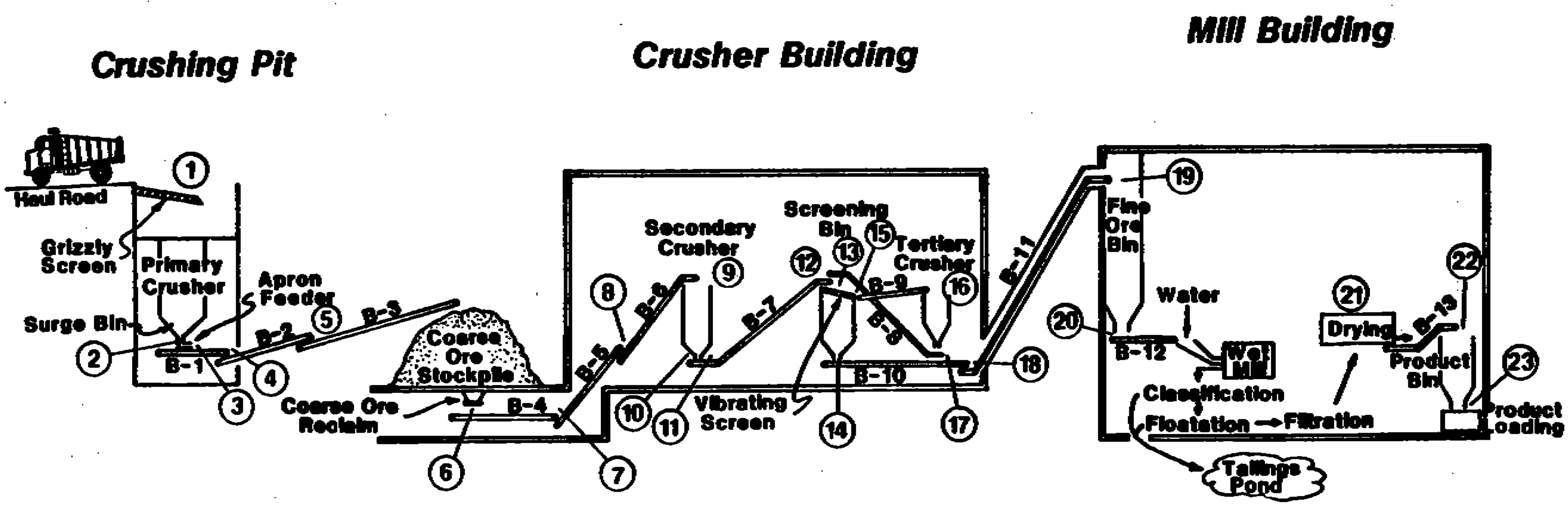


Figure 6.1 Inclusive Metallic Mineral Processing Model Plant.

Table 6-1. LIST OF PROCESS EQUIPMENT AND AIR VOLUMES USED IN DETERMINING MODEL PLANTS

		23 Mg/hr (25 TPH) Model				45 Mg/hr (50 TPH) Model			
				Gas volume				Gas volume	
Model plant point	Source	Number	Size	Nm^3/sec	scfm	Number	Size	Nm^3/sec	scfm
1	Ore dumping station	1		0.47	(1,000)	1		0.47	(1,000)
2	Primary crusher		46 x 91 cm (24" x 36") Jaw	4.72	(10,000)	1	91 x 122 cm (36" x 48") Jaw	7.27	(15,400)
3, 6, 11	Feeders - width	3 each	.46 m(1.5')	1.06	(2,250)	3 each	.46 m(1.5')	1.06	(2,250)
4, 5, 7, 8, 12, 14, 15, 18, 20	Transfer points - width	9 each	.46 m(1.5')	3.19	(6,750)	9 each	.46 m (1.5')	3.19	(6,750)
9	Secondary crusher hood	1	.92 m (3') cone	0.35	(750)	1	2.1 m (7') cone	0.47	(1,000)
10	Secondary crusher outlet	1		3.54	(7,500)	1		3.54	(7,500)
13	Screening		.92 m x 2.4 m(3'x8') rod deck	3.54	(7,500)	1	1.8 x 2.1 m (6'x7') rod deck	6.14	(13,000)
16	Tertiary crusher hood		.92 m (3') cone	0.35	(750)	1	2.1 m (7') cone	0.47	(1,000)
17	Tertiary crusher outlet	1		3.54	(7,500)	1		3.54	(7,500)
19	Fine ore bin	1		0.71	(1,500)	1		0.71	(1,500)
21	Dryer	1		0.38	(800)	1		0.76	(1,600)
22	Product bin	1		0.47	(1,000)	1		0.71	(1,500)
23	Product loading			0.35	(750)	1		0.35	(750)
	TOTAL			22.67	(48,050)			28.68	(60,750)
Duplicate Process Lines:		1				1			

(continued)

Table 6-1. Continued

Model plant point	Source	68 Mg/hr (75 TPH) Model: Number	Size	Gas volume Nm^3/sec	Gas volume scfm	140 Mg/hr (150 TPH) Model: Number	Size	Gas volume Nm^3/sec	Gas volume scfm
1	Ore dumping station	1		0.47	(1,000)	1		0.94	(2,000)
2	Primary crusher	1	91 x 122 cm (36" x 48") Jaw	7.27	(15,400)	1	122 x 152 cm (48" x 60") Jaw	9.68	(20,500)
3, 6, 11	Feeders - width	1 2	.60 m (2') .46 m (1.5')	1.18	(2,500)	1 2	.60 m (2') .75 m (2.5')	1.65	(3,500)
4, 5, 7, 8, 12, 14, 15, 18, 20	Transfer points - width	7 2	.46 m(1.5') .60 m (2')	3.42	(7,250)	10 1	.60 m (2') .75 m (2.5')	5.31	(11,250)
9	Secondary crusher hood	1	2.1 m (7') cone	0.47	(1,000)	1	2.1 m (7') cone	0.47	(1,000)
10	Secondary crusher outlet	1		5.43	(11,500)	1		5.43	(11,500)
13	Screening	1	1.8 x 3.0 m (6'x10') rod deck	8.64	(18,300)	1	1.8 x 3.6 m (6'x12') rod deck	10.38	(22,000)
16	Tertiary crusher hood	1	2.1 m (7') cone	0.47	(1,000)	1	2.1 m (7') shorthead	0.28	(600)
17	Tertiary crusher outlet	1		5.43	(11,500)	1		6.84	(14,500)
19	Fine ore bin	1		0.71	(1,500)	1		1.42	(3,000
21	Dryer	1		1.13	(2,400)	1		1.89	(4,000)
22	Product bin	1		0.71	(1,500)	1		1.42	(3,000)
23	Product loading	1		1.27	(2,700)	1		2.97	(6,300)
	TOTAL			36.60	(77,550)			48.68	(103,150)
Duplicate Process Lines:		1				1			

(continued)

Table 6-1. Continued

Model plant point	Source	272 Mg/hr (300 TPH) Model Number	Size	Gas volume Nm^3/sec	Gas volume scfm	540 Mg/hr (600 TPH) Model Number	Size	Gas volume Nm^3/sec	Gas volume scfm
1	Ore dumping station	1		1.65	(3,500)	1		2.41	(5,100)
2	Primary crusher	1	107 x 165 cm (42" x 65") GYR	2.74	(5,800)	1	122 x 152 cm (48" x 60") GYR	2.88	(6,100)
3, 6, 11	Feeders - width	3 2	.92 m (3') .75 m (2.5')	3.30	(7,000)	7	.75 m (2.5')	4.63	(9,800)
4, 5, 7, 8, 12, 14, 15, 18, 20	Transfer points - width	8 6 2	.60 m (2') .75 m (2.5') .92 m (3')	6.84	(14,500)	12 11	.75 m (2.5') .92 m (3')	14.87	(31,500)
9	Secondary crusher hood	2	2.1 m (7') cones	0.94	(2,000)	3	2.1 m (7') cones	1.42	(3,000)
10	Secondary crusher outlet	2		10.86	(23,000)	3		16.28	(34,500)
13	Screening	2	1.8 x 4.8 m (6'x16') rod deck	13.69	(29,000)	3	1.8 x 4.8 m (6'x16') rod deck	20.30	(43,000)
16	Tertiary crusher hood	2	2.1 m (7') shorthead	0.57	(1,200)	3	2.1 m (7') shorthead	0.71	(1,500)
17	Tertiary crusher outlet	2		13.69	(29,000)	3		20.53	(43,500)
19	Fine ore bin	1		2.12	(4,500)	1		2.60	(5,500)
21	Dryer	1		3.78	(8,000)	1		5.48	(11,600)
22	Product bin	1		1.42	(3,000)	1		1.42	(3,000)
23	Product loading	1		3.45	(7,300)	1		3.59	(7,600)
	TOTAL			65.06	(137,000)			97.12	(205,700)
Duplicate Process Lines:		2				3			

(continued)

Table 6-1. Concluded

Model plant point	Source	1,100 Mg/hr (1,200 TPH) Model				2,200 Mg/hr (2,400 TPH) Model			
		Number	Size	Gas volume Nm^3/sec	Gas volume scfm	Number	Size	Gas volume Nm^3/sec	Gas volume scfm
1	Ore dumping station	1		4.72	(10,000)	1		8.50	(18,000)
2	Primary crusher	1	152 x 152 cm (60" x 60")GYR	4.72	(10,000)	1	152 x 152 cm (60" x 80")GYR	6.61	(14,000)
3, 6, 11	Feeders - width	5 4	1.0 m (3.5') .92 m (3')	6.99	(14,800)	9 8	1.2 m (4') 1.0 m (3.5')	15.10	(32,000)
4, 5, 7, 8, 12, 14, 15, 18, 20	Transfer points - width	2 8 19	1.0 m (3.5') .92 m (3') .75 m (2.5')	18.50	(39,200)	2 16 40	1.2 m (4') 1.0 m (3.5') .92 m (3')	43.42	(92,000)
9	Secondary crusher hood	4	2.1 m (7') cones	1.89	(4,000)	8	2.1 m (7') cones	3.78	(8,000)
10	Secondary crusher outlet	4		21.71	(46,000)	8		43.42	(92,000)
13	Screening	4	1.8 x 4.8 m (6'x16') rod deck	26.90	(57,000)	8	1.8 x 4.8 m (6'x16') rod deck	53.81	(114,000)
16	Tertiary crusher hood	4	2.1 m (7') shorthead	0.94	(2,000)	8	2.1 m (7') shorthead	1.89	(4,000)
17	Tertiary crusher outlet	4		27.38	(58,000)	8		54.75	(116,000)
19	Fine ore bin	4		3.49	(7,400)	8		6.94	(14,700)
21	Dryer	3		8.26	(17,500)	6		16.42	(35,000)
22	Product bin	3		2.12	(4,500)	5		4.25	(9,000)
23	Product loading	3		5.38	(11,400)	6		10.86	(23,000)
	TOTAL			133.00	(281,800)			269.85	(571,700)
Duplicate Process Lines:		4				8			

References: Non-Metallic Processing Plants - Background Information for Proposed Standards - U.S. Environmental Protection Agency, March, 1979. Industrial Ventilation - A Manual of Recommended Practices, 11th Edition, American Conference of Government Industrial Hygienists - 1970. Responses to Section 114 Questionnaires by Metallic Mineral Processing Industries.

B. Ore storage unit – defined as an enclosed ore storage area and associated conveyor belt transfer points if the area is isolated from the crushing unit.

C. Dryer unit – including the dryer and associated conveyor belt transfer points.

D. Product loadout unit – including all packaging, product bins, conveyor belt transfer points, and loadout mechanisms excluding ship loading facilities.

Because the inclusive model facility contains emission points and processes common to the whole industry, all ten individual industries can be described and grouped as they relate to the inclusive facility. The ten individual industries can be grouped into seven categories according to the ways in which they vary from the model facility. The seven categories are keyed alphabetically and are as follows

A. no tertiary crushing, drying, or product loadout;

B. no secondary or tertiary crushing or drying;

C. no secondary or tertiary crushing, drying, or product loadout;

D. all-inclusive category;

E. no drying or product loadout;

F. no drying;

G. no primary, secondary or tertiary crushing or fine ore bins.

The ten industries showing growth rates correspond to the above categories as follows

A. gold;

B. aluminum;

C. uranium;

D. copper, lead/zinc, molybdenum, tungsten;

E. silver;

F. iron;

G. titanium/zirconium.

Antimony, beryllium, titanium hard rock, and vanadium ores are not included because no growth in processing capacity is projected for these industries (see Section 3.1). Domestic production of nickel may increase in the future; however, this increase will occur as a byproduct of copper production in Minnesota. Commercial development of these deposits is not expected until after 1985 which is beyond the time frame covered in this document.

6.3 REGULATORY ALTERNATIVES

Chapter 4 presented the emission control technologies that can be used to control particulate emissions from metallic mineral processing plants. Each of the control techniques form the basis for a regulatory alternative for each process unit. In order to evaluate the environmental impacts, numerical emission limits can be selected that would represent each of these regulatory alternatives. These emission limits are derived by applying the control equipment option and its efficiency to the uncontrolled emission rate from each process unit. Because any promulgated emission limits must be achievable by all anticipated sources under all reasonable process conditions, the emission limit should represent the emission level achieved by the control technique option under the most adverse control conditions. Although the emission levels represented by the alternatives are based on the performance of a specific emission control device (for example, a 1.5-kPa (6-inches of water) wet scrubber) under worst-case conditions, it must be emphasized that the specified emission control device will achieve lower emission levels under less than worst case conditions. The converse is also true. The specific emission limit represented by a regulatory alternative can usually be attained by control equipment designed for less rigorous conditions than the control equipment upon which the regulatory alternative is based.

Source test data indicate that the most adverse particulate control conditions that could be expected in the metallic mineral industries are represented by an uncontrolled particulate emission concentration of 2.3 g/DNm^3 (1.0 gr/dscf) with a mean particle size ($\bar{x}$) of 1.5 μm. As discussed in Chapter 4, the 2.3 g/DNm^3 (1.0 gr/dscf) concentration level is not as high as that currently found at some facilities; however, a comparison of source test data with the combined factors of uncontrolled emission concentration and particle size distribution indicates that the highest controlled emission rates would occur with this combination.

6.3.1 Regulatory Alternative 1

One of the regulatory alternatives available for consideration is the option of no new source performance standard(s). This is the baseline control level and is generally representative of the level of control required by existing State Implementation Plan (SIP) regulations. Most states do not have specific regulations for the metallic mineral processing industries. Instead these facilities are usually regulated under a miscellaneous industrial process regulation. The typical state industrial process emission limits are derived from the following equations:

$p \leqq 30$	$p \geqq 30$
$E = 4.1 \times p^{0.67}$	$E = 55 \times p^{0.11} - 40$

Where p = production in tons/hr

E = emissions in lb/hr

However, test data indicate that current controlled emission rates at existing facilities are often actually less than allowed by SIP regulations. Most process operations at existing metallic mineral processing plants use dynamic wet scrubbers with a pressure drop of about 1.5 kPa (6 inches of water) to comply with the SIP requirements. Therefore, dynamic wet scrubbers at this pressure drop, as presented in Chapter 4, have been selected as the baseline control device. This control device is referred to as Control Option 1. Fractional efficiency curves for a 1.5-kPa (6-inch) dynamic scrubber indicate that with the most adverse expected particle size distribution ($\bar{x}$ = 1.5 μm) and inlet concentrations of 2.3 g/DNm^3 (1.0 gr/dscf), the achievable emission level would be 0.35 g/DNm^3 (0.15 gr/dscf).

6.3.2 Regulatory Alternative 2

As explained in Chapter 4, the control efficiency of wet scrubbers can be increased by raising the pressure drop across the unit. As a result, the theoretical number of control options based on wet scrubbers is unlimited.

A 3.7-kPa (15-inch) venturi scrubber has been selected to represent an intermediate level of control between the baseline and the baghouse or high energy scrubber control level. This control unit is Control Option 2. Performance evaluations indicate that the 3.7-kPa (15-inch) scrubber is capable of reducing the worst-case uncontrolled emissions level (1.0 gr/dscf and particle size $\bar{x}$ = 1.5 μm) to 0.14 g/DNm^3 (0.06 gr/dscf). This intermediate level of control represents Regulatory Alternative 2.

6.3.3 Regulatory Alternative 3

The most effective feasible control level option for most conditions in the metallic mineral industries is a fabric filter which is Control Option 3a under Regulatory Alternative 3. Source test data indicate that a baghouse will reduce the worst-case uncontrolled emissions (particle size distribution, $\bar{x}$ = 1.5 μm) to a controlled level less than 0.046 g/DNm^3 (0.02 gr/dscf).

Because of high moisture conditions, baghouses may not be practical for all emission points. A wet scrubber may be used under these conditions. Comparison of control efficiency evaluations indicates that a 7.5-kPa (30-inch) venturi scrubber would equal the performance of the baghouse under worst-case, high-moisture conditions. This high energy scrubber is Control Option 3b under Regulatory Alternative 3. Therefore, the most effective control level is represented by an emission limit of 0.046 g/DNm^3 (0.02 gr/dscf).

6.3.4 The "Worst-Case Analysis Method"

Because of the possible confusion with the use of worst-case premises in the development of the regulatory alternative, the explanation of the "worst-case analysis method" first presented in Chapters 3 and 4, deserves repeating here.

Discussions of worst-case conditions and the design of control equipment to handle worst-case conditions should not be interpreted as a recommendation or a requirement that certain types of equipment would be necessary to meet a specific emission level under all conditions found in the metallic mineral industries. The selection of control equipment for an actual emissions source requires consideration of the characteristics of only that source. Rather, the discussions of worst-case conditions are based on two premises. First, if an emission level can be demonstrated as achievable under worst-case conditions, then it is achievable under all conditions found in the industry. Second, if the cost of achieving an emission level is based on the cost of control equipment designed to meet that emission limit under worst-case conditions, then the actual cost of control equipment designed to meet the emission level under less than worst-case conditions should be less.

6.3.5 Control Equipment Options for Each Regulatory Alternative

For purposes of economic analysis, the design parameters of each control equipment option for each regulatory alternative have been set. The 1.5-kPa (6-inch) dynamic scrubber which is the basis for Regulatory Alternative 1 operates at a liquid to gas ratio of 0.13 L/m^3 (1 gal./$10^3 ft^3$). The 3.7-kPa (15-inch) venturi scrubber which is the basis for Alternative 2 operates at a liquid to gas ratio of 0.94 L/m^3 (7 gal./$10^3 ft^3$). The 7.5-kPa (30 inches of water) venturi scrubber of Alternative 3b has a liquid to gas ratio of 1.07 L/m^3 (8 gal./$10^3 ft^3$). The baghouse option for Alternative 3a is a pulse jet cleaning type with an air to cloth ratio of 6 to 1. The bag fabric is assumed to be Dacron felt and the unit operates at a pressure drop of 1.5 kPa (6 inches of water). All emissions collected from the baghouse were presumed recycled to the process at negligible cost. The control equipment alternatives are keyed numerically for presentation in the tables.

- Control Option 1 – 1.5-kPa (6-inch W.G.) dynamic scrubber
- Control Option 2 – 3.7-kPa (15-inch W.G.) venturi scrubber
- Control Option 3a – 1.5-kPa (6-inch W.G.) baghouse
- Control Option 3b – 7.5-kPa (30-inch W.G.) venturi scrubber

6.4 MODEL PLANT PARAMETERS

6.4.1 Introduction

This section presents the parameters necessary for evaluating the economic, energy and environmental impacts of the regulatory alternatives for each model plant in each individual industry. The process and control device parameters are assembled on the basis of responses to Section 114 letters, plant visits, literature searches, and discussions with control equipment manufacturers (GCA, 1979). The following subsections (6.4.2 to 6.4.11) present the parameters for each of the ten ore processing industries with expected growth in processing capacity.

Each of the subsections is divided into four sections. The four sections present the process units, model plant capacity, capacity independent model plant parameters, and capacity dependent model plant parameters.

Each description includes a schematic figure of a model facility and each emission point associated with the process equipment is identified. The grouping of emission points into unit processes is also presented.

6.4.1.1 Process Unit. Associated emission points at each model plant can be grouped together into one process unit. Each of these process units is treated as a single source and can be controlled by one emission control system. The economic, energy and environmental impact analysis of the regulatory alternatives is based on the application of each control equipment option to each process unit. In order to determine the environmental impacts through dispersion analysis, stack and flue gas parameters from the control device must be specified. Tables are provided in each subsection which present the process units and stack and control system parameters for each model plant and regulatory alternative.

6.4.1.2 Model Plant Capacity. Many economic factors associated with the industries vary with the production rate. These "economies of scale" must be considered in determining the economic impact of the regulatory options. Therefore, the range of production capacities found within each individual industry must be represented by the model plants. One or more production capacity model plants are presented for each of the growth industries and are representative of the range of capacities expected in the individual industry. Within each model plant for a particular industry the particular emission points vary only by size of equipment and number of parallel processing lines. The processing methods presented in the process schematic remain constant throughout the capacity range.

6.4.1.3 Capacity Independent Model Plant Parameters. Some parameters selected for comparing the economic and environmental impacts of the regulatory alternative vary among the various metallic mineral industries, but are assumed to be constant in an individual industry across its capacity range. These parameters are operating hours, capacity utilization rate, growth rate, ore grade processed, and the total ore processed. The values presented for each parameter have been determined to be representative of the individual metallic mineral processing industry (GCA, 1979).

6.4.1.4 Capacity Dependent Model Plant Parameters. Although some parameters may be taken as constant, others vary with capacity. These parameters include the land required for the plant and the process energy requirements of the total plant and are provided for each model plant capacity for each industry. For costing purposes, it is assumed that only product recovered from dryer or load out units is of sufficient quality to be economically recoverable. Within an individual industry the process configuration is constant for each model plant; however, the size and number of each process unit or emission point may vary at different capacities. A table is provided in each subsection that provides the number, size and gas volume associated with each emission point. Separate tables are provided in each subsection for the total plant energy requirements.

6.4.2 Aluminum Ore Processing Facility

6.4.2.1 Process Units Description. Aluminum is produced from alumina which results when bauxite is processed. The aluminum model plants consist of four process units, three associated with bauxite processing (raw product) and one associated with alumina processing. The process units are listed below.

Bauxite ore

A. Coarse ore storage and reclaim.

B. Hammer mill and all screens and associated transfer points.

C. Fine ore bins and associated transfer points.

Alumina

D. Product loadout and associated transfer points.

As noted in Chapter 3, ship loading and unloading and calcining are not included. Dockside transfer operations after ship unloading or before ship loading are covered in this document.

6.4.2.2 Model Plant Capacity. Model plant capacities are 140 Mg/hr (150 tons/hr) and 270 Mg/hr (300 tons/hr) based on the expected process rate of new plants.

6.4.2.3 Capacity Independent Model Plant Parameters.

- Hours of operations - 5,820 hours/year.
- Capacity Utilization - 91 percent.
- New facilities by 1985 - 2.
- Bauxite ore grade - 22 percent aluminum.

6.4.2.4 Capacity Dependent Model Plant Parameters.

140 Mg/hr (150 tons/hr) Model Plant.

- Land Required 126,000 M^2 (1,360,000 ft^2).*
- Energy Required 8.04 PJ/yr.**

*Includes only the mineral processing plant itself without the tailings pond areas. The plant area assumes a rectangular boundary located a minimum of 61 meters (200 ft) from the buildings.

**
$$PJ/yr = \frac{Petajoule}{year} = \frac{1 \times 10^{15} \text{ joules}}{year}$$

270 Mg/hr (300 tons/hr) Model Plant.

- Land Required 204,000 M^2 (2,200,000 ft^2)*
- Energy Required 16.08 PJ/yr.**

---

*Includes only the mineral processing plant itself without the tailings pond areas. The plant area assumes a rectangular boundary located a minimum of 61 meters (200 ft) from the buildings.

**$PJ/yr = \frac{\text{Petajoule}}{\text{year}} = \frac{1 \times 10^{15} \text{ joules}}{\text{year}}$

Table 6-2. LIST OF PROCESS EQUIPMENT AND AIR VOLUME REQUIREMENTS USED IN DETERMINING MODEL ALUMINUM ORE PLANTS

Model plant point	Source	140 Mg/hr (150 tons/hr) Model				270 Mg/hr (300 tons/hr) Model			
		Number	Size	Gas volume Nm^3/sec	(scfm)	Number	Size	Gas volume Nm^3/sec	(scfm)
1	Coarse ore reclaim			2.83	(6,000)			3.78	(8,000)
2	Feeders - width	1	0.76 m (2.5')	0.59	(1,250)	2	0.92 m (3')	1.42	(3,000)
3, 4, 7 8, 10	Transfer points - width	5 1	0.6 m (2') 0.76 m (2.5')	2.95	(6,500)	5 4 2	0.3 m (1') 0.75 m (2.5') 0.92 m (3')	4.96	(10,500)
5	Hammermill	1	107 cm x 168 cm 42" x 66"	3.78	(8,000)	2	107 cm x 168 cm 42" x 66"	7.55	(16,000)
6	Screening	1	1.8 m x 3.7 m (6' x 12') rod deck	5.93	(12,550)	2	1.8 m x 4.9 m (6' x 16') rod deck	11.80	(25,000)
9	Fine ore bin	1		1.42	(3,000)	1		2.12	(4,500)
11	Product bin	1		1.18	(2,500)	1		1.42	(3,000)
12	Product loading	1		2.36	(5,000)	1		3.45	(7,300)
	TOTAL			21.04	(44,800)			36.50	(77,300)
Duplicate Processing Lines:		1				2			

References: Non-Metallic Processing Plants - Background Information for Proposed Standards - U.S. Environmental Protection Agency, March 1979.
Industrial Ventilation - A Manual of Recommended Practices, 11th Edition, American Conference of Government Industrial Hygienists - 1970.
Responses to Section 114 Questionnaires by Metallic Mineral Processing Industries.

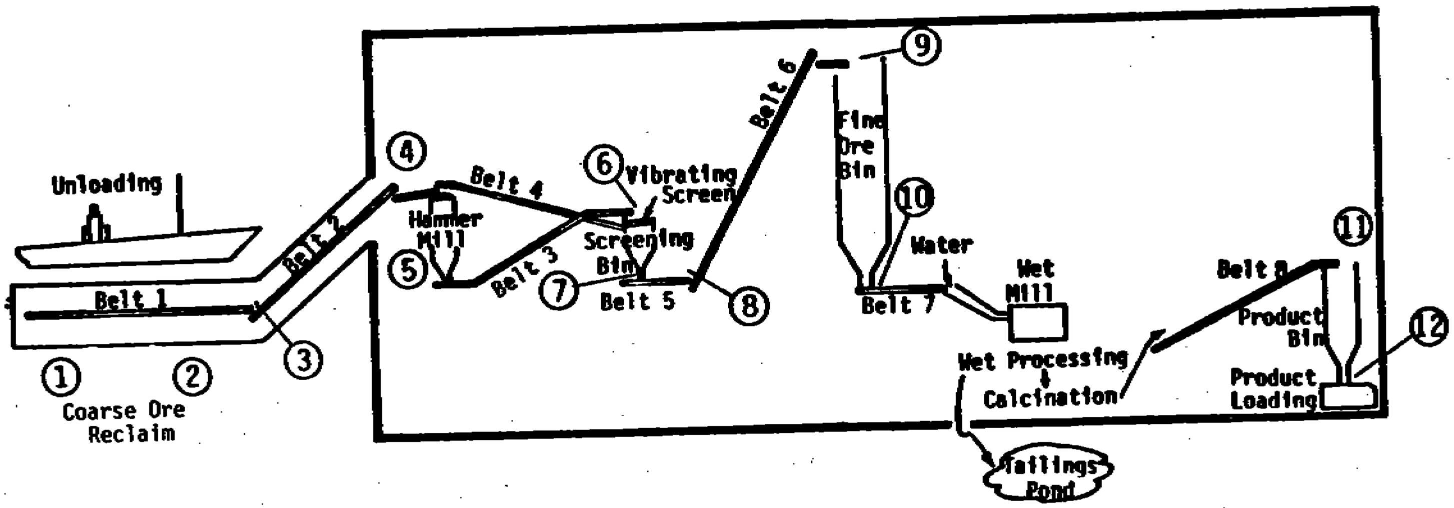


Figure 6-2. Aluminum ore processing industry model plant.

Table 6-3. STACK AND CONTROL SYSTEM PARAMETERS FOR ALUMINUM ORE MODEL PLANTS

Plant capacity Mg/hr	Plant capacity (tons/hr)	Process unit*	Flow rate Nm^3/s	Flow rate (scfm)	Stack Temp. °C	Stack Temp. (°F)	Stack Height m	Stack Height (ft)	Stack Diameter m	Stack Diameter (ft)	Power Requirements kW, Regulatory Alternatives 1	2	3a	3b	Emission Rate kg/hr (lb/hr), Regulatory Alternatives 1 kg/hr	1 (lb/hr)	2 kg/hr	2 (lb/hr)	3 kg/hr	3 (lb/hr)
136	(150)	A	4.48	(9500)	20	(68)	14	(46)	0.7	(2.3)	24.8	32.0	9.0	62.0	5.54	(12.21)	2.22	(4.89)	0.74	(1.63)
		B	10.38	(22000)	20	(68)	14	(46)	1.0	(3.3)	53.0	71.5	19.7	137.4	12.83	(28.28)	5.13	(11.31)	1.71	(3.77)
		C	1.89	(4000)	20	(68)	14	(46)	0.7	(2.3)	9.5	14.0	4.0	30.0	2.34	(5.15)	0.93	(2.06)	0.31	(0.69)
		D	4.39	(9300)	24	(75)	14	(46)	0.7	(2.3)	24.2	32.0	8.0	55.0	5.43	(11.96)	2.17	(4.78)	0.72	(1.59)
272	(300)	A	6.61	(14000)	20	(68)	14	(46)	0.7	(2.3)	35.1	47.0	13.3	86.1	8.16	(18.00)	3.27	(7.20)	1.09	(2.40)
		B(2)	10.38	(22000)	20	(68)	14	(46)	1.0	(3.3)	53.0	71.5	19.7	137.4	12.83	(28.28)	5.13	(11.31)	1.71	(3.77)
		C	2.83	(6000)	20	(68)	14	(46)	0.7	(2.3)	14.7	21.8	5.2	35.8	3.50	(7.71)	1.40	(3.09)	0.47	(1.03)
		D	6.14	(13000)	24	(75)	14	(46)	0.7	(2.3)	32.9	43.9	12.3	80.1	7.58	(16.71)	3.03	(6.69)	1.01	(2.23)

*For multiple units the number of identical process units is given in parenthesis. Parameters presented are for each individual unit.

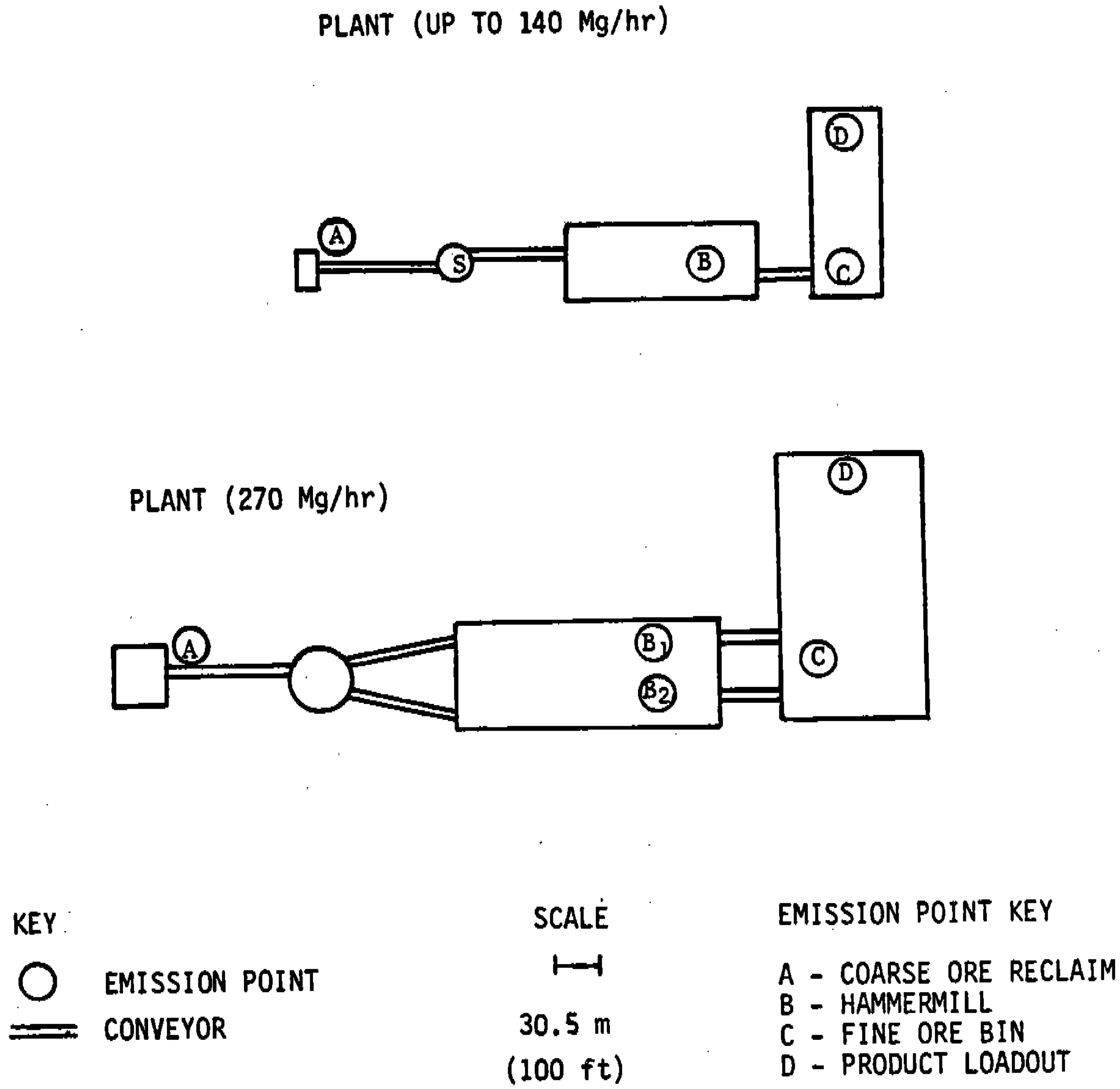


Figure 6-3. Aluminum model plant plot plans.

Table 6-4. ENERGY REQUIREMENTS FOR AN ALUMINUM ORE PROCESSING PLANT[a]

	Gigajoules[b] per net megagram of aluminum metal	Million BTU's per net ton of aluminum metal
Mining		
Drilling	0.01	0.01
Drill bits, drilling machines		
Explosives	0.02	0.02
SUBTOTAL	0.03	0.03
Shovel loading		
Electrical energy	0.13	0.12
Materials, repair, and maintenance	0.03	0.03
SUBTOTAL	0.16	0.15
Truck transportation		
Diesel fuel oil	0.12	0.11
Truck materials, tires, and repair	0.02	0.02
SUBTOTAL	0.14	0.13
Crushing, washing, and screening		
Crushing and screening electrical energy	0.15	0.14
Pumping electrical energy	0.08	0.07
Machinery wear and service energy	0.02	0.02
SUBTOTAL	0.25	0.23
Drying	2.21	2.00
Transportation	2.77	2.51
Bayer processing		
Crushing and grinding		
Electrical energy	0.38	0.35
Lime	1.00	0.90
SUBTOTAL	1.38	1.25
Digestion		
Steam	19.73	17.90
Caustic soda	5.24	4.75
SUBTOTAL	24.97	22.65

(continued)

Table 6-4. Concluded

	Gigajoules[b] per net megagram of aluminum metal	Million BTU's per net ton of aluminum metal
Clarification		
Electrical energy	0.37	0.34
Cooling		
Electrical energy	0.07	0.06
Precipitation-filtration		
Electrical energy	0.82	0.74
Evaporation		
Steam	11.11	10.08
Spent liquor recovery		
Electrical energy	0.89	0.81
Net steam usage	0.97	0.88
SUBTOTAL	1.76	1.69
TOTAL	46.05	41.86
Ore grade	0.22	0.22
Gigajoule per net megagram (ton) of aluminum ore (bauxite)	10.13	9.21

[a]Battelle, 1975.

[b]Gigajoule = 10^9 joules.

6.4.3 Copper Ore Processing Facility

6.4.3.1 Process Units Description. The copper model plants consist of the following process units:

A. The primary crushing including the primary crusher, grizzly, screens, coarse ore storage bins, and transfer points.

B. Secondary crushing units including a secondary crusher and associated screens, ore bins, and transfer points.

C. Tertiary crushing units including a tertiary crusher and associated screens, fine ore bins, and transfer points.

D. Fine ore bins if not ducted to a crusher control device.

E. The dryer unit including the dryer and associated transfer points.

F. The product loadout unit including all packaging, product bins, and transfer points.

6.4.3.2 Model Plant Capacity. Model plant sizes are 140 Mg/hr (150 tons/hr) and 540 Mg/hr (600 tons/hr) based on new plant information.

6.4.3.3 Capacity Independent Model Plant Parameters.

- Hours of Operations - 8,500 hours/year.
- Capacity Utilization - 96 percent.
- New facilities by 1985 - 2.
- Ore Grade - 0.45 percent.

6.4.3.4 Capacity Dependent Model Plant Parameters.

140 Mg/hr (150 tons/hr) Model Plant.

- Land Required 126,000 M^2 (1,360,000 ft^2).*
- Energy Required 0.38 PJ/yr.

540 Mg/hr (600 tons/hr) Model Plant.

- Land Required 364,000 M^2 (3,920,000 ft^2).*
- Energy Required 1.55 PJ/yr.

---

*Includes only the mineral processing plant itself without the tailings pond areas. The plant area assumes a rectangular boundary located a minimum of 61 meters (200 ft) from the buildings.

Table 6-5. LIST OF PROCESS EQUIPMENT AND AIR VOLUME REQUIREMENTS IN DETERMINING MODEL COPPER ORE PLANTS

Model plant point	Source	140 Mg/hr (150 tons/hr) Model				540 Mg/hr (600 tons/hr) Model			
		Number	Size	Gas volume Nm^3/sec	Gas volume (scfm)	Number	Size	Gas volume Nm^3/sec	Gas volume (scfm)
1	Ore dumping station	1		0.94	(2,000)	1		2.41	(5,100)
2	Primary crusher	1	122 cm x 152 cm (48" x 60") Jaw	9.68	(20,500)	1	122 cm x 152 cm (48" x 60") GYR	2.88	(6,100)
3, 6, 11	Feeders - width	1 2	0.6 m (2') 0.76 m (2.5')	1.65	(3,500)	3 4	0.76 m (2.5') 0.9 m (3')	4.63	(9,800)
4, 5, 7 8, 12, 14 15, 18, 20	Transfer points - width	10 1	0.6 m (2') 0.76 m (2.5')	5.31	(11,250)	12 11	0.76 m (2.5') 0.9 m (3')	14.87	(31,500)
9	Secondary crusher hood	1	2.1 m (7') cone	0.47	(1,000)	3	2.1 m (7') cones	1.42	(3,000)
10	Secondary crusher	1		5.43	(11,500)	3		16.28	(34,500)
13	Screening	1	1.8 m x 3.7 m (6' x 12') rod deck	10.38	(22,000)	3	1.8 m x 4.9 m (6' x 16') rod deck	20.30	(43,000)
16	Tertiary crusher hood	1	2.1 m (7') shorthead	0.28	(600)	3	2.1 m (7') shorthead	0.71	(1,500)
17	Tertiary crusher	1		6.84	(14,500)	3		20.53	(43,500)
19	Fine ore bin	2		1.42	(3,000)	1		2.60	(5,500)
21	Dryer	1		1.89	(4,000)	1		5.48	(11,600)
22	Product bin	1		1.42	(3,000)	1		1.42	(3,000)
23	Product Loading	1		2.97	(6,300)	1		3.59	(7,600)
	TOTAL			48.68	(103,150)			97.12	(205,700)
Duplicate Processing Lines:		1				3			

References: Non-Metallic Mineral Processing Plants - Background Information for Proposed Standards - U.S. Environmental Protection Agency, March, 1979.
Industrial Ventilation - A Manual of Recommended Practices, 11th Edition, American Conference of Government Industrial Hygienists, 1970.
Responses to Section 114 Questionnaires by Metallic Mineral Processing Industries.

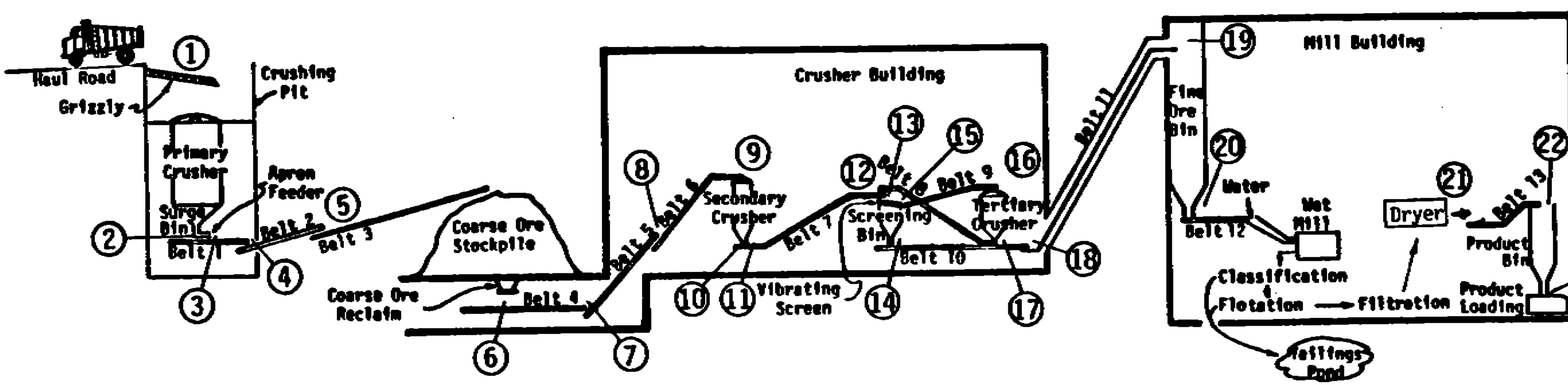


Figure 6-4. Copper ore processing industry model plant.

Table 6-6. STACK AND CONTROL SYSTEM PARAMETERS FOR COPPER ORE MODEL PLANTS

Plant capacity Mg/hr	(tons/hr)	Process unit*	Flow rate Nm³/s	(scfm)	Stack Temp. °C	(°F)	Stack Height m	(ft)	Stack Diameter m	(ft)	Power Requirements kW Regulatory Alternatives 1	2	3a	3b	Emission Rate kg/hr (lb/hr) Regulatory Alternatives 1		2		3	
140	(150)	A	12.62	(26750)	20	(68)	15	(48)	1.0	(3.4)	63.7	88.0	24.0	168.0	15.60	(34.39)	6.24	(13.76)	2.08	(4.59)
		B	7.08	(15000)	20	(68)	15	(48)	1.0	(3.4)	37.4	50.0	14.0	93.0	8.75	(19.29)	3.50	(7.71)	1.17	(2.57)
		C	20.34	(43100)	20	(68)	15	(48)	1.0	(3.4)	106.0	138.0	39.0	262.0	25.13	(55.41)	10.06	(22.17)	3.35	(7.39)
		D	2.36	(5000)	20	(68)	15	(48)	0.7	(2.2)	11.9	18.0	4.5	32.0	2.92	(6.43)	1.17	(2.57)	0.39	(0.86)
		E	1.89	(4000)	93	(200)	30	(100)	1.4	(4.6)	9.5	14.0	4.0	26.0	2.34	(5.15)	0.93	(2.06)	0.31	(0.69)
		F	4.39	(9300)	24	(75)	15	(48)	0.7	(2.2)	24.2	32.0	8.0	55.0	5.43	(11.96)	2.17	(4.78)	0.72	(1.59)
540	(600)	A	11.66	(24700)	20	(68)	15	(48)	1.0	(3.4)	59.0	80.0	22.5	123.0	14.41	(31.76)	5.76	(12.70)	1.92	(4.23)
		B(3)	7.32	(15500)	20	(68)	15	(48)	1.0	(3.4)	38.5	51.0	14.0	95.0	9.04	(19.93)	3.62	(7.97)	1.21	(2.66)
		C(3)	16.53	(35025)	20	(68)	15	(48)	1.0	(3.4)	82.2	120.0	45.0	217.0	20.43	(45.03)	8.17	(18.01)	2.72	(6.00)
		D	3.19	(6750)	20	(68)	15	(48)	0.7	(2.2)	16.9	24.0	8.0	42.0	3.94	(8.68)	1.57	(3.47)	0.53	(1.16)
		E	5.47	(11600)	93	(200)	30	(100)	1.4	(4.6)	29.8	39.0	14.0	73.0	6.76	(14.91)	2.71	(5.97)	0.90	(1.99)
		F	5.00	(10600)	24	(75)	15	(48)	0.7	(2.2)	27.5	36.0	12.0	67.0	6.18	(13.63)	2.47	(5.45)	0.83	(1.82)

*For multiple units the number of identical process units is given in parenthesis. Parameters presented are for each individual unit.

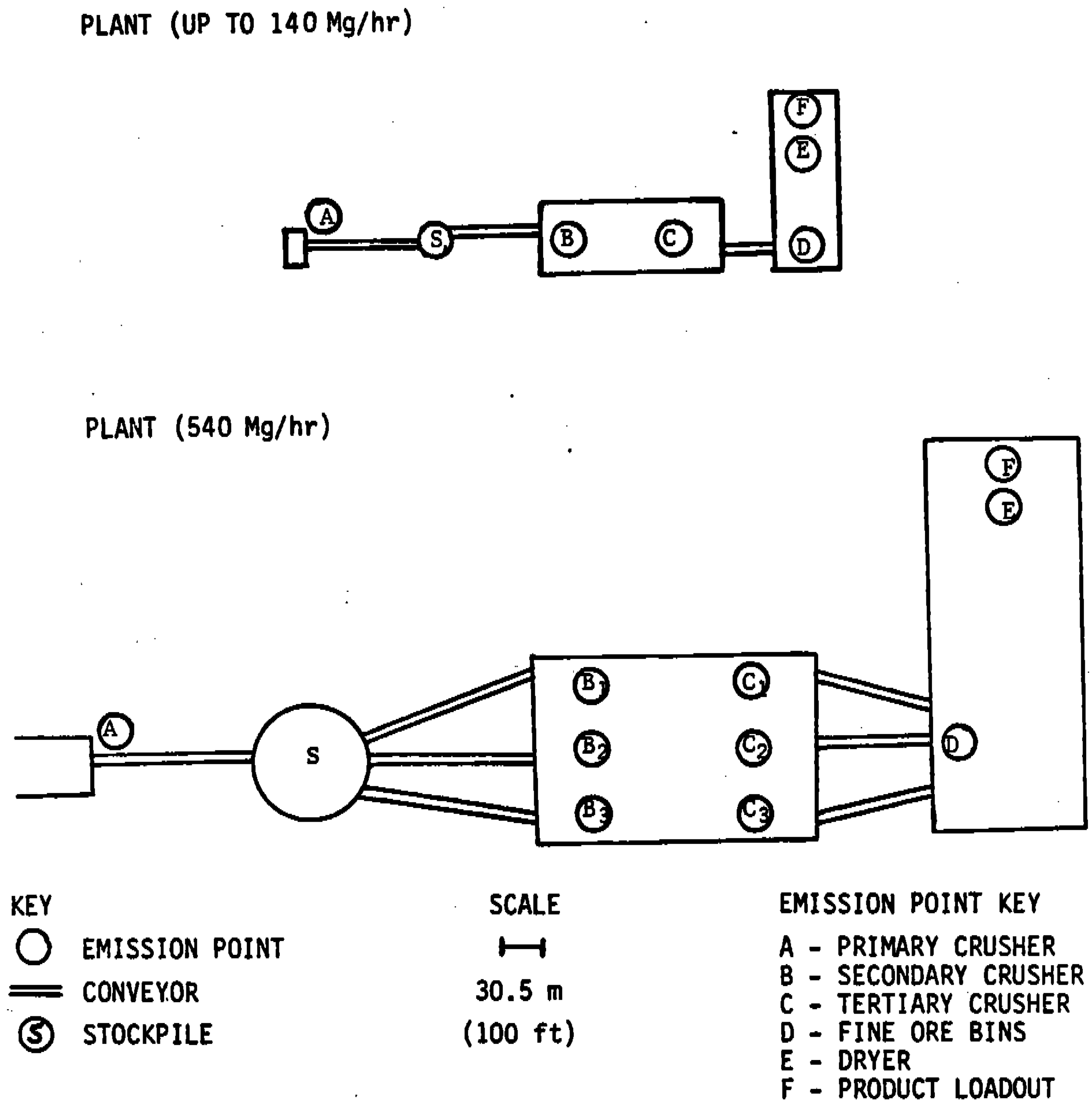


Figure 6-5. Copper model plant plot plans.

Table 6-7. ENERGY REQUIREMENTS FOR A COPPER ORE PROCESSING PLANT[a]

	Gigajoules[b] per net megagram of copper metal	Million BTU's per net ton of copper metal
Mine		
Excavation		
Electrical energy	9.630	8.735
Natural gas	0.257	0.233
Petroleum fuels (diesel)	6.242	5.662
Coal	0.039	0.035
Explosives	5.607	4.904
SUBTOTAL	21.775	19.569
Transportation		
Waste rock to dumps (truck-2 miles)	2.569	2.330
Ore to mill (electric rail-8 miles)	0.982	0.891
SUBTOTAL	3.551	3.221
Concentrator		
Crushing		
Electrical energy	4.840	4.390
Grinding		
Electrical energy	24.588	22.302
Steel balls and rods	5.555	5.039
SUBTOTAL	34.983	31.731
Flotation		
Electrical energy	6.678	6.057
Natural gas	2.867	2.600
Petroleum fuels	0.282	0.256
Steam	0.596	0.541
Inorganic reagents	3.151	2.858
Organic reagents	0.663	0.601
SUBTOTAL	14.237	12.914
TOTAL	74.546	67.435
Ore grade	0.0045	0.0045
Gigajoule per net megagram (ton) of copper ore	0.334	0.303

[a]Battelle, 1975.

[b]Gigajoule = 10^9 joules.

6.4.4 Gold Ore Processing Facility

6.4.4.1 Process Units Description. The gold model plants consist of the following process units:

A. Primary crushing unit including the primary crusher and associated dumping station, grizzly, screens, coarse ore storage bins, and transfer points.

B. Secondary crushing units including a secondary crusher and associated screens, ore bins, and transfer points.

C. Fine ore bins.

Because of the small quantities and characteristics of the final product, product loading operations are not covered on this document.

6.4.4.2 Model Plant Capacity. Model plant sizes are 68 Mg/hr (75 tons/hr) and 140 Mg/hr (150 tons/hr) based on new plant information.

6.4.4.3 Capacity Independent Model Plant Parameters.

- Hours of Operation - 5,820 hours/year.
- Capacity Utilization - 95 percent.
- New facilities by 1985 - 2.
- Ore Grade - 0.00063 percent.

6.4.4.4 Capacity Dependent Model Plant Parameters.

68 Mg/hr (75 tons/hr) Model Plant.

- Land Required 126,000 M^2 (1,360,000 ft^2).*
- Energy Required 0.21 PJ/yr.

140 Mg/hr (150 tons/hr) Model Plant.

- Land Required 126,000 M^2 (1,360,000 ft^2).*
- Energy Required 0.42 PJ/yr.

*Includes only the mineral processing plant itself without the tailings pond areas. The plant area assumes a rectangular boundary located a minimum of 61 meters (200 ft) from the buildings.

Table 6-8. LIST OF PROCESS EQUIPMENT AND AIR VOLUME REQUIREMENTS USED IN DETERMINING MODEL GOLD ORE PROCESSING PLANTS

Model plant point	Source	68 Mg/hr (75 tons/hr) Model				140 Mg/hr (150 tons/hr) Model			
		Number	Size	Gas volume Nm^3/sec	(scfm)	Number	Size	Gas volume Nm^3/sec	(scfm)
1	Ore dumping station	1		0.47	(1,000)	1		0.94	(2,000)
2	Primary crusher	1	91 cm x 122 cm	7.27	(15,400)	1	122 cm x 152 cm (60" x 89") GYR	9.68	(20,500)
3, 8, 11	Feeders - width	2 1	0.6 m (2') 0.46 m (1.5')	0.50	(2,500)	2	0.6 m (2') 0.76 m (2.5')	1.06	(2,250)
4, 5, 10, 11, 12, 14	Transfer points - width	4 2	0.46 m 0.6 m (2')	1.18	(6,250)	6 1	0.6 m (2') 0.76 m (2.5')	3.42	(7,250)
6	Secondary crusher hood	1	2.1 m (7') cone	0.47	(1,000)	1	2.1 m (7') cone	0.47	(1,000)
7	Secondary crusher	1		5.43	(11,500)	1		5.43	(11,500)
9	Screening	1	1.8 m x 3 m (6' x 10') rod deck	8.64	(18,300)	1	1.8 m x 3.6 m (6' x 12') rod deck	10.38	(22,000)
13	Fine ore bin	1		0.71	(1,500)	2		1.42	(3,000)
	TOTAL			24.67	(57,450)			32.80	(69,500)
Duplicate Processing Lines:		4				8			

References: Non-Metallic Mineral Processing Plants - Background Information for Proposed Standards - U.S. Environmental Protection Agency, March, 1979.
Industrial Ventilation - A Manual of Recommended Practices, 11th Edition, American Conference of Government Industrial Hygienists - 1970.
Responses to Section 114 Questionnaire by Metallic Mineral Processing Industries.

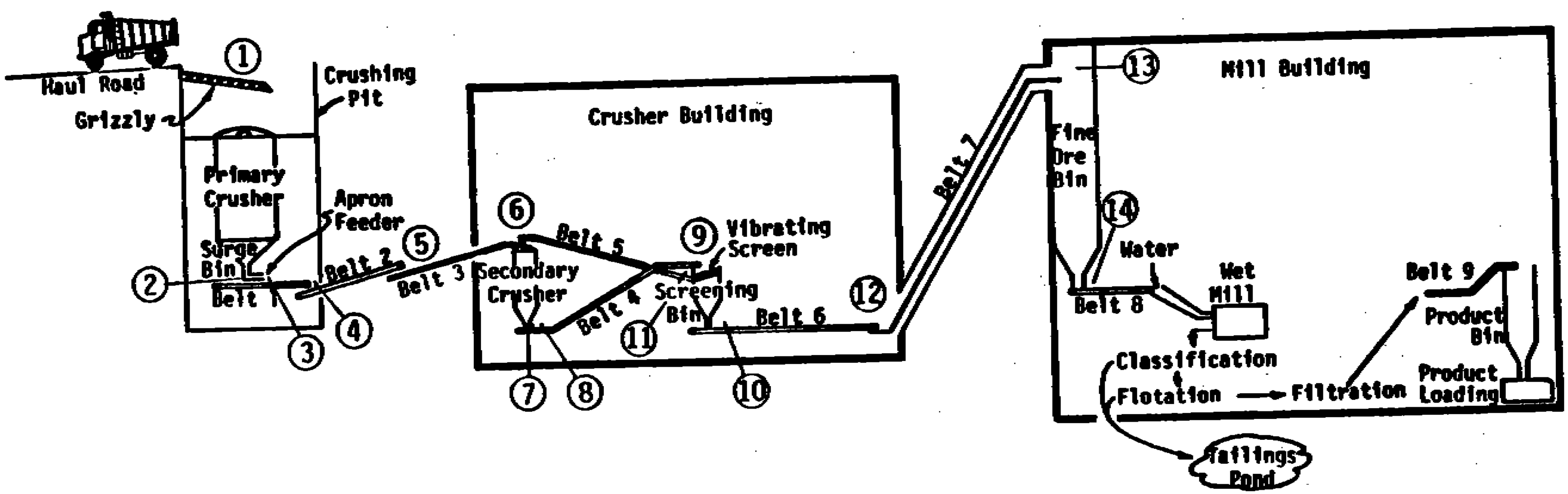
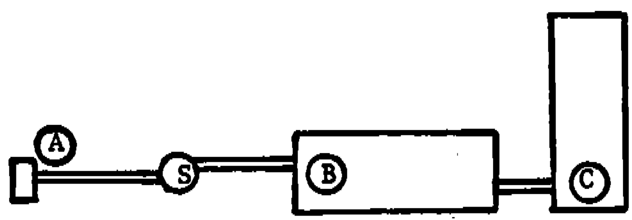


Figure 6-6. Gold ore processing industry model plants.

Table 6-9. STACK AND CONTROL SYSTEM PARAMETERS FOR GOLD ORE MODEL PLANTS

Plant capacity Mg/hr	Plant capacity (tons/hr)	Process unit*	Flow rate Nm^3/s	Flow rate (scfm)	Stack Temp. °C	Stack Temp. (°F)	Stack Height m	Stack Height (ft)	Stack Diameter m	Stack Diameter (ft)	Power Requirements kW, Regulatory Alternatives 1	2	3a	3b	Emission Rate kg/hr (lb/hr), Regulatory Alternatives 1 kg/hr	1 (lb/hr)	2 kg/hr	2 (lb/hr)	3 kg/hr	3 (lb/hr)
68	(75)	A	9.16	(19400)	20	(68)	14	(47)	1.0	(3.4)	47.2	62.0	17.0	120.0	11.31	(24.94)	4.53	(9.98)	1.51	(3.33)
		B	16.77	(35550)	20	(68)	14	(47)	1.0	(3.4)	87.2	116.0	32.0	218.0	20.73	(45.70)	8.29	(18.29)	2.77	(6.10)
		C	1.18	(2500)	20	(68)	14	(47)	0.7	(2.2)	6.0	9.0	2.0	18.0	1.46	(3.22)	0.59	(1.29)	0.20	(0.43)
140	(150)	A	12.39	(26250)	20	(68)	14	(47)	1.0	(3.4)	62.5	86.0	24.0	160.0	15.31	(33.75)	6.12	(13.50)	2.04	(4.50)
		B	18.29	(38750)	20	(68)	14	(47)	1.0	(3.4)	94.3	127.0	35.0	233.0	22.6	(49.83)	9.04	(19.92)	3.02	(6.64)
		C	2.12	(4500)	20	(68)	14	(47)	0.7	(2.2)	10.7	16.0	4.0	30.0	2.63	(5.79)	1.05	(2.31)	0.35	(0.77)

PLANT (UP TO 140 Mg/hr)



KEY

○ EMISSION POINT

═ CONVEYOR

Ⓢ STOCKPILE

SCALE

30.5 m

(100 ft)

EMISSION POINT KEY

A - PRIMARY CRUSHER

B - SECONDARY CRUSHER

C - FINE ORE BIN

Figure 6-7. Gold model plant plot plans.

Table 6-10. ENERGY REQUIREMENTS FOR A GOLD ORE PROCESSING PLANTS[a]

	Gigjoules[b] per net megagram of gold metal	Million BTU's per net ton of gold metal
Open pit mining		
Explosives	9,182	8,328
Gasoline	2,326	2,110
Diesel fuel oil	21,581	19,575
Lubricants	1,103	1,000
SUBTOTAL	34,192	31,013
Crushing and grinding		
Electrical energy	16,840	15,274
Liners	2,059	1,868
Steel balls	168	152
SUBTOTAL	19,067	17,294
Leaching		
Electrical energy	3,645	3,306
Diesel fule oil	6,999	6,348
Chlorine	4,862	4,410
Chlorine transportation (300 miles by rail)	49	44
Sodium cyanide	632	573
Cyanide tranportation (300 miles by rail)	4	4
Soda ash (natural)	309	280
Soda ash transportation (500 miles by rail)	13	12
SUBTOTAL	16,513	14,977
Thickening		
Electrical energy	4,035	3,660
Lime	5,189	4,707
Lime transportation (50 miles by truck)	73	66
Additives	61	55
SUBTOTAL	9,358	8,488

(continued)

Table 6-10. Concluded

	Gigjoules[b] per net megagram of gold metal	Million BTU's per net ton of gold metal
Clarification and precipitation		
Electrical energy	3,272	2,968
Zinc	831	754
Zinc tranportation (500 miles by rail)	4	4
Filter aid	2,224	2,017
Filter aid transportation (500 miles by rail)	19	17
SUBTOTAL	6,350	5,760
Fluxing, melting and casting		
Electrical energy	172	156
Diesel fuel oil	1,069	970
Flux	1	1
SUBTOTAL	1,242	1,127
Pumping tailing and water Reclamation		
Electrical energy	830	753
TOTAL	87,552	79,412
Ore grade	6.0×10^{-6}	6.0×10^{-6}
Gigjoule per net megagram (ton) of gold ore	0.530	0.480

[a]Battelle, 1976.

[b]Gigajoule = 10^9 joules.

6.4.5 Iron Ore Processing Facility

6.4.5.1 Process Units Description. The model plants for the iron ore processing industry consists of the following process units:

A. The primary crushing unit including the primary crusher and associated dumping station, grizzly, screens, coarse ore storage bins, and transfer points.

B. Secondary crushing units including a secondary crusher and associated screens, fine ore bins, and transfer points.

C. Tertiary crushing units including tertiary crusher and associated screens, fine ore bins, and transfer points.

D. The fine ore bins if not ducted to a crusher control device.

E. The product loadout unit including all packaging, product bins, transfer points, and loadout mechanisms before entry holds.

As noted in Chapter 3, emissions from pelletizing furnaces are not covered in this document.

6.4.5.2 Model Plant Capacity. Two new iron ore processing plants are projected between now and 1985, one at 1,100 Mg/hr (1,200 tons/hr) and one at 2,200 Mg/hr (2,400 tons/hr).

6.4.5.3 Capacity Independent Model Plant Parameters.

- Hours of operation - 8,500 hours/year.
- Capacity Utilization - 90 percent.
- New facilities by 1985 - 2.
- Ore grade - 36 percent.

6.4.5.4 Capacity Dependent Model Plant Parameters.

1,100 Mg/hr (1,200 tons/hr) Model Plant

- Land Required 364,000 M^2 (3,920,000 ft^2).*
- Energy Required 1.41 PJ/yr.

2,200 Mg/hr (2,400 tons/hr) Model Plant.

- Land Required 490,000 M^2 (5,270,000 ft^2).*
- Energy Required 2.82 PJ/yr.

---

*Includes only the mineral processing plant itself without the tailings pond areas. The plant area assumes a rectangular boundary located a minimum of 61 meters (200 ft) from the buildings.

Table 6-11. LIST OF PROCESS EQUIPMENT AND AIR VOLUME REQUIREMENTS USED IN DETERMINING MODEL IRON ORE PROCESSING PLANTS

Model plant point	Source	1,100 Mg/hr (1,200 tons/hr) Model				2,200 Mg/hr (2,400 tons/hr) Model			
		Number	Size	Gas volume Nm^3/sec	Gas volume (scfm)	Number	Size	Gas volume Nm^3/sec	Gas volume (scfm)
1	Ore dumping station	1		4.72	(10,000)	1		8.50	(18,000)
2	Primary crusher	1	152 cm (60") GYR	4.72	(10,000)	1	152 cm x 226 cm (60" x 89") GYR	6.61	(14,000)
3, 6, 11	Feeders - width	5 4	1.07 m (3.5') 0.9 m (3')	6.99	(14,800)	9 8	1.2 m (4') 1.07 m (3.5')	15.10	(32,000)
4, 5, 7, 8, 12, 14 15, 18, 20	Transfer points - width	2 8 19	1.07 m (3.5') 0.9 m (3') 0.76 m (2.5')	18.50	(39,200)	2 16 40	1.2 m (4') 1.07 m (3.5') 0.9 m (3')	43.42	(92,000)
9	Secondary crusher hood	4	2.1 m (7') cones	1.89	(4,000)	8	2.1 m (7') cones	3.78	(8,000)
10	Secondary crusher	4		21.71	(46,000)	8		43.42	(92,000)
13	Screening	4	1.8 m x 4.9 m (6' x 16') rod deck	26.90	(57,000)	8	1.8 m x 4.9 m (6' x 16') rod deck	53.81	(114,000)
16	Tertiary crusher hood	4	2.1 m (7') shorthead	0.94	(2,000)	8	2.1 m (7') shorthead	1.89	(4,000)
17	Tertiary crusher	4		27.38	(58,000)	8		54.75	(116,000)
19	Fine ore bin	4		3.49	(7,400)	8		6.94	(14,700)
21	Product bin	3		2.12	(4,500)	3		4.25	(9,000)
22	Product loading	3		5.38	(11,400)	3		10.86	(23,000)
	TOTAL			124.75	(264,300)			253.32	(536,700)
Duplicate Processing Lines:		4				8			

References: Non-Metallic Mineral Processing Plants - Background Information for Proposed Standards - U.S. Environmental Protection Agency, March, 1979.
Industrial Ventilation - A Manual of Recommended Practices, 11th Edition, American Conference of Government Industrial Hygienists - 1970.
Responses to Section 114 Questionnaire by Metallic Mineral Processing Industries.

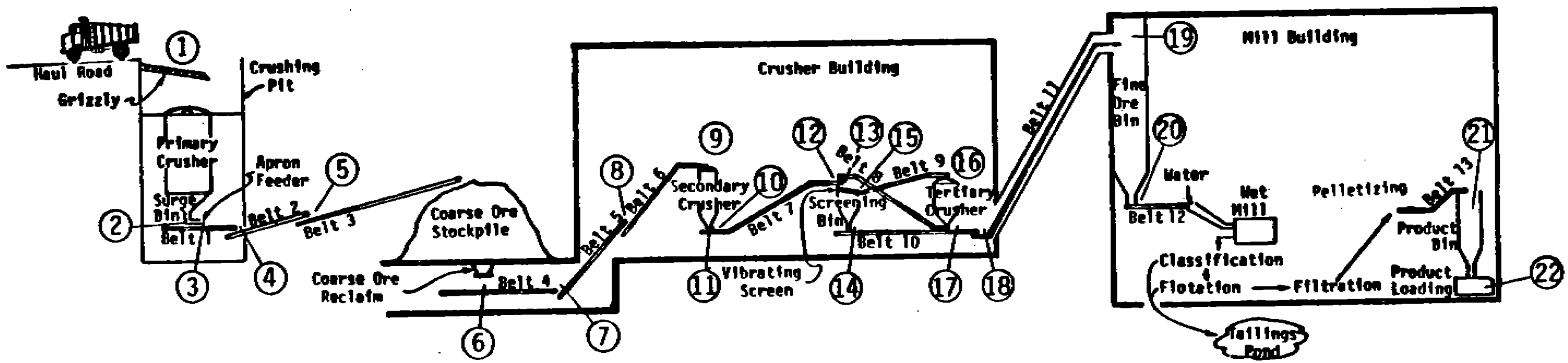


Figure 6-8. Iron ore processing industry model plant.

Table 6-12. STACK AND CONTROL SYSTEM PARAMETERS FOR IRON ORE MODEL PLANTS

Plant capacity Mg/hr	(tons/hr)	Process unit*	Flow rate Nm³/s	(scfm)	Stack Temp. °C	(°F)	Stack Height m	(ft)	Stack Diameter m	(ft)	Power Requirements kW, Regulatory Alternatives 1	2	3a	3b	Emission Rate kg/hr (lb/hr), Regulatory Alternatives 1		2		3	
1100	(1200)	A	18.90	(40050)	20	(68)	14	(47)	1.0	(3.4)	93.4	128.0	37.0	248.0	23.36	(51.49)	9.34	(20.60)	3.12	(6.87)
		B(4)	7.32	(15500)	20	(68)	14	(47)	1.0	(3.4)	38.5	51.0	14.0	95.0	9.04	(19.93)	3.62	(7.97)	1.21	(2.66)
		C(4)	16.22	(34360)	20	(68)	14	(47)	1.0	(3.4)	80.7	117.0	33.0	217.0	20.04	(44.18)	8.02	(17.67)	2.67	(5.89)
		D	4.20	(8900)	20	(68)	14	(47)	1.0	(3.4)	23.1	30.0	8.0	55.0	5.19	(11.44)	2.08	(4.58)	0.69	(1.53)
		E	7.5	(15900)	24	(75)	14	(47)	0.7	(2.2)	39.4	52.5	15.0	97.0	9.27	(20.44)	3.71	(8.18)	1.24	(2.73)
2200	(2400)	A	21.0	(44500)	20	(68)	14	(47)	1.0	(3.4)	111.7	142.0	41.0	278.0	25.95	(57.21)	10.38	(22.89)	3.46	(7.63)
		B(8)	7.32	(15500)	20	(68)	14	(47)	1.0	(3.4)	38.5	51.0	14.0	95.0	9.04	(19.93)	3.62	(7.97)	1.21	(2.66)
		C(8)	18.97	(40185)	20	(68)	14	(47)	1.0	(3.4)	94.0	129.0	37.0	250.0	23.44	(51.67)	9.38	(20.67)	3.13	(6.89)
		D	6.94	(14700)	20	(68)	14	(47)	1.0	(3.4)	36.7	48.0	14.0	93.0	8.57	(18.90)	3.43	(7.56)	1.14	(2.52)
		E	15.11	(32000)	24	(75)	14	(47)	0.7	(2.2)	75.2	109.0	30.7	202.1	18.67	(41.16)	7.47	(16.46)	2.49	(5.49)

*For multiple units the number of identical process units is given in parenthesis. Parameters presented are for each individual unit.

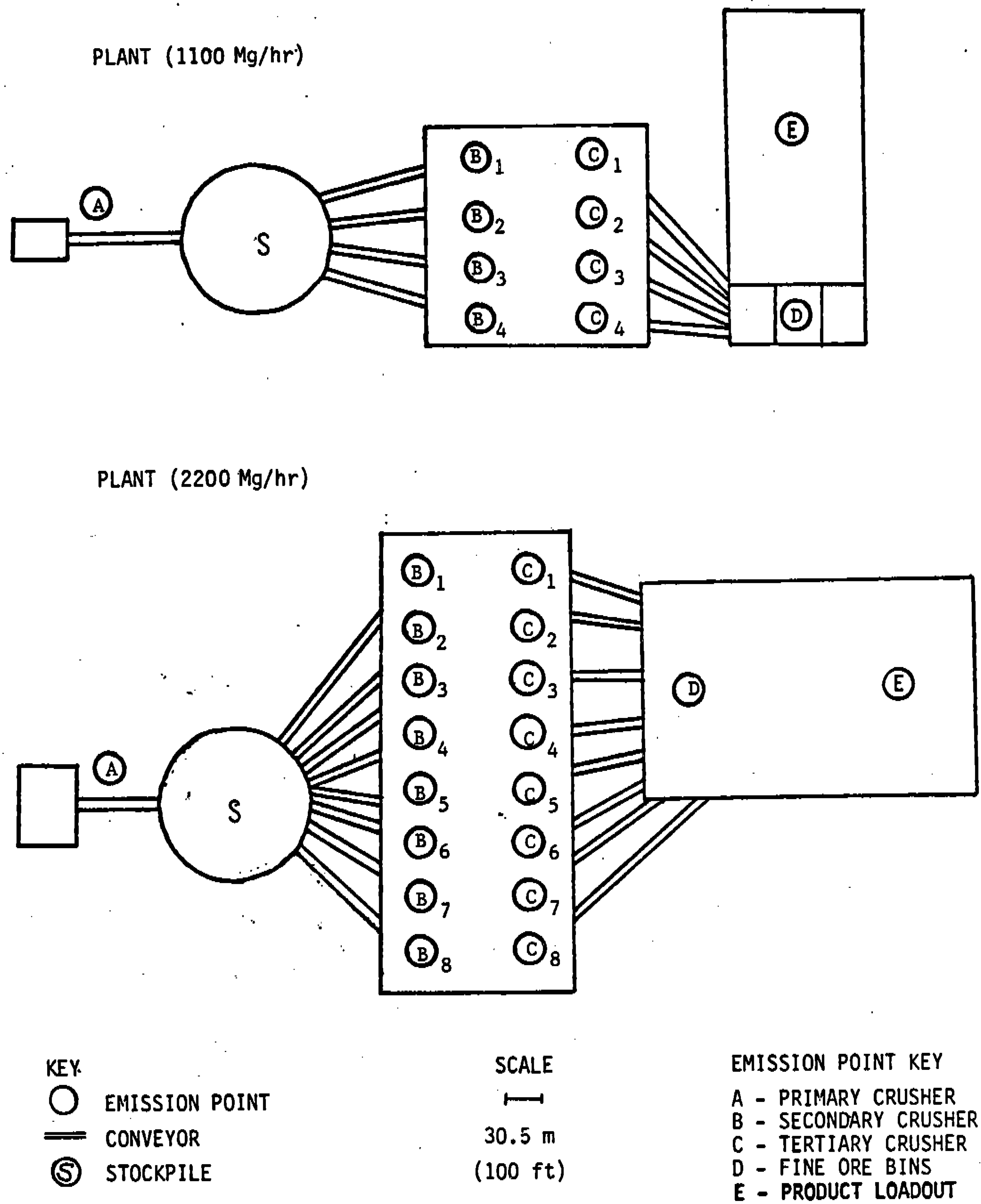


Figure 6-9. Iron model plant plot plans.

Table 6-13. ENERGY REQUIREMENTS FOR AN IRON ORE PROCESSING PLANT

	Megajoule[a] per net megagram of iron ore	1,000 BTU's per net ton of iron ore
Consumption		
Crushing	6.47	5.87
Concentration	145.86	132.30
TOTAL	152.33	138.17

[a]Megajoule equals 10^6 joules.

(114 Questionnaire response)

6.4.6 Lead/Zinc Ore Processing Facility

6.4.6.1 Process Units Description. The model plants for the lead/zinc ore processing industry consist of the following process units:

A. The primary crushing unit including the primary crusher and associated dumping station, grizzly, screens, coarse ore storage bins, and transfer points.

B. Secondary crushing units including a secondary crusher and associated screens, ore bins, and transfer points.

C. Tertiary crushing units including a tertiary crusher and associated screens, fine ore bins and transfer points.

D. The fine ore bins if not ducted to a crusher control device.

E. The dryer unit including the dryer and associated transfer points.

F. The product loadout unit including all packaging,product bins, transfer points, and loadout mechanisms.

6.4.6.2 Model Plant Capacity. Three new lead/zinc ore processing plants are projected between now and 1985, one at 540 Mg/hr (600 tons/hr) and two at 270 Mg/hr (300 tons/hr).

6.4.6.3 Capacity Independent Model Plant Parameters.

- Hours of operation - 5,820 hours/year.
- Capacity Utilization - 87 percent.
- New facilities by 1985 - 3.
- Ore grade - 4.5 percent lead and 1 percent zinc.

6.4.6.4 Capacity Dependent Model Plant Parameters.

270 Mg/hr (300 ton/hr) Model Plant.

- Land Required 204,000 M^2 (2,200,000 ft^2).*
- Energy Required 1.51 PJ/yr.

540 Mg/yr (600 tons/hr) Model Plant.

- Land Required 364,000 M^2 (3,920,000 ft^2).*
- Energy Required 3.02 PJ/yr.

*Includes only the mineral processing plant itself without the tailings pond areas. The plant area assumes a rectangular boundary located a minimum of 61 meters (200 ft) from the buildings.

Table 6-14. LIST OF PROCESS EQUIPMENT AND AIR VOLUME REQUIREMENTS USED IN DETERMINING MODEL LEAD/ZINC ORE PROCESSING PLANTS

Model plant point	Source	270 Mg/hr (300 Tons/hr) Model				540 Mg/hr (600 tons/hr) Model			
		Number	Size	Gas volume Nm³/sec	Gas volume (scfm)	Number	Size	Gas volume Nm³/sec	Gas volume (scfm)
1	Ore dumping station	1		1.65	(3,500)	1		2.41	(5,100)
2	Primary crusher	1	107 cm x 165 cm (42" x 65") GYR	2.74	(5,800)	1	122 cm x 152 cm (48" x 60") GYR	2.88	(6,100)
3, 6, 11	Feeders - width	3 2	0.9 m (3') 0.76 m (2.5')	3.30	(7,000)	3 4	0.76 m (2.5') 0.9 m (3')	4.63	(9,800)
4, 5, 7, 8, 12, 14, 15, 18, 20	Transfer points - width	8 6 2	0.3 m (1') 0.76 m (2.5') 0.92 m (3')	6.84	(14,500)	12 11	0.76 m (2.5') 0.9 m (3')	14.87	(31,500)
9	Secondary crusher hood	2	2.1 m (7') cones	0.94	(2,000)	3	2.1 m (7') cones	1.42	(3,000)
10	Secondary crusher	2		10.86	(23,000)	3		16.28	(34,500)
13	Screening	2	1.8 m x 4.9 m (6' x 16') rod deck	13.69	(29,000)	3	1.8 m x 4.9 m (6' x 16') rod deck	20.30	(43,000)
16	Tertiary crusher hood	2	2.1 m (7') shorthead	0.57	(1,200)	3	2.1 m (7') shorthead	0.71	(1,500)
17	Tertiary crusher	2		13.69	(29,000)	3		20.53	(43,500)
19	Fine ore bin	3		2.12	(4,500)	3		2.60	(5,500)
21	Dryer	2		3.78	(8,000)	2		5.48	(11,600)
22	Product bin	2		1.42	(3,000)	2		1.42	(3,000)
23	Product loading	2		3.45	(7,300)	2		3.59	(7,600)
	TOTAL			65.05	(137,800)			97.12	(205,700)
Duplicate Processing Lines:		2				3			

References: Non-Metallic Mineral Processing Plants - Background Information for Proposed Standards - U.S. Environmental Protection Agency, March 1979.
Industrial Ventilation - A Manual of Recommended Practices, 11th Edition, American Conference of Government Industrial Hygienists -1970.
Responses to Section 114 Questionnaire by Metallic Mineral Processing Industries.

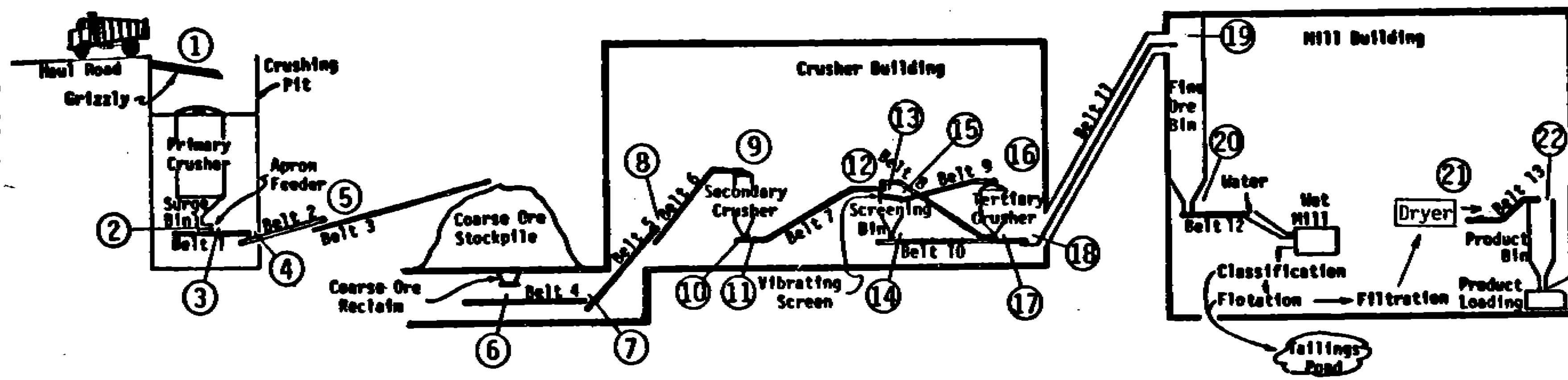


Figure 6-10. Lead/Zinc ore processing industry model plant.

Table 6-15. STACK AND CONTROL SYSTEM PARAMETERS FOR LEAD/ZINC ORE MODEL PLANTS

Plant capacity Mg/hr	(tons/hr)	Process unit*	Flow rate Nm^3/s	(scfm)	Stack Temp. °C	(°F)	Stack Height m	(ft)	Stack Diameter m	(ft)	Power Requirements kW Regulatory Alternatives 1	2	3a	3b	Emission Rate kg/hr (lb/hr) Regulatory Alternatives 1	(1)	2	(2)	3	(3)
270	(300)	A	6.91	(14650)	20	(68)	14	(47)	1.0	(3.4)	36.6	49.0	14.0	90.0	8.55	(18.84)	3.42	(7.53)	1.14	(2.51)
		B(2)	6.96	(14750)	20	(68)	14	(47)	1.0	(3.4)	36.8	49.0	14.0	90.0	8.60	(18.96)	3.44	(7.59)	1.15	(2.53)
		C(2)	16.42	(34800)	20	(68)	14	(47)	1.0	(3.4)	81.7	115.0	33.0	215.0	20.29	(44.74)	8.12	(17.90)	2.71	(5.97)
		D	2.71	(5750)	20	(68)	14	(47)	0.7	(2.2)	14.0	21.0	5.0	35.0	3.35	(7.39)	1.34	(2.96)	0.45	(0.99)
		E	3.78	(8000)	93	(200)	30	(100)	1.4	(4.6)	20.5	28.0	7.0	47.0	4.67	(10.29)	1.86	(4.11)	0.62	(1.37)
		F	4.87	(10300)	24	(75)	14	(47)	0.7	(2.2)	28.0	37.0	10.0	67.0	6.30	(13.89)	2.52	(5.55)	0.84	(1.85)
540	(600)	A	11.66	(24700)	20	(68)	14	(47)	1.0	(3.4)	59.0	80.0	22.0	155.0	14.41	(31.76)	5.76	(12.70)	1.92	(4.23)
		B(3)	7.32	(15500)	20	(68)	14	(47)	1.0	(3.4)	38.5	51.0	14.0	95.0	9.04	(19.93)	3.62	(7.97)	1.21	(2.66)
		C(3)	16.53	(35025)	20	(68)	14	(47)	1.0	(3.4)	82.2	120.0	33.3	217.0	20.43	(45.03)	8.17	(18.01)	2.72	(6.00)
		D	3.19	(6750)	20	(68)	14	(47)	0.7	(2.2)	16.9	24.0	7.0	47.0	3.94	(8.68)	1.57	(3.47)	0.53	(1.16)
		E	5.47	(11600)	93	(200)	30	(100)	1.4	(4.6)	29.8	39.0	10.0	73.0	6.76	(14.91)	2.91	(5.97)	0.90	(1.99)
		F	5.00	(10600)	24	(75)	14	(47)	0.7	(2.2)	27.5	36.0	10.0	65.0	6.18	(13.63)	2.47	(5.45)	0.90	(1.82)

*For multiple units the number of identical process units is presented in parenthesis. Parameters presented are for each individual unit.

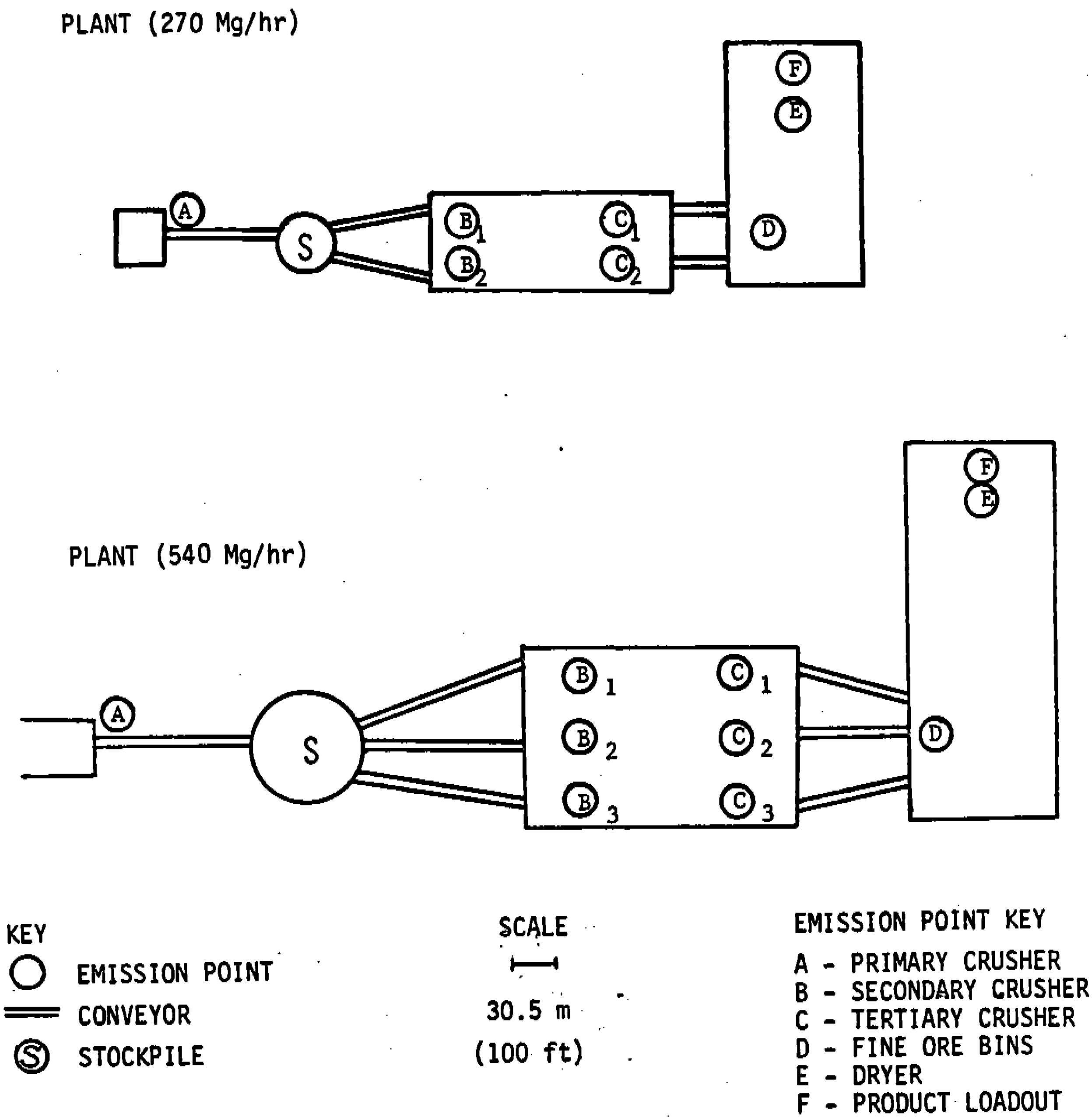


Figure 6-11. Lead/Zinc model plant plot plans.

Table 6-16. ENERGY REQUIREMENTS FOR A LEAD/ZINC ORE PROCESSING PLANT[a]

	Gigajoules[b] per net megagram of lead/zinc metal	Million BTU's per net ton of lead/zinc metal
Mining		
Steel	0.347	0.315
Explosives	0.503	0.456
Electrical energy	4.102	3.721
Diesel fuel oil	1.089	0.988
Gasoline	0.079	0.072
SUBTOTAL	6.121	5.552
Crushing		
Electrical energy	0.240	0.218
Grinding and classifying		
Electrical energy	3.652	3.312
Steel	0.583	0.529
SUBTOTAL	4.475	4.059
Beneficiation		
Conditioning and flotation	1.335	1.211
Thickening and filtering	0.174	0.158
Organic reagents	0.062	0.056
Inorganic reagents	0.227	0.206
Miscellaneous	0.060	0.054
SUBTOTAL	1.858	1.685
Rail transportation	1.130	1.025
Drying		
Electrical energy	0.023	0.021
TOTAL	13.63	12.36
Ore grade	0.07	0.07
Gigajoule per net megagram (ton) of lead/zinc ore	0.954	0.865

[a]Battelle, 1975.

[b]Gigajoule = 10^9 joules.

6.4.7 Molybdenum Ore Processing Facility

6.4.7.1 Process Units Description. The model plants for the molybdenum ore processing industry consist of the following process units:

A. The primary crusher unit including the primary crushing unit including the primary crusher and associated dumping station, grizzly, screens, coarse ore storage bins, and transfer points.

B. Secondary crushing units including a secondary crusher and associated screens, ore bins, and transfer points.

C. Tertiary crushing units including a tertiary crusher and associated screens, fine ore bins, and transfer points.

D. The fine ore bins if not ducted to a crusher control device.

E. The dryer unit including the dryer and associated transfer points.

F. The product loadout units including all packaging product bins, transfer points, and loadout mechanisms.

6.4.7.2 Model Plant Capacity. Three new molybdenum ore processing plants are projected between now and 1985, one at 270 Mg/hr (300 tons/hr) and two at 1,100 Mg/hr (1,200 tons/hr).

6.4.7.3 Capacity Independent Model Plant Parameters.

- Hours of Operation - 8,500 hours/year.
- Capacity Utilization - 84 percent.
- New facilities by 1985 - 3.
- Ore grade - 0.4 percent.

6.4.7.4 Capacity Dependent Model Plant Parameters.

270 Mg/hr (300 tons/hr) Model Plant.

- Land Required 204,000 M^2 (2,200,000 ft^2).*
- Energy Required 1.53 PJ/yr.

1,100 Mg/hr (1,200 tons/hr) Model Plant.

- Land Required 364,000 M^2 (3,920,000 ft^2).*
- Energy Required 6.12 PJ/yr.

---

*Includes only the mineral processing plant itself without the tailings pond areas. The plant area assumes a rectangular boundary located a minimum of 61 meters (200 ft) from the buildings.

Table 6-17. LIST OF PROCESS EQUIPMENT AND AIR VOLUME REQUIREMENTS USED IN DETERMINING MODEL MOLYBDENUM ORE PROCESSING PLANTS

Model plant point	Source	270 Mg/hr (300 tons/hr) Model				1,100 Mg/hr (1,200 tons/hr) Model			
		Number	Size	Gas volume Nm/sec	Gas volume (scfm)	Number	Size	Gas volume Nm^3/sec	Gas volume (scfm)
1	Ore dumping station	1		1.65	(3,500)	1		4.72	(10,000)
2	Primary crusher	1	107 cm x 165 cm (42" x 65") GYR	2.74	(5,800)	1	152 cm (60")GYR	4.72	(10,000)
3, 6, 11	Feeders - width	3 2	0.92 m (3') 0.76 m (2.5')	3.30	(7,000)	5 4	1.0 m (3.5') 0.92 m (3')	6.99	(14,800)
4, 5, 7, 8, 12, 14, 15, 18, 20	Transfer points - width	8 6 2	0.30 m (1') 0.76 m (2.5') 0.92 m (3')	6.84	(14,500)	2 8 19	1.0 m (3.5') 0.92 m (3') 0.76 m (2.5')	18.50	(39,200)
9	Secondary crusher hood	2	2.1 m (7') cones	0.94	(2,000)	4	2.1 m (7') cones	1.89	(4,000)
10	Secondary crusher	2		10.87	(23,000)	4		21.71	(46,000)
13	Screening	2	1.8 m x 4.9 m (6' x 16') rod deck	13.69	(29,000)	4	1.8 m x 4.9 m (6' x 16') rod deck	26.90	(57,000)
16	Tertiary crusher hood	2	2.1 m (7') shorthead	0.57	(1,200)	4	2.1 m (7') shorthead	0.94	(2,000)
17	Tertiary crusher	2		13.69	(29,000)	4		27.38	(58,000)
19	Fine ore bin	3		2.12	(4,500)	4		3.49	(7,400)
21	Dryer	2		3.78	(8,000)	3		8.26	(17,500)
22	Product bin	2		1.42	(3,000)	3		2.12	(4,500)
23	Product loading	2		3.45	(7,300)	3		5.38	(11,400)
	TOTAL			65.04	(137,800)			133.01	(281,800)
Duplicate Processing Lines:		2				4			

References: Non-Metallic Mineral Processing Plants - Background Information for Proposed Standards - U.S. Environmental Protection Agency, March, 1979.
Industrial Ventilation - A Manual of Recommended Practices, 11th Edition, American Conference of Government Industrial Hygienists - 1970.
Responses to Section 114 Questionnaires by Metallic Mineral Processing Industries.

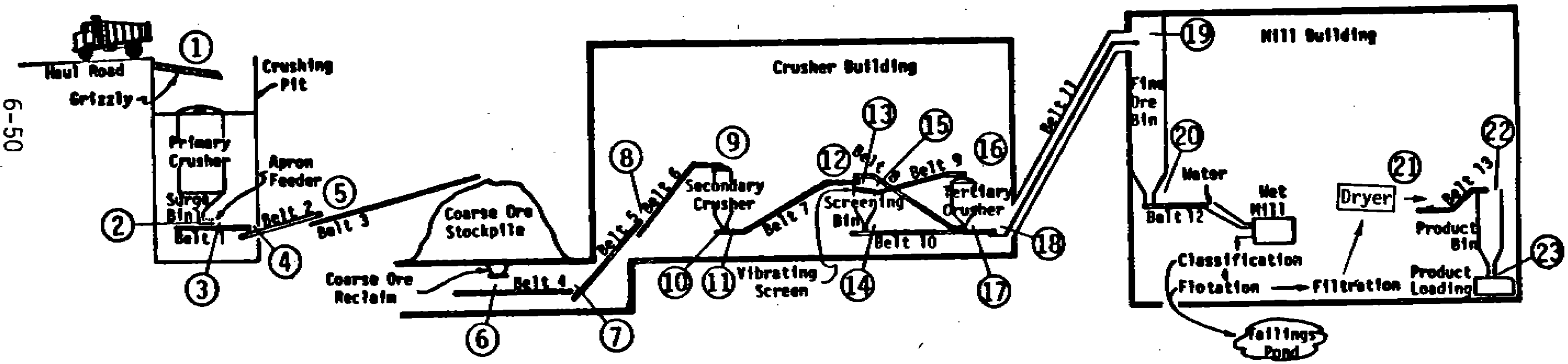


Figure 6-12. Molybdenum ore processing industry model plant.

Table 6-18. STACK AND CONTROL SYSTEM PARAMETERS FOR MOLYBDENUM ORE MODEL PLANTS

Plant capacity Mg/hr (tons/hr)	Process unit*	Flow rate Nm^3/s (scfm)	Stack Temp. °C (°F)	Stack Height m (ft)	Stack Diameter m (ft)	Power Requirements kW Regulatory Alternatives 1	2	3a	3b	Emission Rate kg/hr (lb/hr) Regulatory Alternatives 1	2	3
270 (300)	A	6.91 (14650)	20 (68)	15 (48)	1.0 (3.4)	36.6	49.0	14.0	90.0	8.55 (18.84)	3.42 (7.53)	1.14 (2.51)
	B(2)	6.96 (14750)	20 (68)	15 (48)	1.0 (3.4)	36.8	49.0	14.0	90.0	8.60 (18.96)	3.44 (7.59)	1.15 (2.53)
	C(2)	16.42 (34800)	20 (68)	15 (48)	1.0 (3.4)	81.7	115.0	33.0	217.0	20.29 (44.74)	8.12 (17.90)	2.71 (5.97)
	D	2.71 (5750)	20 (68)	15 (48)	0.7 (2.2)	14.0	21.0	5.0	35.0	3.35 (7.39)	1.34 (2.96)	0.45 (0.99)
	E	3.78 (8000)	93 (200)	30 (100)	1.4 (4.6)	20.5	28.0	7.0	47.0	4.67 (10.29)	1.86 (4.11)	0.62 (1.37)
	F	4.87 (10300)	24 (75)	15 (48)	0.7 (2.2)	28.0	37.0	10.0	67.0	6.30 (13.89)	2.52 (5.55)	0.84 (1.85)
1100 (1200)	A	18.90 (40050)	20 (68)	15 (48)	1.0 (3.4)	93.4	128.0	37.0	248.0	23.36 (51.49)	9.34 (20.60)	3.12 (6.87)
	B(4)	7.32 (15500)	20 (68)	15 (48)	1.0 (3.4)	38.5	51.0	14.0	95.0	9.04 (19.93)	3.62 (7.97)	1.21 (2.66)
	C(4)	16.22 (34360)	20 (68)	15 (48)	1.0 (3.4)	80.7	117.0	33.0	217.0	20.04 (44.18)	8.02 (17.67)	2.67 (5.89)
	D	4.20 (8900)	20 (68)	15 (48)	0.7 (2.2)	23.1	30.0	8.0	55.0	5.19 (11.44)	2.08 (4.58)	0.69 (1.53)
	E	8.26 (17500)	93 (200)	30 (100)	1.4 (4.6)	43.0	57.0	16.0	108.0	10.20 (22.50)	4.08 (9.00)	1.36 (3.00)
	F	7.50 (15900)	24 (75)	15 (48)	0.7 (2.2)	39.4	52.5	15.0	97.0	9.27 (20.44)	3.71 (8.18)	1.24 (2.73)

*For multiple units the number of identical process units is given in parenthesis. Parameters presented are for each individual unit.

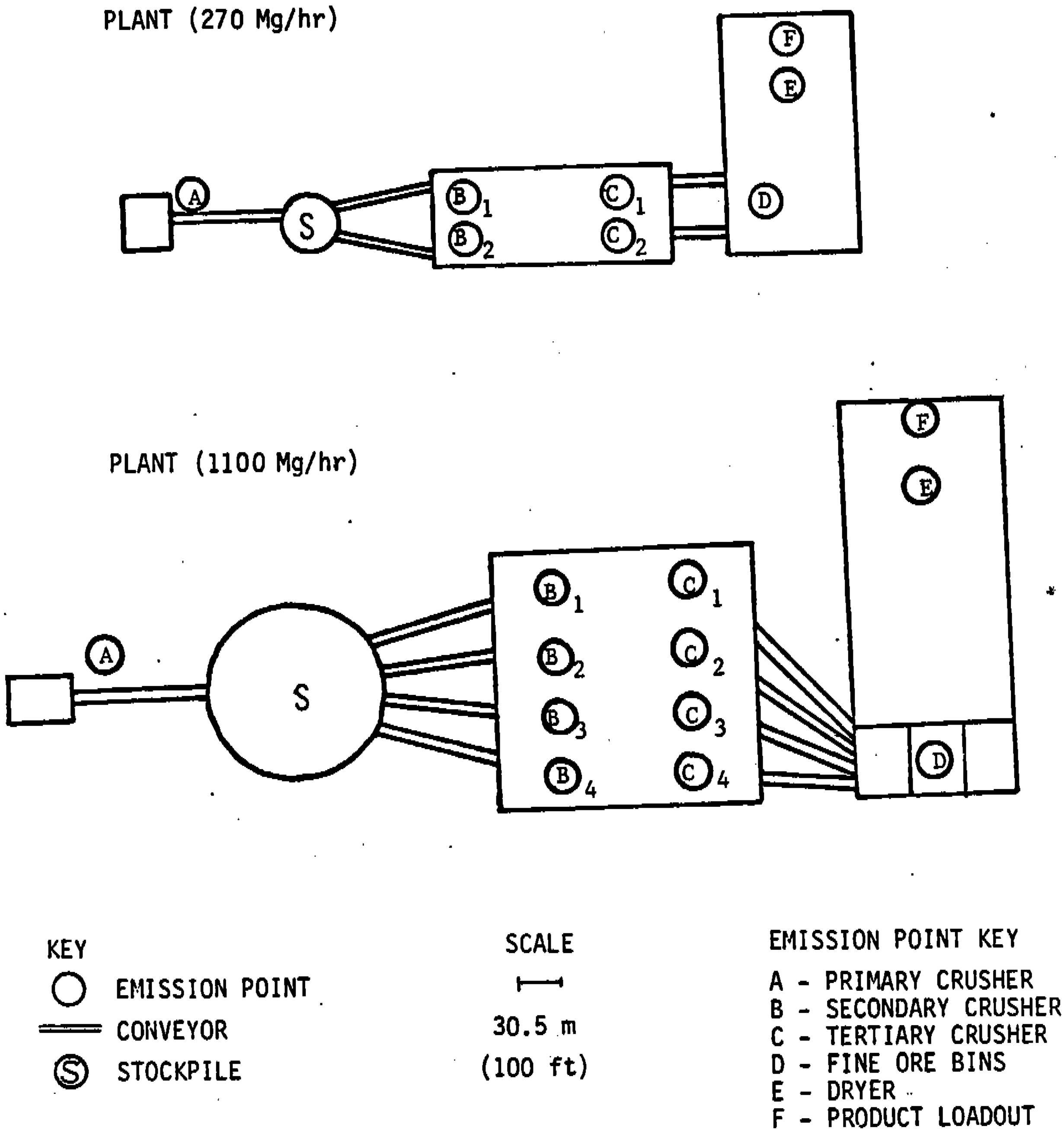


Figure 6-13. Molybdenum model plant plot plans.

Table 6-19. ENERGY REQUIREMENTS FOR MOLYBDENUM ORE PROCESSING PLANT[a]

	Gigajoules[b] per net megagram of molybdenum metal	Million BTU's per net ton of molybdenum metal
Mining		
Electrical energy	21.54	19.54
Natural gas	24.53	22.25
Liquid hydrocarbons	8.17	7.41
Explosives	3.32	3.01
SUBTOTAL	57.56	52.21
Concentration		
Crushing	5.90	5.35
Grinding	37.01	33.57
Flotation	17.39	15.77
Other electrical energy (e.g. tailings disposal, water pumping, etc.)	16.33	14.81
Inorganic reagents	7.03	6.38
Organic reagents	4.09	3.71
Steel for grinding	7.69	6.98
SUBTOTAL	95.44	86.57
General plant energy	9.91	8.99
TOTAL	162.92	147.77
Ore grade	0.004	0.004
Gigajoule per net megagram (ton) of molybdenum ore	0.662	0.600

[a]Battelle, 1976.

[b]Gigajoule = 10^9 joules.

6.4.8 Silver Ore Processing Facility

6.4.8.1 Process Units Description. The model plants for the silver ore processing industry consist of the following process units:

A. The primary crusher unit including the primary crusher and associated dumping station, grizzly, screens, coarse ore storage bins, and transfer points.

B. Secondary crushing units including a secondary crusher and associated screens, ore bins, and transfer points.

C. Tertiary crushing units including a tertiary crusher and associated screens, fine ore bins, and transfer points.

D. Fine ore bins.

Because of the small quantities and characteristics of the final product, product loading operations are not covered in this document.

6.4.8.2 Model Plant Capacity. Three new silver ore processing plants are projected between now and 1985, two at 45 Mg/hr (50 tons/hr) and one at 140 Mg/hr (150 tons/hr).

6.4.8.3 Capacity Independent Model Plant Parameters.

- Hours of operation - 5,820 hours/year.
- Capacity Utilization - 90 percent.
- New facilities by 1985 - 3.
- Ore grade - 0.015 percent.

6.4.8.4 Capacity Dependent Model Plant Parameters.

45 Mg/hr (50 tons/hr) Model Plant.

- Land Required 126,000 M^2 (1,360,000 ft^2).*
- Energy Required 0.095 PJ/yr.

140 Mg/hr (150 tons/hr) Model Plant.

- Land Required 126,000 M^2 (1,360,000 ft^2).*
- Energy Required 0.285 PJ/yr.

---

*Includes only the mineral processing plant itself without the tailings pond areas. The plant area assumes a rectangular boundary located a minimum of 61 meters (200 ft) from the buildings.

Table 6-20. LIST OF PROCESS EQUPMENT AND AIR VOLUME REQUIREMENTS USED IN DETERMINING MODEL SILVER ORE PROCESSING PLANTS

Model plant point	Source	45 Mg/hr (50 tons/hr) Model				140 Mg/hr (150 tons/hr) Model			
		Number	Size	Gas volume Nm^3/sec	(scfm)	Number	Size	Gas volume Nm^3/sec	(scfm)
1	Ore dumping station	1		0.47	(1,000)	1		0.94	(2,000)
2	Primary crusher	1	92 cm x 122 cm (26" x 48") JAW	7.27	(15,400)	1	122 cm x 152 cm (48" x 60") JAW	9.68	(20,500)
3, 6, 11	Feeders - width	3 each	.46 m (1.5')	1.06	(2,250)	1 2	.6 m (2') .76 m (2.5')	1.65	(3,500)
4, 5, 7, 8, 12, 14 15, 18, 20	Transfer points - width	9 each	.46 m (1.5')	3.19	(6,750)	10 1	.6 m (2') .76 m (2.5')	5.31	(11,250)
9	Secondary crusher hood	1	2.1 m (7') cone	0.47	(1,000)	1	2.1 m (7') cone	0.47	(1,000)
10	Secondary crusher outlet	1		3.54	(7,500)	1		5.43	(11,500)
13	Screening	1	1.8 m x 2.1 m (6' x 7') rod deck	6.14	(13,000)	1	1.8 m x 3.6 m (6' x 12') rod deck	10.38	(22,000)
16	Tertiary crusher hood	1	2.1 m (7') cone	0.47	(1,000)	1	2.1 m (7') shorthead	0.28	(600)
17	Tertiary crusher outlet	1		3.54	(7,500)	1		6.84	(14,500)
19	Fine ore bin	1		0.71	(1,500)	2		1.42	(3,000)
	TOTAL			26.86	(56,900)			42.40	(89,850)
Duplicate Processing Lines:		1				1			

References: Non-Metallic Mineral Processing Plants - Background Information for Proposed Standards - U.S. Environmental Protection Agency, March, 1979.
Industrial Ventilation - A Manual of Recommended Practices, 11th Edition, American Conference of Government Industrial Hygienists - 1970.
Responses to Section 114 Questionnaires by Metallic Mineral Processing Industries.

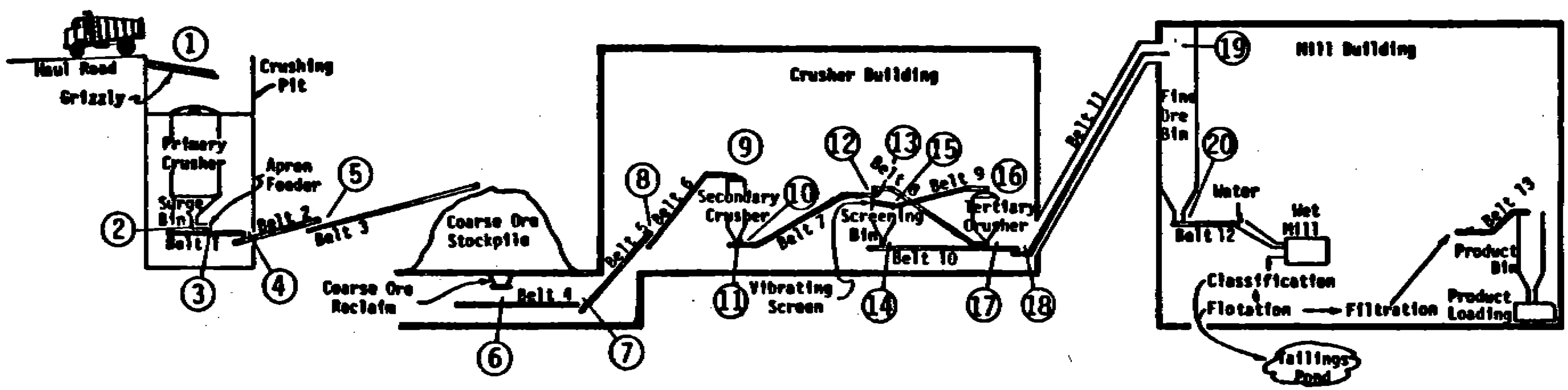
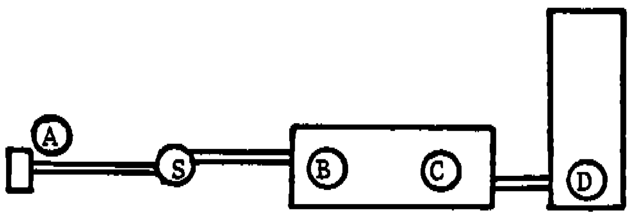


Figure 6-14. Silver ore processing industry model plant.

Table 6-21. STACK AND CONTROL SYSTEM PARAMETERS FOR SILVER ORE PLANTS

Plant capacity Mg/hr	Plant capacity (tons/hr)	Process unit*	Flow rate Nm^3/s	Flow rate (scfm)	Stack Temp. °C	Stack Temp. (°F)	Stack Height m	Stack Height (ft)	Stack Diameter m	Stack Diameter (ft)	Power Requirements kW, Regulatory Alternatives 1	2	3a	3b	Emission Rate kg/hr (lb/hr), Regulatory Alternatives 1 kg/hr	1 (lb/hr)	2 kg/hr	2 (lb/hr)	3 kg/hr	3 (lb/hr)
45	(50)	A	9.16	(18650)	20	(68)	15	(48)	1.0	(3.4)	45.5	60.0	16.0	110.0	10.88	(23.98)	4.35	(9.59)	1.45	(3.20)
		B	4.48	(9500)	20	(68)	15	(48)	1.0	(3.4)	24.8	32.0	9.0	62.0	5.54	(12.21)	2.22	(4.89)	0.74	(1.63)
		C	12.51	(26500)	20	(68)	15	(48)	1.0	(3.4)	63.1	87.1	22.8	168.4	15.45	(34.07)	6.18	(13.63)	2.06	(4.55)
		D	1.06	(2250)	20	(68)	15	(48)	0.7	(2.2)	4.8	7.0	2.0	16.0	1.31	(2.89)	0.52	(1.16)	0.18	(0.39)
140	(150)	A	12.62	(26750)	20	(68)	15	(48)	1.0	(3.4)	63.7	88.0	23.0	170.0	15.60	(34.39)	6.24	(13.76)	2.08	(4.59)
		B	7.08	(15000)	20	(68)	15	(48)	1.0	(3.4)	37.4	50.0	14.0	93.0	8.75	(19.28)	3.50	(7.71)	1.17	(2.57)
		C	20.34	(43100)	20	(68)	15	(48)	1.0	(3.4)	106.0	138.0	39.0	265.0	25.13	(55.41)	10.06	(22.17)	3.35	(7.39)
		D	2.36	(5000)	20	(68)	15	(48)	0.7	(2.2)	11.9	18.0	5.0	32.0	2.92	(6.43)	1.17	(2.57)	0.39	(0.86)

PLANT (UP TO 140 Mg/hr)



KEY:

○ EMISSION POINT

═ CONVEYOR

○ STOCKPILE

SCALE

30.5 m
(100 ft)

EMISSION POINT KEY

A - PRIMARY CRUSHER
B - SECONDARY CRUSHER
C - TERTIARY CRUSHER
D - FINE ORE BIN

Figure 6-15. Silver model plant plot plans.

Table 6-22. ENERGY REQUIREMENTS FOR SILVER ORE PROCESSING PLANTS[a]

	Gigajoules[b] per net megagram of silver bars	Million BTU's per net ton of silver bars
Underground mining, crushing, grinding, and concentrating		
Electrical energy	1,405.0	1,274.4
Diesel fuel oil	202.5	183.7
Gasoline	12.2	11.1
LP gas	32.0	29.0
Oxygen	0.1	0.1
Lubricants	8.8	8.0
Explosives	78.2	70.9
Lime	3.2	2.9
Steel shapes	62.6	56.8
Soda ash (synthetic)	30.2	27.4
Xanthates	8.5	7.7
Transportation	0.6	0.5
SUBTOTAL	1,843.9	1,672.5
Leaching and thickening		
Electrical energy	153.6	139.3
Distillate fuel oil	140.0	127.0
Sodium cyanide	14.0	12.7
Soda ash (synthetic)	13.9	12.6
Lime	103.9	94.2
Additives	1.4	1.3
SUBTOTAL	426.8	387.1
Clarification and precipitation		
Electrical energy	65.5	59.4
Zinc	16.6	15.1
Filter aid	46.5	42.2
SUBTOTAL	128.6	116.7
TOTAL	2,393.9	2,176.3
Ore grade	0.00015	0.00015
Gigajoule per net megagram (ton) of silver ore	0.359	0.326

[a]Battelle, 1976.

[b]Gigajoule = 10^9 joules.

6.4.9 Titanium/Zirconium Sand Type Ore Processing Facility

6.4.9.1 Process Units Description. The model plants for the titanium/zirconium sand type ore processing industry consists of the following process units:

A. The dryer unit including the dryer and associated transfer points.

B. The product loadout including all product bins, transfer points, and loadout mechanisms.

As noted in Chapter 3, calcining operations are not included.

6.4.9.2 Model Plant Capacity. Titanium/zirconium sand type ore processing capacity is expected to increase as a result of a 270 Mg/hr (300 ton/hr) expansion and a new 540 Mg/hr (600 ton/hr) plant.

6.4.9.3 Capacity Independent Model Plant Parameters.

- Hours of operation - 8,500 hr/yr.
- Capacity utilization - 90 percent.
- New facilities by 1985 - 1.
- Expansions by 1985 - 1.
- Ore grade - 1.5 percent TiO_2
  0.9 percent Zirconium

6.4.9.4 Capacity Dependent Model Plant Parameters.

270 Mg/hr (300 tons/yr) Model Plant

- Land Required – 108,000 M^2 (1,160,000 ft^2)*
- Energy Required – 0.10 PJ/yr

540 Mg/hr (600 tons/hr) Model Plant

- Land Required – 204,000 M^2 (2,200,000 ft^2)*
- Energy Required – 0.22 PJ/yr

---

*Includes only the mineral processing plant itself without the tailings pond areas. The plant area assumes a rectangular boundary located a minimum of 61 meters (200 ft) from the buildings.

Table 6-23. LIST OF PROCESS EQUIPMENT AND AIR VOLUME REQUIREMENTS USED IN DETERMINING MODEL TITANIUM/ZIRCONIUM SAND TYPE ORE PROCESSING PLANTS

Model plant point	Source	270 Mg/hr (300 tons/hr) Model			540 Mg/hr (600 tons/hr) Model		
		Equipment size and (number)	Gas volume Nm^3/sec	(scfm)	Equipment size and (number)	Gas volume Nm^3/sec	(scfm)
1	Dryer	(2)	3.78	(8,000)	(2)	5.48	(11,600)
2, 3, 4, 5, 11, 12, 15	Transfer points - width	(7) 4 - 0.3 m (1') 3 - 0.76 (2.5')	2.71	(5,750)	(11) 8 - 0.3 m (1') 3 - 0.92 m (3')	4.02	(8,500)
10	Screen	(1) 1.8 m x 3.7 m (6' x 12') rod deck	10.38	(22,000)	(2) 1.8 m x 4.9 m (6' x 16') rod deck	13.69	(29,000)
6, 8, 13, 16	Product bin	(4)	2.83	(6,000)	(8)	5.66	(12,000)
7, 9, 14, 17	Product loading	(4)	6.89	(14,600)	(8)	13.77	(29,200)
	TOTAL		26.59	(56,350)		42.62	(90,300)
Duplicate Processing Lines:		2			3		

References: Non-Metallic Mineral Processing Plants - Background Information for Proposed Standards - U.S. Environmental Protection Agency, March 1979.
Industrial Ventilation - A Manual of Recommended Practices, 11th Edition, American Conference of Government Industrial Hygienists - 1970.
Responses to Section 114 Questionnaires by Metallic Mineral Processing Industries.

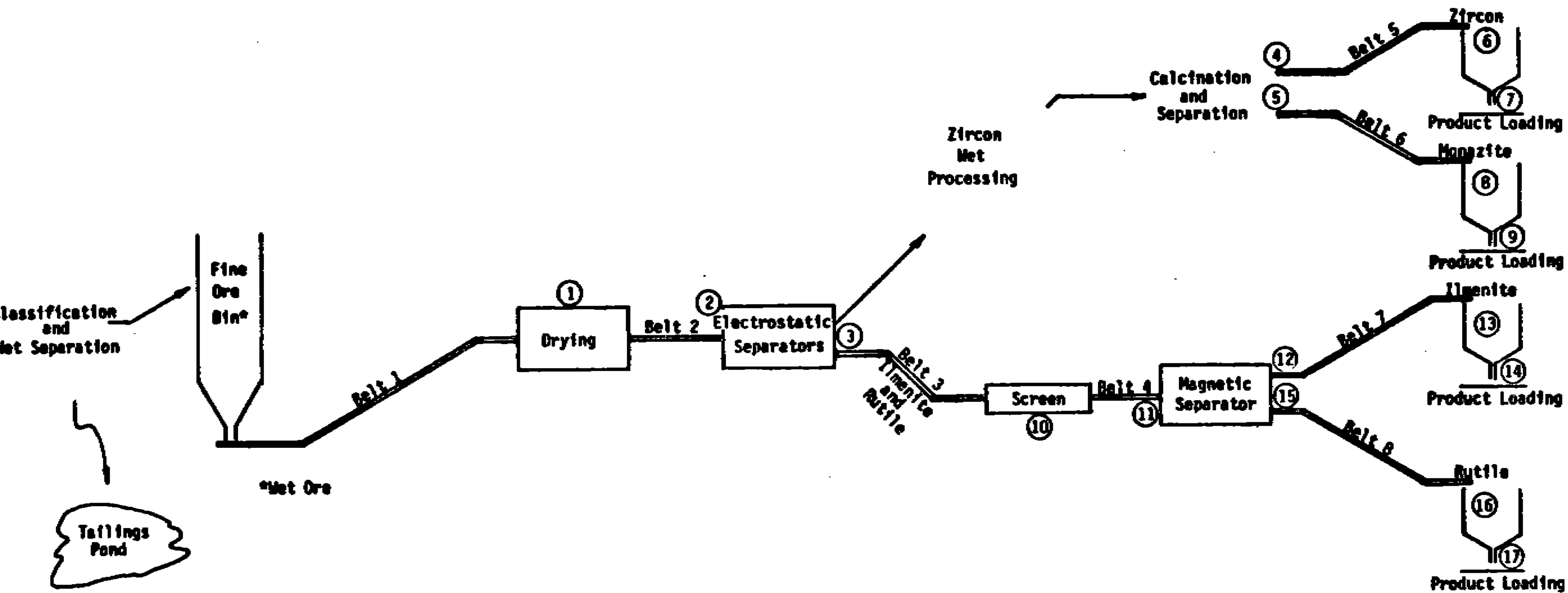


Figure 6-16. Titanium/Zirconium sand type ore processing industry model plant.

Table 6-24. STACK AND CONTROL SYSTEM PARAMETERS FOR TITANIUM/ZIRCONIUM SAND TYPE ORE MODEL PLANT

Plant capacity Mg/hr	(tons/hr)	Process unit	Flow rate Nm^3/s	(scfm)	Stack Temp. °C	(°F)	Stack Height m	(ft)	Stack Diameter m	(ft)	Power Requirements kW Regulatory Alternatives 1	2	3a	3b	Emission Rate kg/hr (lb/hr) Regulatory Alternatives 1	2	3
270	(300)	A	15.93	(33,750)	93	(200)	30	(100)	1.38	(4.6)	79.3	115.0	32.1	209.0	19.68 (43.39)	7.88 (17.36)	2.63 (5.79)
		B	10.66	(22,600)	24	(75)	15	(48)	0.67	(2.2)	54.3	72.8	19.9	139.6	13.18 (29.06)	5.27 (11.61)	1.76 (3.87)
540	(600)	A	21.05	(44,600)	93	(200)	30	(100)	1.38	(4.6)	112.2	142.7	40.7	275.6	26.01 (57.34)	10.41 (22.95)	3.47 (7.65)
		B	21.57	(45,700)	24	(75)	15	(48)	0.67	(2.2)	116.7	146.2	41.6	282.2	26.65 (58.76)	10.66 (23.49)	3.55 (7.83)

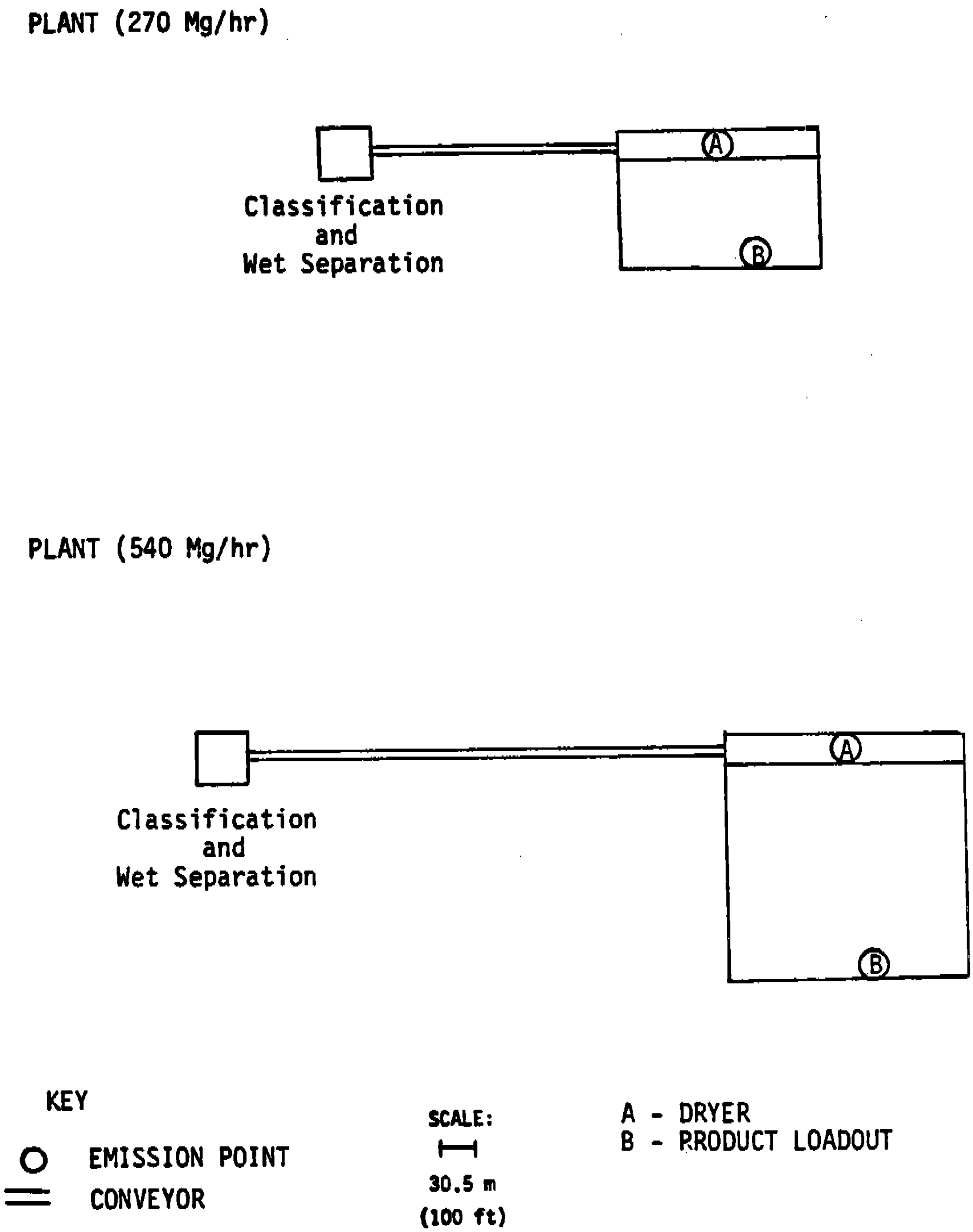


Figure 6-17. Titanium/Zirconium sand type ore model plant plot plans.

6.4.10 Tungsten Ore Processing Facility

6.4.10.1 Process Units Description. The model plants for the tungsten ore processing industry consist of the following process units:

A. The primary crushing unit including the primary crusher and associated dumping station, grizzly, screens, coarse ore storage bins, and transfer points.

B. Secondary crushing units including a secondary crusher, and associated screens, ore bins, and transfer points.

C. Tertiary crushing units including a tertiary crusher, and associated screens, fine ore bins, and transfer points.

D. Fine ore bins when not directed to a crusher control device.

E. The dryer unit including the dryer and associated transfer points.

F. The product loadout unit including all packaging, product bins, transfer points, and loadout mechanisms.

6.4.10.2 Model Plant Capacity. Tungsten ore processing capacity is expected to increase as a result of a new 23 Mg/hr (25 ton/hr) plant.

6.4.10.3 Capacity Independent Model Plant Parameters.

- Hours of operation - 5,820 hours/year.
- Capacity utilization - 90 percent.
- New facilities by 1985 - 1.
- Ore grade - 0.5 percent.

6.4.10.4 Capacity Dependent Model Plant Parameters.

23 Mg/yr (25 tons/hr) Model Plant.

- Land Required 126,000 M^2 (1,360,000 ft^2).*
- Energy Required 0.16 PJ/yr.

---

*Includes only the mineral processing plant itself without the tailings pond areas. The plant area assumes a rectangular boundary located a minimum of 61 meters (200 ft) from the buildings.

Table 6-25. LIST OF PROCESS EQUIPMENT AND AIR VOLUME REQUIREMENTS USED IN DETERMINING MODEL TUNGSTEN ORE PROCESSING PLANTS

Model plant point	Source	23 Mg/hr (25 TPH) Model			
		Number	Size	Gas volume	
				Nm^3/sec	(scfm)
1	Ore dumping station	1		0.47	(1,000)
2	Primary crusher		61 cm x 91 cm (24" x 36") Jaw	4.72	(10,000)
3, 6, 11	Feeders - width	3 each	0.46 m (1.5')	1.06	(2,250)
4,5,7, 8, 12, 14, 15, 18, 20	Transfer points - width	9 each	0.46 m (1.6')	3.19	(6,750)
9	Secondary crusher hood	1	0.92 m (3') cone	0.35	(750)
10	Secondary crusher outlet	1		3.54	(7,500)
13	Screening		0.92 m x 2.4 m (3' x 8') rod deck	3.54	(7,500)
16	Tertiary crusher hood		0.92 m (3') cone	0.35	(750)
17	Tertiary crusher outlet	1		3.54	(7,500)
19	Fine ore bin	1		0.71	(1,500)
21	Dryer	1		0.38	(800)
22	Product bin	1		0.47	(1,000)
23	Product loading			0.35	(750)
	TOTAL			22.67	(48,050)
Duplicate Process Lines:		1			

References: Non-Metallic Mineral Processing Plants - Background Information for Proposed Standards - U.S. Environmental Protection Agency, March, 1979.
Industrial Ventilation - A Manual of Recommended Practices, 11th Edition, American Conference of Government Industrial Hygienists, 1970.
Responses to Section 114 Questionnaires by Metallic Mineral Processing Industries.

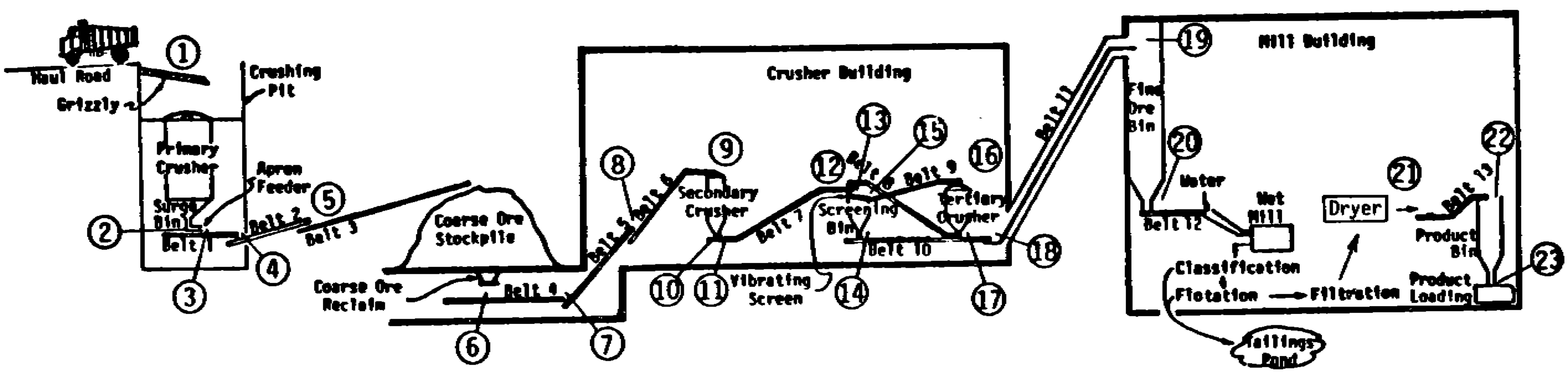
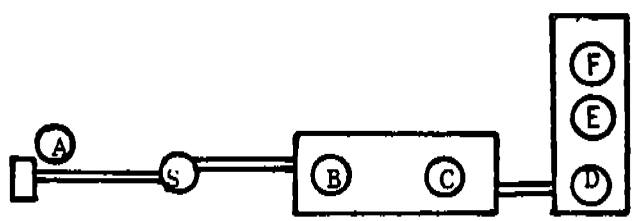


Figure 6-18. Tungsten ore processing industry model plant.

Table 6-26. STACK AND CONTROL SYSTEM PARAMETERS FOR TUNGSTEN ORE MODEL PLANTS

Plant capacity Mg/hr	(tons/hr)	Process unit*	Flow rate Nm^3/s	(scfm)	Stack Temp. °C	(°F)	Stack Height m	(ft)	Stack Diameter m	(ft)	Power Requirements kW, Regulatory Alternatives 1	2	3a	3b	Emission Rate kg/hr (lb/hr), Regulatory Alternatives 1		2		3	
23	(25)	A	5.90	(12500)	20	(68)	15	(48)	1.0	(3.4)	31.8	42.0	12.0	78.0	7.29	(16.07)	2.92	(6.43)	0.97	(2.14)
		B	5.31	(11250)	20	(68)	15	(48)	1.0	(3.4)	29.0	38.0	11.0	70.0	6.56	(14.46)	2.63	(5.79)	0.88	(1.93)
		C	9.32	(19750)	20	(68)	15	(48)	1.0	(3.4)	47.8	62.5	17.3	122.1	11.51	(25.39)	4.62	(10.15)	1.54	(3.39)
		D	1.06	(2250)	20	(68)	15	(48)	0.7	(2.2)	4.8	7.0	2.0	18.0	1.31	(2.89)	0.53	(1.16)	0.18	(0.39)
		E	0.38	(800)	93	(200)	30	(100)	1.38	(4.6)	2.1	3.0	0.9	8.0	0.47	(1.03)	0.18	(0.41)	0.06	(0.14)
		F	0.83	(1750)	24	(75)	14.1	(47)	0.7	(2.2)	4.1	6.0	1.7	16.0	1.02	(2.25)	0.41	(0.90)	0.14	(0.30)

PLANT (23 Mg/hr)



KEY:

- ○ EMISSION POINT
- ═ CONVEYOR
- Ⓢ STOCKPILE

SCALE: ⊢—⊣ 30.5 m (100 ft)

EMISSION POINT KEY

A - PRIMARY CRUSHER

B - SECONDARY CRUSHER

C - TERTIARY CRUSHER

D - FINE ORE BIN

E - DRYER

F - PRODUCT LOADOUT

Figure 6-19. Tungsten model plant plot plans.

Table 6-27. ENERGY REQUIREMENTS FOR TUNGSTEN ORE PROCESSING PLANT[a]

	Gigajoules[b] per net megagram of tungsten metal	Million BTU's per net ton of tungsten metal
Mining, crushing, and grinding		
Diesel fuel oil	123.03	111.6
Gasoline	1.03	0.93
Explosives	7.19	6.52
Steel balls and rods, drill bits	12.48	11.32
SUBTOTAL	143.73	130.37
Concentration, gravity and flotation		
Electrical energy	21.06	19.1
Soda ash (natural)	2.25	2.04
Caustic soda	1.92	1.74
Copper sulfate	1.93	1.75
Lime	1.04	0.94
Sodium silicate	0.84	0.76
Sodium cyanide	1.66	1.51
Organic reagents	3.90	3.54
Reagent transportation	0.12	0.11
SUBTOTAL	34.72	31.49
Concentration, hydrometallurgical		
Electrical energy	1.17	1.06
Natural gas	13.48	12.23
Hydrochloric acid	33.77	30.63
Hydrochloric acid transportation (200 miles by rail)	0.49	0.44
Caustic soda	10.82	9.81
Caustic soda transportation (200 miles by rail)	0.04	0.04
SUBTOTAL	59.77	54.21
Transportation of concentrate		
(1,170 miles by rail)	1.69	1.53
(4,100 miles by water)	2.20	2.00
SUBTOTAL	3.89	3.53
TOTAL	242.11	219.60
Ore grade	0.005	0.005
Gigajoule per net megagram (ton) of tungsten ore	1.21	1.10

[a]Battelle, 1976.

[b]Gigajoule = 10^9 joules.

6.4.11 Uranium Ore Processing Facility

6.4.11.1 Process Units Description. The uranium model plants consist of the following process units:

A. The primary crushing unit including the primary crusher and associated dumping station, grizzly, screens, coarse ore storage bins, and transfer points.

B. The fine ore bins.

Because of the possible hazards associated with radioactive emissions, the emissions from uranium process dryers and from the handling of uranium processing product (yellowcake) will be evaluated by the Office of Radiation Programs and, if appropriate, covered by a National Emission Standard for Hazardous Air Pollutants (NESHAP) for radionuclides.

6.4.11.2 Model Plant Capacity. New model plant capacity in the uranium industry is expected to include two 23 Mg/hr (25 ton/hr) plants and three 68 Mg/hr (75 tons/hr) plants.

6.4.11.3 Capacity Independent Model Plant Parameters.

- Hours of operation - 5,820 hours/year.
- Capacity utilization - 95 percent.
- New facilities by 1985 - 5.
- Ore grade - 0.13 percent uranium.

6.4.11.4 Capacity Dependent Model Plant Parameters.

23 Mg/hr (25 tons/hr) Model Plant.

- Land Required 81,700 M^2 (880,000 ft^2).*
- Energy Required 0.17 PJ/yr.**

68 Mg/hr (75 ton/hr) Model Plant.

- Land Required 590,000 M^2 (6,400,000 ft^2).*
- Energy Required 0.51 PJ/yr.**

---

* Includes only the mineral processing plant itself without the tailings pond areas. The plant area assumes a rectangular boundary located a minimum of 61 meters (200 ft) from the buildings.

** Klemenic, 1979.

Table 6-28. LIST OF PROCESS EQUIPMENT AND AIR VOLUME REQUIREMENTS USED IN DETERMINING MODEL URANIUM ORE PROCESSING PLANTS

Model plant point	Source	23 Mg/hr (25 tons/hr) Model				68 Mg/hr (75 tons/hr) Model			
		Number	Size	Gas volume Nm^3/sec	Gas volume (scfm)	Number	Size	Gas volume Nm^3/sec	Gas volume (scfm)
1	Dumping station	1		0.47	(1,000)	1		0.47	(1,000)
2	Primary crusher	1	61 cm x 81 cm (24" x 36") Jaw	4.72	(10,000)	1	91 cm x 122 cm (36" x 48") Jaw	7.27	(15,400)
3	Feeders - width	1 each	(1.5') 0.46 m	0.35	(750)	1	1 - (2') 0.6 cm	0.47	(1,000)
4, 6, 8	Transfer points - width	3 each	(1.5') 0.46 m	1.06	(2,250)	4 2	(1.5') 0.46 cm (2') 0.6 cm	1.87	(4,000)
5	Screening	1	0.92 m x 2.4 m (3' x 8') rod deck	3.54	(7,500)	1	1.8 cm x 2.5 cm (6' x 10') rod deck	5.81	(12,300)
7	Fine ore bin	1		0.71	(1,500)	1		0.71	(1,500)
	TOTAL			10.85	(23,000)			16.60	(25,200)
Duplicate Processing Lines:		1				1			

References: Non-Metallic Mineral Processing Plants - Background Information for Proposed Standards - U.S. Environmental Protection Agency, March, 1979.
Industrial Ventilation - A Manual of Recommended Practices, 11th Edition, American Conference of Government Industrial Hygienists, 1970.
Responses to Section 114 Questionnaires by Metallic Mineral Processing Industries.

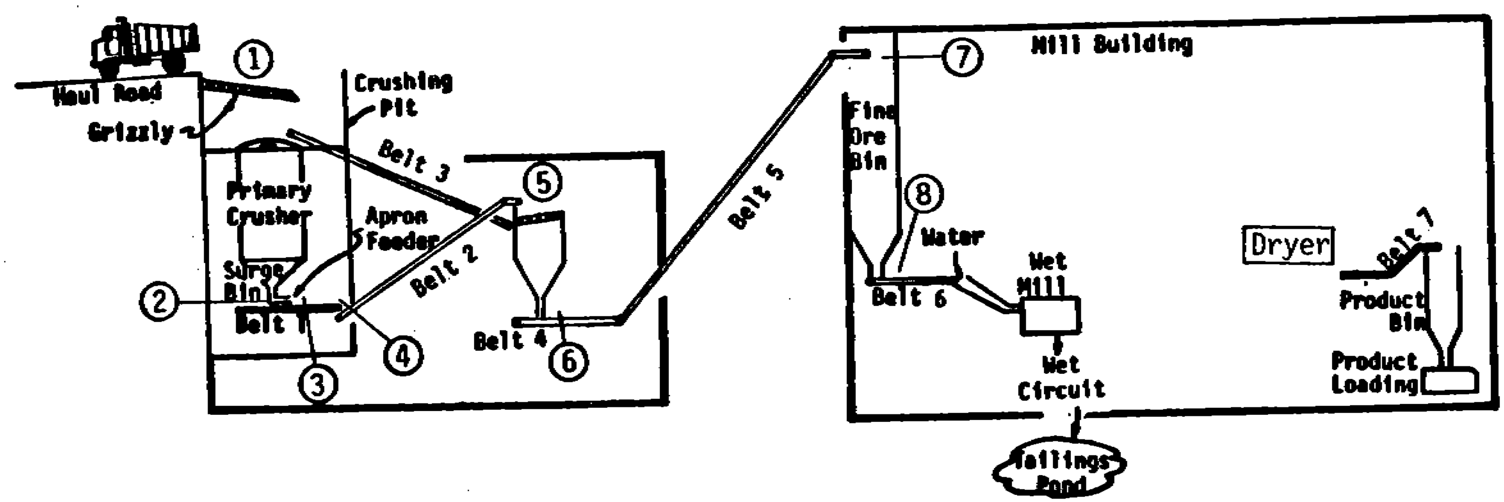
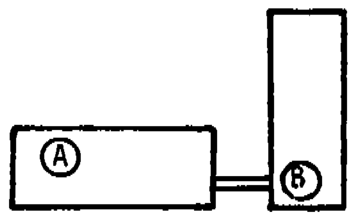


Figure 6-20. Uranium ore processing industry model plant.

Table 6-29. STACK AND CONTROL SYSTEM PARAMETERS FOR URANIUM ORE MODEL PLANTS

Plant capacity Mg/hr	(tons/hr)	Process unit*	Flow rate Nm^3/s (scfm)	Stack Temp. °C (°F)	Stack Height m (ft)	Stack Diameter m (ft)	Power Requirements KW Regulatory Alternatives 1	2	3a	3b	Emission Rate kg/hr (lb/hr) Regulatory Alternatives 1	2	3
23	(25)	A	5.55 (11750)	20 (68)	14 (47)	1.1 (3.8)	30.1	40.0	10.8	70.0	6.85 (15.11)	2.74 (6.04)	0.91 (2.01)
		B	5.31 (11250)	20 (68)	14 (47)	1.1 (3.8)	28.0	39.0	10.1	75.0	6.56 (14.46)	2.63 (5.79)	0.88 (1.93)
68	(75)	A	8.68 (18400)	20 (68)	14 (47)	1.1 (3.8)	44.9	60.0	16.0	110.0	10.73 (23.66)	4.29 (9.46)	1.43 (3.15)
		B	7.93 (16800)	20 (68)	14 (47)	1.1 (3.8)	41.2	57.0	16.0	105.0	9.80 (21.60)	3.92 (8.64)	1.31 (2.88)

PLANT (UP TO 68 Mg/hr)



KEY:	SCALE:	EMISSION POINT KEY
○ EMISSION POINT	30.5 m	A - PRIMARY CRUSHER
═ CONVEYOR	(100 ft)	B - FINE ORE BINS

Figure 6-21. Uranium model plant plot plans.

6.5 REFERENCES FOR CHAPTER 6

Battelle Columbus Laboratories, 1975. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 4 - Energy Data and Flowsheets, High-Priority Commodities) Report compiled for U.S. Bureau of Mines, U.S. Department of Commerce. National Technical Information Service PB-245 759. 179 p.

Battelle Columbus Laboratories, 1976. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 6 - Energy Data and Flowsheets, Low-Priority Commodities) Report compiled for U.S. Bureau of Mines, U.S. Department of Commerce. National Technical Information Service PB-261 150. 257 p.

Klemenic, John, 1979. Uranium Production Capability in the United States. Report compiled for U.S. Department of Energy. October, 1979. 10 p.

7. ENVIRONMENTAL IMPACT

The air pollution impacts of applying the control alternatives presented in Chapter 6 are discussed in this chapter. For this analysis, the particulate emission control alternatives will be evaluated in terms of the model plants developed in Chapter 6. A comparison will be made between the impacts of baseline control techniques and the impacts of better systems of emission control. In addition to reducing particulate emissions, the application of the emission control technologies could have secondary environmental and energy use impacts. These could include the increased generation of solid wastes, wastewater, and noise, as well as increased consumption of energy. Secondary impacts will also be evaluated in this chapter.

7.1 AIR POLLUTION IMPACT

The air pollution impact is based upon the reduction in particulate emissions achieved by application of the emission control systems under the three regulatory alternatives discussed in Chapter 6. These impacts are analyzed in terms of model plant types that are projected additions to the metallic mineral processing industries by 1985. As discussed in Section 9.1, industry growth information was solicited from three sources:

- representatives of the metallic mineral processing industry,
- the U.S. Bureau of Mines, and
- *The Engineering and Mining Journal* and other periodicals.

7.1.1 National Particulate Emissions

Table 7-1 shows the total capacity additions by 1985 for the metallic mineral industry, the capacity utilization fraction, the annual operating schedule, and the air flow rate through dust collectors of the various size model plants. These data were used to calculate the allowable emissions under the three regulatory alternative systems for each of the model plant sizes.

Table 7-1. NEW CAPACITY AND OPERATING PARAMETERS FOR MODEL PLANTS USED FOR ESTIMATING ENVIRONMENTAL IMPACTS

Industry segment	Projected number of new plants	Model plant sizes (production capacity) Mg/hr	(ton/hr)	Utilization rate	Operating schedule hours/year	Total dry gas volume to collectors Nm^3/sec	(scfm)
Aluminum	1	140	(150)	0.91	5,820	21.04	(44,800)
	1	270	(300)			36.50	(77,300)
Copper	1	140	(150)	0.96	8,500	48.68	(103,150)
	1	540	(600)			97.12	(205,700)
Gold	1	68	(75)	0.95	5,820	24.67	(57,450)
	1	140	(150)			32.80	(69,500)
Iron	1	1,100	(1,200)	0.90	8,500	124.75	(264,300)
	1	2,200	(2,400)			253.32	(536,700)
Lead/Zinc	2	270	(300)	0.87	5,820	130.10	(275,600)[a]
	1	540	(600)			97.12	(205,700)
Molybdenum	1	270	(300)	0.84	8,500	65.04	(137,800)
	2	1,100	(1,200)			266.02	(563,600)[a]
Silver	2	45	(50)	0.90	5,820	53.72	(113,800)[a]
	1	140	(150)			42.40	(89,850)
Titanium/ Zirconium	1	270	(300)	0.90	8,500	26.59	(56,350)
	1	540	(600)			42.62	(90,300)
Tungsten	1	23	(25)	0.90	5,820	22.67	(48,050)
Uranium	2	23	(25)	0.95	5,820	21.70	(46,000)[a]
	3	68	(75)			49.80	(105,600)[b]

[a]Air flow includes two plants at the specific new production capacity shown.

[b]Air flow includes three plants at the specific new production capacity shown.

Table 7-2 shows the annual allowable emission rates for the three regulatory alternative systems and the emission reduction impact for each segment of the metallic mineral processing industry for the year 1985. The incremental nationwide emission reduction impact from applying either Regulatory Alternatives 2 or 3 as opposed to the baseline alternative (Regulatory Alternative 1) is shown as the bottom line in Table 7-2. Table 7-2 shows that Regulatory Alternative 3 provides the highest level of control, reducing total particulate emissions from the metallic mineral industry by approximately 11,800 Mg (13,000 tons) per year by 1985.

Because the particulate matter emitted from lead ore processors would be expected to contain various amounts of lead, an additional concern for lead ore processors is the maintenance of the National Ambient Air Quality Standard (NAAQS) for lead in the vicinity of these plants. In the absence of a New Source Performance Standard (NSPS) for metallic mineral plants and also when considering fugitive sources, new lead ore processing facilities may be required to meet more stringent emission levels than indicated by typical State standards for generic particulate matter. Therefore, the reduction in particulate matter due to the implementation of an NSPS applicable to lead ore processing plant may be less than indicated in Table 7-2 because of a higher level of baseline control required to meet the lead NAAQS.

7.1.2 Dispersion Analysis

Ground-level particulate matter concentrations at specified locations downwind from eight model metallic mineral processing plants have been estimated using atmospheric dispersion modelling (Summerhays, 1981). Dispersion analyses were based on the Industrial Source Complex (ISC) model (Bowers et al., 1979). The ISC model is an expanded version of the single source CRSTER model, modified to account for aerodynamic downwash and a larger number of sources and receptors.

The ISC modelling exercises were based on the model plant characteristics (stack dimensions, plant configurations, and stack gas flow characteristics) presented in Chapter 6. Meteorological data (temperature, air mass stability, wind speed, and direction) were taken from weather stations located in areas of the country in which new metallic mineral plants are expected. The only terrain effects included

Table 7-2. AIR IMPACTS OF THE REGULATORY ALTERNATIVES FOR THE METALLIC MINERAL PROCESSING MODEL PLANTS

Industry	Projected number of new plants	Model plant sizes Mg/hr	(ton/hr)	Allowable 1985 emissions for each regulatory alternative Mg (ton) 1[a]		2[b]		3(a or b)[c]		1985 emission reduction impact for each regulatory alternative Mg (ton) 1[a]	2[b,d]		3(a or b)[c,e]	
Aluminum	1	140	(150)	150	(170)	62	(68)	20	(22)	0	88	(102)	130	(148)
	1	270	(300)	260	(290)	100	(110)	35	(38)	0	160	(180)	225	(252)
Copper	1	140	(150)	510	(560)	200	(220)	68	(73)	0	310	(340)	442	(487)
	1	540	(600)	1,030	(1,130)	410	(450)	130	(150)	0	620	(680)	900	(980)
Gold	1	68	(75)	190	(210)	78	(86)	26	(29)	0	112	(124)	164	(180)
	1	140	(150)	240	(260)	94	(100)	32	(35)	0	146	(160)	208	(225)
Iron	1	1,100	(1,200)	1,310	(1,440)	520	(580)	180	(190)	0	790	(860)	1,130	(1,250)
	1	2,200	(2,400)	2,670	(2,930)	1,070	(1,170)	360	(390)	0	1,600	(1,760)	2,310	(2,540)
Lead/Zinc	2	270	(300)	930	(1,030)	370	(410)	120	(140)	0	560	(620)	810	(890)
	1	540	(600)	700	(770)	280	(310)	94	(100)	0	420	(460)	606	(670)
Molybdenum	1	270	(300)	700	(770)	280	(310)	94	(100)	0	420	(460)	606	(670)
	2	1,100	(1,200)	2,790	(3,070)	1,110	(1,230)	370	(410)	0	1,680	(1,840)	2,420	(2,660)
Silver	2	45	(50)	390	(430)	150	(170)	52	(57)	0	240	(260)	338	(373)
	1	140	(150)	300	(330)	120	(130)	41	(45)	0	180	(200)	259	(285)
Titanium/	1	270	(300)	280	(300)	110	(120)	37	(41)	0	170	(180)	243	(259)
Zirconium	1	540	(600)	450	(500)	180	(200)	60	(66)	0	270	(300)	390	(434)
Tungsten	1	23	(25)	160	(180)	65	(72)	22	(24)	0	95	(108)	138	(156)
Uranium	2	23	(25)	150	(170)	62	(68)	21	(23)	0	90	(102)	129	(147)
	3	68	(75)	360	(400)	140	(160)	45	(53)	0	220	(240)	315	(347)
TOTAL				13,570	(14,940)	5,401	(5,964)	1,807	(1,986)	0	8,171	(8,976)	11,763	(12,953)

[a] 1 = Baseline dynamic wet scrubber with Δp = 1.5 kPa (6 inches) and an emission level of 0.34 g/DNm³ (0.15 gr/dscf).

[b] 2 = Venturi scrubber with Δp = 3.7 kPa (15 inches) and an emission level of 0.14 g/DNm³ (0.06 gr/dscf).

[c] 3(a or b) = Fabric filter with Δp = 1.5 kPa (6 inches) or high energy venturi scrubber with Δp = 7.5 kPa (30 inches); both with an emission level of 0.046 g/DNm³ (0.02 gr/dscf).

[d] Regulatory Alternative 2 reduces baseline emission levels by approximately 60 percent.

[e] Regulatory Alternative 3 reduces baseline emission levels by approximately 87 percent.

in the modelling were those implicitly contained in the meteorological data. All receptors were assumed to be at the same elevation as the plant. If any of these plants are located in a valley or at a lower elevation than the surrounding terrain, the concentrations at ground level could be significantly higher than those estimated.

Tables 7-3 through 7-5 present the maximum annual average concentrations for specified points at various distances downwind from plants emitting particulate matter at the rates prescribed by the regulatory alternatives. For all plants modelled the highest concentrations occur at the plant boundary for all three regulatory alternatives. The plant boundary concentrations range from 33 $\mu g/m^3$ for a uranium plant to 182 $\mu g/m^3$ for a large iron ore plant. The corresponding values for Regulatory Alternative 2 are 13 $\mu g/m^3$ and 73 $\mu g/m^3$. The values for Regulatory Alternative 3 range from 4 $\mu g/m^3$ to 24 $\mu g/m^3$. As a point of comparison, the maximum average annual concentration allowed by the National Ambient Air Quality Standards for particulate matter is 75 $\mu g/m^3$.

Tables 7-6 through 7-8 present the highest second-highest 24-hour average concentrations and the distances from the plant boundary at which these occur. The second-highest 24-hour averages are presented because the corresponding National Ambient Air Quality Standard for particulate matter (150 $\mu g/m^3$ as a 24-hour average concentration) may be exceeded only once a year. The maximum second-highest value occurred at the plant boundaries for all plants except the small iron ore plants where it occurred 100 meters (328 feet) outside the boundary. The 24-hour concentrations ranged from 153 $\mu g/m^3$ for uranium plants to 1,007 $\mu g/m^3$ for large iron ore plants operating under Regulatory Alternative 1. The corresponding values for Regulatory Alternative 2 are 61 $\mu g/m^3$ and 403 $\mu g/m^3$, and the values for Regulatory Alternative 3 ranged from 20 $\mu g/m^3$ to 134 $\mu g/m^3$.

7.2 WATER POLLUTION IMPACT

Two control systems most often used by the metallic mineral processing industry to control particulate emissions are fabric filters and wet scrubbers. The application of a fabric filter or electrostatic precipitator control system (dry emission-reduction systems) will not have any

Table 7-3. PARTICULATE MATTER CONCENTRATIONS (ANNUAL AVERAGES) IN THE VICINITY OF METALLIC MINERAL PLANTS OPERATING UNDER REGULATORY ALTERNATIVE 1

Industry	Model Plant Sizes		Maximum annual average concentrations (μg/m³) Distance from plant boundary						
	Mg/hr	(ton/hr)	0 m (0 ft)	100 m (328 ft)	200 m (656 ft)	500 m (1,640 ft)	1,000 m (3,280 ft)	1,500 m (4,920 ft)	2,500 m (8,200 ft)
Uranium	68	(75)	33	24	17	10	5	3	2
Gold	68	(75)	38	25	21	12	7	5	3
Aluminum	270	(300)	68	47	35	18	9	6	3
Lead/Zinc	270	(300)	62	53	43	27	16	12	7
Copper	540	(600)	97	93	76	49	16	12	16
Molybdenum	1,100	(1,200)	143	120	99	65	49	34	22
Iron	1,100	(1,200)	106	99	77	47	27	19	11
Iron	2,200	(2,400)	182	143	120	80	50	36	22

Table 7-4. PARTICULATE MATTER CONCENTRATIONS (ANNUAL AVERAGES) IN THE VICINITY OF METALLIC MINERAL PLANTS OPERATING UNDER REGULATORY ALTERNATIVE 2

	Model Plant Sizes		Maximum annual average concentrations ($\mu g/m^3$)						
			Distance from plant boundary						
Industry	Mg/hr	(ton/hr)	0 m (0 ft)	100 m (328 ft)	200 m (656 ft)	500 m (1,640 ft)	1,000 m (3,280 ft)	1,500 m (4,920 ft)	2,500 m (8,200 ft)
Uranium	68	(75)	13	10	7	4	2	1	1
Gold	68	(75)	15	10	8	5	3	2	1
Aluminum	270	(300)	27	19	14	7	4	2	1
Lead/Zinc	270	(300)	25	21	17	11	6	5	3
Copper	540	(600)	39	37	30	20	6	5	6
Molybdenum	1,100	(1,200)	57	48	40	26	20	14	9
Iron	1,100	(1,200)	42	40	31	19	11	8	4
Iron	2,200	(2,400)	73	57	48	32	20	14	9

Table 7-5. PARTICULATE MATTER CONCENTRATIONS (ANNUAL AVERAGES) IN THE VICINITY OF METALLIC MINERAL PLANTS OPERATING UNDER REGULATORY ALTERNATIVE 3

Industry	Model Plant Sizes		Maximum annual average concentrations ($\mu g/m^3$)						
			Distance from plant boundary						
	Mg/hr	(ton/hr)	0 m (0 ft)	100 m (328 ft)	200 m (656 ft)	500 m (1,640 ft)	1,000 m (3,280 ft)	1,500 m (4,920 ft)	2,500 m (8,200 ft)
Uranium	68	(75)	4	3	2	1	<1	<1	<1
Gold	68	(75)	5	3	3	2	<1	<1	<1
Aluminum	270	(300)	9	6	5	2	1	<1	<1
Lead/Zinc	270	(300)	8	7	6	4	2	2	<1
Copper	540	(600)	13	12	10	7	2	2	2
Molybdenum	1,100	(2,200)	19	16	13	9	7	5	3
Iron	1,100	(2,200)	14	13	10	6	4	3	1
Iron	2,200	(2,400)	24	19	16	11	7	5	3

Table 7-6. PARTICULATE MATTER CONCENTRATIONS (24-HOUR AVERAGES) IN THE VICINITY OF METALLIC MINERAL PLANTS OPERATING UNDER REGULATORY ALTERNATIVE 1

Industry	Model Plant Sizes		Second maximum 24-hour average concentrations ($\mu g/m^3$)	Distance from plant boundary (meters)
	Mg/hr	(ton/hr)		
Uranium	68	(75)	153	0
Gold	68	(75)	144	0
Aluminum	270	(300)	355	0
Lead/Zinc	270	(300)	258	0
Copper	540	(600)	403	0
Molybdenum	1,100	(1,200)	532	0
Iron	1,100	(1,200)	618	100
Iron	2,200	(2,400)	1,007	0

Table 7-7. PARTICULATE MATTER CONCENTRATIONS (24-HOUR AVERAGES) IN THE VICINITY OF METALLIC MINERAL PLANTS OPERATING UNDER REGULATORY ALTERNATIVE 2

Industry	Model Plant Sizes		Second maximum 24-hour average concentrations ($\mu g/m^3$)	Distance from plant boundary (meters)
	Mg/hr	(ton/hr)		
Uranium	68	(75)	61	0
Gold	68	(75)	58	0
Aluminum	270	(300)	142	0
Lead/Zinc	270	(300)	103	0
Copper	540	(600)	161	0
Molybdenum	1,100	(1,200)	213	0
Iron	1,100	(1,200)	247	100
Iron	2,200	(2,400)	403	0

Table 7-8. PARTICULATE MATTER CONCENTRATIONS (24-HOUR AVERAGES) IN THE VICINITY OF METALLIC MINERAL PLANTS OPERATING UNDER REGULATORY ALTERNATIVE 3

Industry	Model Plant Sizes		Second maximum 24-hour average concentrations ($\mu g/m^3$)	Distance from plant boundary (meters)
	Mg/hr	(ton/hr)		
Uranium	68	(75)	20	0
Gold	68	(75)	19	0
Aluminum	270	(300)	47	0
Lead/Zinc	270	(300)	34	0
Copper	540	(600)	54	0
Molybdenum	1,100	(1,200)	71	0
Iron	1,100	(1,200)	82	100
Iron	2,200	(2,400)	134	0

water pollution impact. The disposal of water-borne particles collected in wet scrubbers, however, must be considered.

Milling wastewater handling practices vary throughout the industry. There has been a significant trend toward recycling of process water, particularly in water-limited areas. The combination of water recycling and evaporation enables many plants in arid areas to process ore with no discharge of wastewater. At these plants, wet scrubber slurries are typically added to the wet milling operations in order to supplement the water requirements of these operations. Thus, there would be no water/solid waste impact from operations in arid regions using wet scrubbers.

At other operations, excess mine water, rainfall, or the build up of interfering compounds may require the discharge of excess water from the system. In most of these operations, the wet scrubber slurries can be processed through the wet milling operations, thus eliminating direct water/solid waste impact.

In cases where the direct discharge of wet scrubber slurries to tailings ponds is required, the impact of these additional discharges on the total discharge requirements of mine/mill operations was analyzed. The total mine/mill water usage requirements were abstracted from a development document for proposed effluent guidelines for the ore mining and processing industry (Environmental Protection Agency, 1980). This document provided daily water discharge volumes for specific existing and projected new plants for each segment of the metallic mineral processing industries.

The total plant water usage shown in Table 7-9 was generated by performing a linear regression of actual data on plant size and the corresponding daily water discharge volume. After determining the linear regression equation, the model plant sizes were substituted into the equation to determine their daily water discharge. The control equipment water usage quantities were estimated assuming the recycling of water through the control device with the scrubbing liquid disposed of as a slurry containing 5 percent solids. Thus, for every 5 kilograms of dust collected, 95 kilograms (95 liters) of water were used.

Table 7-9 shows the industry water discharge rates and the incremental water usage due to the use of 1.5-, 3.7-, or 7.5-kPa (6-, 15-,

Table 7-9. WATER IMPACTS OF THE CONTROL OPTIONS UNDER THE THREE REGULATORY ALTERNATIVES FOR THE METALLIC MINERAL PROCESSING MODEL PLANTS

Industry	Projected number of new plants	Model plant sizes		Total mine/mill water discharge (MGD)[a]	Water discharges for the control options (MGD)			Water discharges for the control options as a percentage of the total plant water discharge (%)		
		Mg/hr	(ton/hr)		1[b]	2[c]	3(b)[d,e]	1[b]	2[c]	3(b)[d,e]
Aluminum	1	140	(150)	0.81	0.0125	0.0138	0.0144	1.5	1.7	1.8
	1	270	(300)	3.70	0.0216	0.0239	0.0250	0.6	0.7	0.7
Copper	1	140	(150)	13.40	0.0478	0.0490	0.0500	0.3	0.4	0.4
	1	540	(600)	53.60	0.0863	0.0954	0.0996	0.2	0.2	0.2
Gold	1	68	(75)	1.20	0.0161	0.0178	0.0185	1.3	1.5	1.5
	1	140	(150)	2.00	0.0194	0.0215	0.0224	1.0	1.1	1.1
Iron	1	1,100	(1,200)	25.00	0.1108	0.1226	0.1278	0.4	0.5	0.5
	1	2,200	(2,400)	52.30	0.2250	0.2489	0.2595	0.4	0.5	0.5
Lead/Zinc	2	270	(300)	24.00	0.0770	0.0852	0.0888	0.3	0.4	0.4
	1	540	(600)	24.70	0.0575	0.0636	0.0663	0.2	0.3	0.3
Molybdenum	1	270	(300)	5.50	0.0578	0.0639	0.0666	1.1	1.2	1.2
	2	1,100	(1,200)	35.00	0.2364	0.2614	0.2724	0.6	0.7	0.8
Silver	2	45	(50)	2.04	0.0318	0.0352	0.0366	1.6	1.7	1.8
	1	140	(150)	1.68	0.0251	0.0278	0.0290	1.5	1.6	1.7
Titanium/	1	270	(300)	3.31	0.0236	0.0261	0.0272	0.7	0.8	0.8
Zirconium	1	540	(600)	6.60	0.0379	0.0419	0.0437	0.6	0.6	0.7
Tungsten	1	23	(25)	0.50	0.0134	0.0149	0.0155	2.7	3.0	3.1
Uranium	2	23	(25)	2.08	0.0128	0.0142	0.0148	0.6	0.7	0.7
	3	68	(75)	5.01	0.0273	0.0300	0.0315	0.5	0.6	0.6
TOTAL				262.43	1.1401	1.2571	1.3096	0.4	0.5	0.5

[a]Million gallons per day (MGD).

[b]1 = Baseline, dynamic wet scrubber with Δp = 1.5 kPa (6 inches) and an emission level of 0.34 g/DNm^3 (0.15 gr/dscf).

[c]2 = Venturi scrubber with Δp = 3.7 kPa (15 inches) and an emission level of 0.14 g/DNm^3 (0.06 gr/dscf).

[d]3(a or b) = Fabric filter with Δp = 1.5 kPa (6 inches) or high energy venturi scrubber with Δp 7.5 kPa (30 inches); both with an emission level of 0.046 g/DNm^3 (0.02 gr/dscf).

[e]Control option 3(a) has no water pollution impact and is not included on this table.

or 30-inch) wet scrubbers to meet the requirements of Regulatory Alternatives 1, 2, and 3, respectively. The percentage increase in water discharge due to wet scrubbers for most plants is small, usually less than 1 percent. There is little difference in the water impacts of the three regulatory alternatives from the use of wet scrubbers.

In the case of small tungsten plants, the comparison between mill discharges and wet scrubber discharges is somewhat biased because most small plants surveyed in the document cited above are located in arid regions of country where mine/mill water discharges are small because of recycling. In these cases it is expected that a combination of recycling of scrubber water through the milling process and the increased use of baghouses would significantly reduce the wastewater impacts of Regulatory Alternative 3 to less than those cited in Table 7-9.

7.3 SOLID WASTE DISPOSAL IMPACT

Compliance with New Source Performance Standards and the subsequent reduction of particulate emissions will lead to increased production of solid waste by the emission reduction systems. The quantities of solid waste that could be produced by new facilities in each industry segment are equal to the incremental reduction in particulate emissions with Regulatory Alternatives 2 and 3. These quantities are listed in Table 7-2 for the three regulatory alternatives. The total increase in solid waste for the metallic minerals industry if Regulatory Alternative 3 is employed would be approximately 11,800 Mg (13,000 tons) in 1985.

Most metallic mineral processing facilities are currently recycling the solid waste from dry collectors back into the process because the collected particles are primarily ore or process concentrates. Slurries produced by wet collectors are also recycled back to the process, or conveyed to a tailings pond where the solid particles are separated by gravity. Any increase in the production of solid wastes from the application of emission control techniques will be insignificant by comparison with the amount of tailings produced in the beneficiation of metallic minerals. A comparison of control equipment and beneficiation solid waste production was made using iron ore and bauxite as worst-case examples because less tailings are produced per unit of ore processed than with other metallic ores. This comparison indicates that wet scrubber and baghouse wastes, under worst-case conditions, would be less than 1.0 percent of the beneficiation tailings.

7.4 ENERGY IMPACT

The potential energy impact of a regulatory alternative is dependent on the particular control equipment option used to meet the emission level. In comparison with a 1.5-kPa (6-inch) pressure drop wet scrubber (baseline), a 1.5-kPa (6-inch) pressure drop baghouse (control option 3a) will usually use less energy for a given air flow rate. This energy savings occurs because baghouses typically use more efficient fans than wet scrubbers and because baghouses require no energy consumption associated with the pumping of scrubber liquid. Therefore the universal application of baghouses to meet the requirements of Regulatory Alternative 3 would actually cause a decrease in energy consumption from present conditions.

On the other hand the energy consumption from high energy (7.5-kPa (30-inch)) wet scrubbers can be two to three times the energy consumption of low energy (1.5-kPa (6-inch)) wet scrubbers. The application of a high energy wet scrubber to control emissions from all points in the model plants surveyed would increase energy consumption from 0.04 percent for aluminum ore plants to 7 percent for titanium/zirconium ore plants. This increase is based on a comparison of total plant energy consumption (excluding calcining and pelletizing) with current control equipment (1.5-kPa (6-inch) wet scrubbers) and total plant energy consumption with 7.5-kPa (30-inch) wet scrubbers. Total plant energy consumption was listed in Chapter 6. The increase in energy consumption for all industries with the use of 3.75-kPa (15-inch) wet scrubbers would be 75 terajoules (TJ) per year. The increase in energy consumption for all industries with the use of 7.5-kPa (30-inch) wet scrubbers would be 317 TJ per year. These impacts for Regulatory Alternative 3b are worst-case projections from the standpoint of control equipment energy use because it is extremely unlikely that all plants will use only 30-inch pressure drop scrubbers. Rather, it is likely that most installations will include baghouses for unit processes without moisture concerns and wet scrubbers (often with less than 30-inch pressure drop) for unit processes with moisture concerns. Table 7-10 provides the process and control equipment energy requirements for the model plants under consideration. Control equipment energy requirements for a specific regulatory alternative are calculated on the assumption that one particular control option is applied to all process units in the model plant.

7.5 NOISE IMPACT

When compared with the noise resulting from the operation of ore crushing and grinding equipment, any additional noise from properly designed exhaust fans for the control system will be insignificant. No significant increase in noise levels over those existing under baseline control is expected with Regulatory Alternatives 2 or 3.

7.6 OTHER ENVIRONMENTAL CONCERNS

7.6.1 Irreversible and Irretrievable Commitment of Natural Resources

The alternative control systems will require the installation of additional equipment, regardless of which alternative emission control system is selected. This will require the additional use of steel and other resources. This commitment of resources will be small compared with the national usage of each resource. There are expected to be no significant amounts of space (or land) required for the installation of control equipment. The additional land required for the disposal of solids collected from control devices will be insignificant compared with the land required for the disposal of tailings from the beneficiation of metallic minerals.

7.6.2 Environmental Impact of Delayed Standards

The impacts on air pollution, water pollution, solid waste disposal, and energy use associated with delaying proposal and promulgation of standards are discussed in each of their respective sections as the impacts of Regulatory Alternative 1.

Table 7-10. ENERGY IMPACTS OF THE CONTROL OPTIONS UNDER THE THREE REGULATORY ALTERNATIVES FOR THE METALLIC MINERAL PROCESSING MODEL PLANTS[a,b,c]

Industry	Projected number of new plants	Model plant sizes Mg/hr	(ton/hr)	Ore process energy requirements (PJ/year)[d]	Energy requirements for the control options (TJ/year)[e] 1[f]	2[g]	3a[h]	3b[i]
Aluminum	1	140	(150)	8.04	2.34	3.13	0.85	5.96
	1	270	(300)	16.08	3.95	5.36	1.47	9.99
Copper	1	140	(150)	0.38	7.73	10.40	2.86	19.46
	1	540	(600)	1.55	15.16	21.17	7.14	37.97
Gold	1	68	(75)	0.21	2.94	3.92	1.07	7.46
	1	140	(150)	0.42	3.51	4.80	1.32	8.86
Iron	1	1,100	(1,200)	1.41	19.36	27.00	7.59	50.43
	1	2,200	(2,400)	2.82	39.28	53.21	15.11	101.99
Lead/Zinc	2	270	(300)	3.02	14.08	19.40	5.44	35.58
	1	540	(600)	3.02	10.38	14.50	4.00	26.73
Molybdenum	1	270	(300)	1.53	10.28	14.17	3.98	26.10
	2	1,100	(1,200)	12.24	41.36	57.50	16.16	107.46
Silver	2	45	(50)	0.19	5.80	7.80	2.08	15.48
	1	140	(150)	0.28	4.59	6.16	1.70	11.73
Titanium/	1	270	(300)	0.10	4.10	5.70	1.60	10.70
Zirconium	1	540	(600)	0.22	7.00	8.80	2.50	17.10
Tungsten	1	23	(25)	0.16	2.51	3.32	0.94	6.54
Uranium	2	23	(25)	0.34	2.44	3.32	0.88	6.06
	3	68	(75)	1.53	5.40	7.35	2.01	13.50
TOTAL				53.55	202.21	277.01	78.70	519.10

[a] Battelle, 1975.

[b] Battelle, 1976.

[c] 114 questionnaire responses.

[d] Petajoule (PJ) equals 10^{15} joules.

[e] Terajoule (TJ) equals 10^{12} joules.

[f] 1 = Baseline, dynamic wet scrubber with Δp = 1.5 kPa (6 inches) and an emission level of 0.34 g/DNm^3 (0.15 gr/dscf).

[g] 2 = Venturi scrubber with Δp = 3.7 kPa (15 inches) and an emission level of 0.14 g/DNm^3 (0.06 gr/dscf).

[h] 3a = Fabric filter with Δp - 1.5 kPa (6 inches) and an emission level of 0.046 g/DNm^3 (0.02 gr/dscf).

[i] 3b = High energy venturi scrubber with Δp = 7.5 kPa (30 inches).

7.7 REFERENCES FOR CHAPTER 7

Battelle Columbus Laboratories, 1975. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 4 - Energy Data and Flowsheets, High Priority Commodities). Report Compiled for U.S. Bureau of Mines, U.S. Department of Commerce, National Technical Information Service PB-245 759. 179 p.

Battelle Columbus Laboratories, 1976. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 6 - Energy Data and Flowsheets, Low Priority Commodities). Report Compiled for U.S. Bureau of Mines., U.S. Department of Commerce, National Technical Information Service PB-261 150. 257 p.

Bowers, J. F., J. R. Bjorklund, and C. S. Cheney. Industrial Source Complex (ISC) Dispersion Model User's Guide. U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. 2 Vols. EPA-450/4-79-030 and EPA-450/4-79-031. December, 1979.

Environmental Protection Agency, 1980. Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Ore Mining and Dressing Point Source Category (Draft Document). Washington, D.C. 602 p.

Summerhays, J. U. S. Environmental Protection Agency. 1981. Memo to S. Cuffe, U. S. Environmental Protection Agency. February 19. Dispersion Analyses for Metallic Mineral Processing Plants.

8. COSTS

8.1 COSTS OF AIR POLLUTION CONTROL FOR METALLIC MINERAL PROCESSING INDUSTRIES

8.1.1 Summary of Cost Results

In this chapter, costs have been developed for the application of each control option discussed in Chapter 6 to the emission points described in the model plant parameters. This section summarizes the results of the cost analysis. Methodology for development of the costs for each control option will be discussed in Section 8.1.3. All costs presented in Section 8.1 are in fourth-quarter 1979 dollars.

Tables 8-1 through 8-19 present capital and annualized costs that have been developed for the regulatory alternatives for each new model plant size. As stated previously in Chapter 5, expansion of a metallic mineral processing plant would involve the addition of a complete new crushing line. All control equipment costs in this case would be the same as for a new source. Because of the National Ambient Air Quality Standard for lead, lead ore processing plants may be required to apply more effective (and presumably, more expensive) control systems than would be required by the State Implementation Plans (SIP's) for attaining the NAAQS for generic particulate matter. This higher level of control would be required even in the absence of an NSPS for metallic mineral plants. Thus, the actual incremental costs (that is the cost above baseline control) incurred by lead ore processing plants in meeting the emission level corresponding to a Regulatory Alternative 2 or 3 could be less than those presented in this chapter.

The costs presented in Tables 8-1 through 8-19 do not include the costs of an initial compliance test. As indicated in Appendix D, the cost of a test of particulate emission concentration (replicated three times) would range from $5,000 to $9,000. A survey of the current State Implementation Plan regulations indicates that most states would require a compliance test for a new plant. Therefore this cost would be similar for all three regulatory alternatives.

Credit for recovered product also has been included in Tables 8-1 through 8-19, and net annualized costs, representing the annualized costs minus any credit for recovered product, are shown. The net annualized cost of a regulatory alternative describes the overall cost of controlling an entire metallic mineral processing plant with a given control option. As indicated in Tables 8-1 through 8-19 the highest net annualized cost is that of control option 3b which is based on the cost of 30-inch pressure drop wet scrubber. This cost is a worst case estimate because it is likely that a plant would have the option of installing other types of control equipment to meet the emission levels of Regulatory Alternative 3. For example, baghouses could be used in preference to high energy wet scrubbers in process streams with low moisture. In exhaust streams characterized by low inlet concentrations and/or large particle sizes, low energy wet scrubbers could be used in preference to high energy wet scrubbers. In general, the total industry cost of meeting the emission level represented by a regulatory alternative is not the cost of the control option upon which the alternative is based multiplied by the number of new plants because many new plants may be able to use less expensive control devices to meet that emission level.

Tables 8-20 through 8-29 present the marginal cost effectiveness (CE) of each regulatory alternative, determined by the following equation:

$$CE = \frac{A-B}{X-Y}$$

where A equals the cost of the regulatory alternative of interest, B equals the cost of Regulatory Alternative 1 (baseline), X equals emissions expected with Regulatory Alternative 1, and Y equals the emissions expected with the regulatory alternative of interest.

8.1.2 Product Recovery Credits and Dust Disposal Costs

Product recovery credits have been attributed to only two emission sources - dryers and product loadout - because concentrated product is handled only at these points. Table 8-30 presents the data used in developing product recovery credits. Tables 8-1 through 8-19 show that the product recovery credits are relatively insignificant to the total control costs. For those sources where no product recovery is assigned, the credits achieved from the recycle of collected material are offset by the cost of recycling this material.

8.1.3 Costs of Control Options: Scrubbers and Baghouses

Capital and annualized costs have been developed for the control of each process emission source (including crushers, dryers, ore bins, and product loadout) using each of the four control options. The control options are: (1) a centrifugal fan (mechanically aided) wet scrubber (baseline), (2) a 3.75-kPa (15-inch) pressure drop venturi scrubber, (3a) a 1.5-kPa (6-inch) pressure drop baghouse, and (3b) a 7.50-kPa (30-inch) pressure drop venturi scrubber. Specifications for these control options are shown in Table 8-31. The selection of one of the above control options to attain a given emission level will depend on the inlet loading and particle size distribution. The performance of the control options will vary over the range of circumstances within the metallic mineral industry. Therefore, the selection of low energy scrubbers can be used where conditions permit. For a discussion of model plants and control options, see Chapter 6.

Equipment costs were obtained from vendors of pollution control equipment (Valerioti, 1979) and from published sources (Neveril, 1978). Equipment costs for the venturi scrubbers were obtained from Neveril (1978) and include the cost of the basic scrubber (venturi elbow, separator, and controls), a fan, a pump, and the associated motors required to operate the system. The cost of the venturi scrubbers are based on volumetric flow rate, operating pressure, and materials of construction. The costs presented assume the material of construction is carbon steel; however, when venturi scrubbers are used on dryers of sulfur-containing concentrates, corrosion can be a problem necessitating a stainless steel fan and scrubber unit. These costs do not reflect the use of stainless steel on the dryer unit. Calculations show that the net annualized cost to the entire plant would increase by about three percent by using a stainless steel fan and scrubber on the dryer.

The cost of the basic unit for a centrifugal fan wet scrubber including an integral fan was supplied by Valerioti (1979). The cost of a fan motor and the cost of pumps and associated motors were estimated from Neveril (1978) and were added to the base cost of the centrifugal fan wet scrubber to obtain the total equipment cost. Equipment costs for the baghouse were provided by Neveril (1978) and include the basic baghouse structure, insulation, the bags, a fan, and motor to provide air flow through the system. Bag cleaning by pulse jet is accomplished by the use of compressed air jets located at the top of the bags. No costs have been assigned for an air compressor because it is assumed compressed air is available in the plant.

Component capital costs, shown in Tables 8-32 through 8-35, have been developed from published information (Weaver, 1973; Peters, 1968). These factors account for material costs and labor expenses other than the basic equipment purchase cost. Items that are typically associated with a project, such as instrumentation, electrical work, and site preparation are included as well as engineering expenses and contractor's fees. Application of these factors to the equipment costs provided the capital investment (including direct and indirect capital costs) for each control system. Annualized costs also have been developed for these control systems based upon the parameters shown in Table 8-36.

8.1.4 Capital Costs for Metallic Mineral Processing Plants

Table 8-37 presents metallic mineral processing plant costs derived from Bureau of Mines contacts and literature sources. These plant capital costs have been obtained for the ten metallic mineral industries showing growth rates and include both mine and mills costs in all cases except for the aluminum industry as explained in Section 8.1.4.1.

The capital costs presented in Table 8-37 were developed by plotting separately the plant size versus capital investment for each metal and then curve fitting the data points. In a few cases the reference sources providing capital cost data did not correlate very well. In such cases, more than one curve was plotted for each particular reference source. Thus, there are low, average, and high capital cost estimates for copper and molybdenum in Table 8-37.

A selected bibliography for Table 8-37 is provided at the end of this chapter. An entire set of references plus the calculations that form the basis for the estimates are provided in the docket.

8.1.4.1 Mine Capital Costs. Mine capital costs include acquisition of the property, exploration and development, equipment and construction costs, facilities and utilities, and working capital. Acquisition costs are a nominal fee to acquire lease rights. Exploration costs are based on an estimate of the work required to provide sufficient data to show that the quantity and quality of the resources will economically justify a mining operation for a particular deposit. The major part of the exploration cost consists of drilling and engineering expenditures. There are no mine capital costs included for aluminum processing plants because 90 percent of bauxite used in this country is imported.

An estimate of the development cost includes the work necessary to prepare the deposit for production. For example, in the case of an open-pit mine this work consists primarily of removing overburden (waste material) to expose the ore body; however, for an underground operation it includes the costs of shaft sinking and of driving drifts and raises. Both types of mines are equipped with hoisting facilities, as well as hauling, pumping, and ventilating equipment. Equipment and construction costs include the cost of all mobile equipment in the pit and the cost of permanent structures. Working capital is a function of operating cost and therefore does not vary directly with the capital investment.

8.1.4.2 Mill Capital Cost. Mill capital costs include the cost of all crushing, grinding, flotation, and leaching facilities and equipment. Aluminum capital costs are based on the Bayer process which is the predominant process used in the United States to produce alumina from bauxite (Kurtz, 1980). In general, capital costs for all other metals are the costs of constructing and installing all operations and equipment required to produce the final products listed in Table 3-3. Working capital also is part of the total mill cost; however, it is a function of operating cost and not a function of capital investment.

Table 8-38 shows the total capital requirements itemized for a 25 ton/hr tungsten plant.

Table 8-1. COSTS OF REGULATORY ALTERNATIVES FOR THE 140 Mg (150 TON)/HOUR ALUMINUM ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Coarse ore reclaim	Hammer mill	Fine ore bin	Product loadout	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	WS(M)	WS(M)	247	103	2	101
2	WS(V_{15})	WS(V_{15})	WS(V_{15})	WS(V_{15})	269	120	2	118
3a	BH	BH	BH	BH	324	124	2	122
3b	WS(V_{30})	WS(V_{30})	WS(V_{30})	WS(V_{30})	310	156	2	154

BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-2. COSTS OF REGULATORY ALTERNATIVES FOR THE 270 Mg (300 TON)/HOUR ALUMINUM ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Coarse ore reclaim	Hammer mill	Fine ore bin	Product loadout	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	WS(M)	WS(M)	318	144	5	139
2	WS(V_{15})	WS(V_{15})	WS(V_{15})	WS(V_{15})	365	175	5	170
3a	BH	BH	BH	BH	549	212	5	207
3b	WS(V_{30})	WS(V_{30})	WS(V_{30})	WS(V_{30})	448	239	5	234

BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-3. COSTS OF REGULATORY ALTERNATIVES FOR THE 140 Mg (150 TON)/HOUR COPPER ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Crushers[a]	Ore bins	Dryer	Product loadout	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	WS(M)	WS(M)	427	205	< 1	205
2	WS(V_{15})	WS(V_{15})	WS(V_{15})	WS(V_{15})	493	263	< 1	263
3a	BH	BH	BH	BH	772	310	< 1	310
3b	WS(V_{30})	WS(V_{30})	WS(V_{30})	WS(V_{30})	588	372	< 1	372

[a]Includes primary, secondary, and tertiary crushing units.
BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-4. COSTS OF REGULATORY ALTERNATIVES FOR THE 540 Mg (600 TON)/HOUR COPPER ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Crushers[a]	Ore bins	Dryer	Product loadout	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	WS(M)	WS(M)	812	419	< 1	419
2	WS(V_{15})	WS(V_{15})	WS(V_{15})	WS(V_{15})	969	522	< 1	522
3a	BH	BH	BH	BH	1,530	618	< 1	618
3b	WS(V_{30})	WS(V_{30})	WS(V_{30})	WS(V_{30})	1,135	722	< 1	722

[a]Includes primary, secondary, and tertiary crushing units.
BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-5. COSTS OF REGULATORY ALTERNATIVES FOR THE 68 Mg (75 TON)/HOUR GOLD ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Crushers[a]	Ore bins	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	257	111	0	111
2	WS(V_{15})	WS(V_{15})	291	136	0	136
3a	BH	BH	436	168	0	168
3b	WS(V_{30})	WS(V_{30})	322	177	0	177

[a]Includes primary and secondary crushing units.
BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-6. COSTS OF REGULATORY ALTERNATIVES FOR THE 140 Mg (150 TON)/HOUR GOLD ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Primary crusher	Ore bins	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	292	129	0	129
2	$WS(V_{15})$	$WS(V_{15})$	342	162	0	162
3a	BH	BH	519	200	0	200
3b	$WS(V_{30})$	$WS(V_{30})$	385	211	0	211

[a]Includes primary and secondary crushing units.

BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; $WS(V_{15})$ = 3.75-kPa (15-inch) venturi scrubber; and $WS(V_{30})$ = 7.50-kPa (30-inch) venturi scrubber.

Table 8-7. COSTS OF REGULATORY ALTERNATIVES FOR THE 1,100 Mg (1,200 TON)/HOUR IRON ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Crushers[a]	Ore bins	Product loadout	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	WS(M)	990	492	0	492
2	WS(V_{15})	WS(V_{15})	WS(V_{15})	1,131	628	0	628
3a	BH	BH	BH	1,972	782	0	782
3b	WS(V_{30})	WS(V_{30})	WS(V_{30})	1,434	933	0	933

[a]Includes primary, secondary, and tertiary crushing units.
BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-8. COSTS OF REGULATORY ALTERNATIVES FOR THE 2,200 Mg (2,400 TON)/HOUR IRON ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Crushers[a]	Ore bins	Product loadout	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	WS(M)	1,888	991	0	991
2	WS(V_{15})	WS(V_{15})	WS(V_{15})	2,307	1,266	0	1,266
3a	BH	BH	BH	3,983	1,549	0	1,549
3b	WS(V_{30})	WS(V_{30})	WS(V_{30})	2,825	1,858	0	1,858

[a]Includes primary, secondary, and tertiary crushing units.
BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber;
WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-9. COSTS OF REGULATORY ALTERNATIVES FOR THE 270 Mg (300 TON)/HOUR LEAD/ZINC ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Crushers[a]	Ore bins	Dryer	Product loadout	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	WS(M)	WS(M)	588	260	1	259
2	WS(V_{15})	WS(V_{15})	WS(V_{15})	WS(V_{15})	686	325	1	324
3a	BH	BH	BH	BH	1,040	402	1	401
3b	WS(V_{30})	WS(V_{30})	WS(V_{30})	WS(V_{30})	800	434	1	433

[a]Includes primary, secondary, and tertiary crushing units.
BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-10. COSTS OF REGULATORY ALTERNATIVES FOR THE 540 Mg (600 TON)/HOUR LEAD/ZINC ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Crushers[a]	Ore bins	Dryer	Product loadout	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	WS(M)	WS(M)	812	364	1	363
2	WS(V_{15})	WS(V_{15})	WS(V_{15})	WS(V_{15})	969	466	1	465
3a	BH	BH	BH	BH	1,527	589	1	588
3b	WS(V_{30})	WS(V_{30})	WS(V_{30})	WS(V_{30})	1,135	628	1	627

[a]Includes primary, secondary, and tertiary crushing units.
BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-11. COSTS OF REGULATORY ALTERNATIVES FOR THE 270 Mg (300 TON)/HOUR MOLYBDENUM ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Crushers[a]	Ore bins	Dryer	Product loadout	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	WS(M)	WS(M)	587	284	2	282
2	WS(V_{15})	WS(V_{15})	WS(V_{15})	WS(V_{15})	686	363	2	361
3a	BH	BH	BH	BH	1,040	412	2	410
3b	WS(V_{30})	WS(V_{30})	WS(V_{30})	WS(V_{30})	800	502	2	500

[a]Includes primary, secondary, and tertiary crushing units.
BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-12. COSTS OF REGULAGORY ALTERNATIVES FOR THE 1100 Mg (1200 TON)/HOUR MOLYBDENUM ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Crushers[a]	Ore bins	Dryer	Product loadout	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	WS(M)	WS(M)	1,069	528	4	524
2	WS(V_{15})	WS(V_{15})	WS(V_{15})	WS(V_{15})	1,218	675	4	671
3a	BH	BH	BH	BH	2,115	839	4	835
3b	WS(V_{30})	WS(V_{30})	WS(V_{30})	WS(V_{30})	1,530	992	4	988

[a]Includes primary, secondary, and tertiary crushing units.
BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber;
WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-13. COSTS OF REGULATORY ALTERNATIVES FOR THE 45 Mg (50 TON)/HOUR SILVER ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Crusher[a]	Ore bins	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	266	117	0	117
2	$WS(V_{15})$	$WS(V_{15})$	304	143	0	143
3a	BH	BH	457	176	0	176
3b	$WS(V_{30})$	$WS(V_{30})$	358	193	0	193

[a]Includes primary, secondary, and tertiary crushing units.

BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; $WS(V_{15})$ = 3.75-kPa (15-inch) venturi scrubber; and $WS(V_{30})$ = 7.50-kPa (30-inch) venturi scrubber.

Table 8-14. COSTS OF REGULATORY ALTERNATIVES FOR THE 140 Mg (150 TON)/HOUR SILVER ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Crusher[a]	Ore bins	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	358	162	0	162
2	$WS(V_{15})$	$WS(V_{15})$	405	196	0	196
3a	BH	BH	667	257	0	257
3b	$WS(V_{30})$	$WS(V_{30})$	517	285	0	270

[a]Includes primary, secondary, and tertiary crushing units.

BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; $WS(V_{15})$ = 3.75-kPa (15-inch) venturi scrubber; and $WS(V_{30})$ = 7.50-kPa (30-inch) venturi scrubber.

Table 8-15. COSTS OF REGULATORY ALTERNATIVES FOR THE 270 Mg (300 TON)/HOUR TITANIUM/ZIRCONIUM SAND TYPE ORE PROCESSING INDUSTRY MODEL PLANT (1979 Dollars)

Regulatory alternative	Dryer	Product loadout	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	205	93	3	90
2	WS(V_{15})	WS(V_{15})	246	136	3	133
3a	BH	BH	415	164	3	161
3b	WS(V_{30})	WS(V_{30})	297	195	3	192

BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-16. COSTS OF REGULATORY ALTERNATIVES FOR THE 540 Mg (600 TON)/HOUR TITANIUM/ZIRCONIUM SAND TYPE ORE PROCESSING INDUSTRY MODEL PLANT (1979 Dollars)

Regulatory alternative	Dryer	Product loadout	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	281	159	4	155
2	WS(V_{15})	WS(V_{15})	349	198	4	194
3a	BH	BH	661	262	4	258
3b	WS(V_{30})	WS(V_{30})	484	315	4	311

BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber;
WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-17. COSTS OF REGULATORY ALTERNATIVES FOR THE 23 Mg (25 TON)/HOUR TUNGSTEN ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Crushers[a]	Ore bins	Dryer	Product loadout	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	WS(M)	WS(M)	216	97	0	97
2	WS(V_{15})	WS(V_{15})	WS(V_{15})	WS(V_{15})	225	104	0	104
3a	BH	BH	BH	BH	311	121	0	121
3b	WS(V_{30})	WS(V_{30})	WS(V_{30})	WS(V_{30})	262	138	0	138

[a]Includes primary, secondary, and tertiary crushing units.
BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-18. COSTS OF REGULATORY ALTERNATIVES FOR THE 23 Mg (25 TON)/HOUR URANIUM ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Primary crusher	Ore bins	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	115	51	0	51
2	$WS(V_{15})$	$WS(V_{15})$	135	62	0	62
3a	BH	BH	177	68	0	68
3b	$WS(V_{30})$	$WS(V_{30})$	144	79	0	79

BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; $WS(V_{15})$ = 3.75-kPa (15-inch) venturi scrubber; and $WS(V_{30})$ = 7.50-kPa (30-inch) venturi scrubber.

Table 8-19. COSTS OF REGULATORY ALTERNATIVES FOR THE 68 Mg (75 TON)/HOUR URANIUM ORE PROCESSING INDUSTRY MODEL PLANT (1979 dollars)

Regulatory alternative	Primary crusher	Ore bins	Fixed capital investment (thousand $)	Annualized costs (thousand $/yr)	Product recovery credit (thousand $/yr)	Net annualized costs (thousand $/yr)
1	WS(M)	WS(M)	154	70	0	70
2	WS(V_{15})	WS(V_{15})	177	84	0	84
3a	BH	BH	267	103	0	103
3b	WS(V_{30})	WS(V_{30})	192	106	0	106

BH = baghouse; WS(M) = centrifugal fan (mechanically aided) wet scrubber; WS(V_{15}) = 3.75-kPa (15-inch) venturi scrubber; and WS(V_{30}) = 7.50-kPa (30-inch) venturi scrubber.

Table 8-20. MARGINAL COST EFFECTIVENESS OF REGULATORY ALTERNATIVES FOR THE ALUMINUM ORE PROCESSING INDUSTRY MODEL PLANTS (1979 DOLLARS)

Regulatory alternative number	Quantity	Model plant size: 140 Mg/hr (150 ton/hr)	Model plant size: 270 Mg/hr (300 ton/hr)
Baseline			
1a	Total particulate emissions allowed under SIP's: Mg/yr (ton/yr)	587 (645)	667 (733)
1b[a]	Total particulate emissions from 6" wet scrubber: Mg/yr (ton/yr)	153 (168)	263 (289)
2	Total particulate emissions: Mg/yr (ton/yr)	60 (67)	105 (116)
	Emission reduction from baseline: Mg/yr (ton/yr)	93 (101)	158 (173)
	Emission reduction from baseline: (%)	60	60
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	17	31
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.18 (0.08)	0.20 (0.09)
3a	Total particulate emissons: Mg/yr (ton/yr)	20 (22)	36 (39)
	Emission reduction from baseline: Mg/yr (ton/yr)	133 (146)	227 (250)
	Emission reduction from baseline: (%)	87	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	21	68
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.16 (0.07)	0.30 (0.14)
3b	Total particulate emissions: Mg/yr (ton/yr)	20 (22)	36 (39)
	Emission reduction from baseline: Mg/yr (ton/yr)	133 (146)	227 (250)
	Emission reduction from baseline: (%)	87	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	53	95
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.40 (0.18)	0.42 (0.19)

[a]Emission reduction and cost effectiveness are based on this baseline control level.
Note: All marginal cost effectiveness (CE) numbers are calculated using the equation in Section 8.1.1.

Table 8-21. MARGINAL COST EFFECTIVENESS OF REGULATORY ALTERNATIVES FOR THE COPPER ORE PROCESSING INDUSTRY MODEL PLANTS (1979 DOLLARS)

Regulatory alternative number	Quantity	Model plant size 140 Mg/hr (150 ton/hr)	540 Mg/hr (600 ton/hr)
Baseline			
1a	Total particulate emissions allowed under SIP's: Mg/yr (ton/yr)	1,284 (1,413)	2,457 (2,703)
1b[a]	Total particulate emissions from 6" wet scrubber: Mg/yr (ton/yr)	519 (570)	1,021 (1,124)
2	Total particulate emissions: Mg/yr (ton/yr)	205 (225)	408 (449)
	Emission reduction from baseline: Mg/yr (ton/yr)	314 (345)	613 (675)
	Emission reduction from baseline: (%)	60	60
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	58	103
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.18 (0.08)	0.17 (0.08)
3a	Total particulate emissons: Mg/yr (ton/yr)	68 (75)	136 (150)
	Emission reduction from baseline: Mg/yr (ton/yr)	451 (495)	885 (974)
	Emission reduction from baseline: (%)	87	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	105	199
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.23 (0.11)	0.22 (0.10)
3b	Total particulate emissions: Mg/yr (ton/yr)	68 (75)	136 (150)
	Emission reduction from baseline: Mg/yr (ton/yr)	451 (495)	885 (974)
	Emission reduction from baseline: (%)	87	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	167	303
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.37 (0.17)	0.34 (0.16)

[a]Emission reduction and cost effectiveness are based on this baseline control level.
Note: All marginal cost effectiveness (CE) numbers are calculated using the equation in Section 8.1.1.

Table 8-22. MARGINAL COST EFFECTIVENESS OF REGULATORY ALTERNATIVES FOR THE GOLD ORE PROCESSING INDUSTRY MODEL PLANTS (1979 DOLLARS)

Regulatory alternative number	Quantity	Model plant size	
		68 Mg/hr (75 ton/hr)	140 Mg/hr (150 ton/hr)
Baseline			
1a	Total particulate emissions allowed under SIP's: Mg/yr (ton/yr)	510 (561)	584 (642)
1b[a]	Total particulate emissions from 6" wet scrubber: Mg/yr (ton/yr)	195 (215)	236 (260)
2	Total particulate emissions: Mg/yr (ton/yr)	78 (86)	95 (104)
	Emission reduction from baseline: Mg/yr (ton/yr)	117 (129)	141 (156)
	Emission reduction from baseline: (%)	60	60
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	25	33
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.21 (0.10)	0.23 (0.11)
3a	Total particulate emissons: Mg/yr (ton/yr)	26 (29)	32 (35)
	Emission reduction from baseline: Mg/yr (ton/yr)	169 (186)	204 (225)
	Emission reduction from baseline: (%)	87	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	57	71
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.34(0.15)	0.35 (0.16)
3b	Total particulate emissions: Mg/yr (ton/yr)	26 (29)	32 (35)
	Emission reduction from baseline: Mg/yr (ton/yr)	169 (186)	204 (225)
	Emission reduction from baseline: (%)	87	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	66	82
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.39 (0.18)	0.40 (0.18)

[a]Emission reduction and cost effectiveness are based on this baseline control level.

Note: All marginal cost effectiveness (CE) numbers are calculated using the equation in Section 8.1.1.

Table 8-23. MARGINAL COST EFFECTIVENESS OF REGULATORY ALTERNATIVES FOR THE IRON ORE PROCESSING INDUSTRY MODEL PLANTS (1979 DOLLARS)

Regulatory alternative number	Quantity	Model plant size: 1,100 Mg/hr (1,200 ton/hr)	Model plant size: 2,200 Mg/hr (2,400 ton/hr)
Baseline			
1a	Total particulate emissions allowed under SIP's: Mg/yr (ton/yr)	1,859 (2,045)	3,324 (3,657)
1b[a]	Total particulate emissions from 6" wet scrubber: Mg/yr (ton/yr)	1,313 (1,444)	2,666 (2,932)
2	Total particulate emissions: Mg/yr (ton/yr)	525 (578)	1,066 (1,173)
	Emission reduction from baseline: Mg/yr (ton/yr)	788 (866)	1,600 (1,759)
	Emission reduction from baseline: (%)	60	60
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	136	353
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.17 (0.08)	0.22 (0.10)
3a	Total particulate emissons: Mg/yr (ton/yr)	175 (193)	355 (391)
	Emission reduction from baseline: Mg/yr (ton/yr)	1,138 (1,251)	2,311 (2,541)
	Emission reduction from baseline: (%)	87	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	290	636
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.25 (0.12)	0.28 (0.13)
3b	Total particulate emissions: Mg/yr (ton/yr)	175 (193)	355 (391)
	Emission reduction from baseline: Mg/yr (ton/yr)	1,138 (1,251)	2,311 (2,541)
	Emission reduction from baseline: (%)	87	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	441	945
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.39 (0.18)	0.41 (0.19)

[a]Emission reduction and cost effectiveness are based on this baseline control level.
Note: All marginal cost effectiveness (CE) numbers are calculated using the equation in Section 8.1.1.

Table 8-24. MARGINAL COST EFFECTIVENESS OF REGULATORY ALTERNATIVES FOR THE LEAD/ZINC ORE PROCESSING INDUSTRY MODEL PLANTS (1979 DOLLARS)

Regulatory alternative number	Quantity	Model plant size: 270 Mg/hr (300 tons/hr)	Model plant size: 540 Mg/hr (600 tons/hr)
Baseline			
1a	Total particulate emissions allowed under SIP's: Mg/yr (ton/yr)	1,254 (1,380)	1,682 (1,850)
1b[a]	Total particulate emissions from 6" wet scrubber: Mg/yr (ton/yr)	470 (517)	698 (767)
2	Total particulate emissions: Mg/yr (ton/yr)	188 (207)	279 (307)
	Emission reduction from baseline: Mg/yr (ton/yr)	282 (310)	419 (460)
	Emission reduction from baseline: (%)	60	60
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	65	102
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.23 (0.11)	0.24 (0.11)
3a	Total particulate emissons: Mg/yr (ton/yr)	63 (69)	93 (102)
	Emission reduction from baseline: Mg/yr (ton/yr)	407 (448)	605 (665)
	Emission reduction from baseline: (%)	87	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	142	225
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.35 (0.16)	0.37 (0.17)
3b	Total particulate emissions: Mg/yr (ton/yr)	63 (69)	93 (102)
	Emission reduction from baseline: Mg/yr (ton/yr)	407 (448)	605 (665)
	Emission reduction from baseline: (%)	87	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	174	264
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.43 (0.19)	0.44 (0.20)

[a]Emission reduction and cost effectiveness are based on this baseline control level.
Note: All marginal cost effectiveness (CE) numbers are calculated using the equation in Section 8.1.1.

Table 8-25. MARGINAL COST EFFECTIVENESS OF REGULATORY ALTERNATIVES FOR THE MOLYBDENUM ORE PROCESSING INDUSTRY MODEL PLANTS (1979 DOLLARS)

Regulatory alternative number	Quantity	Model plant size: 270 Mg/hr (300 ton/hr)	Model plant size: 1,100 Mg/hr (1,200 ton/hr)
Baseline			
1a	Total particulate emissions allowed under SIP's: Mg/yr (ton/yr)	1,263 (1,390)	2,165 (2,380)
1b[a]	Total particulate emissions from 6" wet scrubber: Mg/yr (ton/yr)	687 (756)	1,400 (1,540)
2	Total particulate emissions: Mg/yr (ton/yr)	275 (302)	560 (615)
	Emission reduction from baseline: Mg/yr (ton/yr)	412 (454)	840 (925)
	Emission reduction from baseline: (%)	60	60
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	79	147
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.19 (0.09)	0.17 (0.08)
3a	Total particulate emissons: Mg/yr (ton/yr)	92 (101)	187 (205)
	Emission reduction from baseline: Mg/yr (ton/yr)	595 (655)	1,213 (1,335)
	Emission reduction from baseline: (%)	87	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	128	311
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.08 (0.04)	0.26 (0.12)
3b	Total particulate emissions: Mg/yr (ton/yr)	92 (101)	187 (205)
	Emission reduction from baseline: Mg/yr (ton/yr)	595 (655)	1,213 (1,335)
	Emission reduction from baseline: (%)	87	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	218	464
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.37 (0.17)	0.38 (0.17)

[a]Emission reduction and cost effectiveness are based on this baseline control level.
Note: All marginal cost effectiveness (CE) numbers are calculated using the equation in Section 8.1.1.

Table 8-26. MARGINAL COST EFFECTIVENESS OF REGULATORY ALTERNATIVES FOR THE SILVER ORE PROCESSING INDUSTRY MODEL PLANTS (1979 DOLLARS)

Regulatory alternative number	Quantity	Model plant size 45 Mg/hr (50 ton/hr)	140 Mg/hr (150 ton/hr)
Baseline			
1a	Total particulate emissions allowed under SIP's: Mg/yr (ton/yr)	472 (519)	586 (645)
1b[a]	Total particulate emissions from 6" wet scrubber: Mg/yr (ton/yr)	194 (213)	305 (336)
2	Total particulate emissions: Mg/yr (ton/yr)	77 (85)	122 (134)
	Emission reduction from baseline: Mg/yr (ton/yr)	117 (128)	183 (202)
	Emission reduction from baseline: (%)	60	60
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	26	34
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.22 (0.10)	0.19 (0.08)
3a	Total particulate emissons: Mg/yr (ton/yr)	25 (28)	41 (45)
	Emission reduction from baseline: Mg/yr (ton/yr)	169 (185)	264 (291)
	Emission reduction from baseline: (%)	86	86
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	59	95
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.35 (0.16)	0.36 (0.16)
3b	Total particulate emissions: Mg/yr (ton/yr)	25 (28)	41 (45)
	Emission reduction from baseline: Mg/yr (ton/yr)	169 (185)	264 (291)
	Emission reduction from baseline: (%)	86	86
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	76	108
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.45 (0.20)	0.41 (0.19)

[a]Emission reduction and cost effectiveness are based on this baseline control level.
Note: All marginal cost effectiveness (CE) numbers are calculated using the equation in Section 8.1.1.

Table 8-27. MARGINAL COST EFFECTIVENESS OF REGULATORY ALTERNATIVES FOR THE TITANIUM/ZIRCONIUM ORE PROCESSING INDUSTRY MODEL PLANTS (1979 DOLLARS)

Regulatory alternative number	Quantity	Model plant size 270 Mg/hr (300 ton/hr)	540 Mg/hr (600 ton/hr)
Baseline			
1a	Total particulate emissions allowed under SIP's: Mg/yr (ton/yr)	427 (470)	601 (661)
1b[a]	Total particulate emissions from 6" wet scrubber: Mg/yr (ton/yr)	280 (308)	449 (493)
2	Total particulate emissions: Mg/yr (ton/yr)	112 (123)	179 (197)
	Emission reduction from baseline: Mg/yr (ton/yr)	168 (185)	270 (296)
	Emission reduction from baseline: (%)	60	60
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	43	39
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.25 (0.11)	0.14 (0.07)
3a	Total particulate emissons: Mg/yr (ton/yr)	37 (41)	60 (66)
	Emission reduction from baseline: Mg/yr (ton/yr)	243 (267)	389 (427)
	Emission reduction from baseline: (%)	87	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	71	103
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.29 (0.13)	0.27 (0.12)
3b	Total particulate emissions: Mg/yr (ton/yr)	37 (41)	60 (66)
	Emission reduction from baseline: Mg/yr (ton/yr)	243 (267)	389 (427)
	Emission reduction from baseline: (%)	87	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	102	156
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.42 (0.19)	0.40 (0.18)

[a]Emission reduction and cost effectiveness are based on this baseline control level.
Note: All marginal cost effectiveness (CE) numbers are calculated using the equation in Section 8.1.1.

Table 8-28. MARGINAL COST EFFECTIVENESS OF REGULATORY ALTERNATIVES FOR THE TUNGSTEN ORE PROCESSING INDUSTRY MODEL PLANTS (1979 DOLLARS)

Regulatory alternative number	Quantity	Model plant size 23 Mg/hr (25 ton/hr)
Baseline		
1a	Total particulate emissions allowed under SIP's: Mg/yr (ton/yr)	562 (618)
1b[a]	Total particulate emissions from 6" wet scrubber: Mg/yr (ton/yr)	163 (180)
2	Total particulate emissions: Mg/yr (ton/yr)	65 (72)
	Emission reduction from baseline: Mg/yr (ton/yr)	98 (108)
	Emission reduction from baseline: (%)	60
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	7
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.07 (0.03)
3a	Total particulate emissons: Mg/yr (ton/yr)	22 (24)
	Emission reduction from baseline: Mg/yr (ton/yr)	141 (156)
	Emission reduction from baseline: (%)	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	24
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.17 (0.08)
3b	Total particulate emissions: Mg/yr (ton/yr)	22 (24)
	Emission reduction from baseline: Mg/yr (ton/yr)	141 (156)
	Emission reduction from baseline: (%)	87
	Costs of regulatory alternative above baseline cost: (thousand $/yr)	41
	Cost effectiveness of regulatory alternative: $/kg ($/lb) of particulate removed	0.29 (0.13)

[a]Emission reduction and cost effectiveness are based on this baseline control level.
Note: All marginal cost effectiveness (CE) numbers are calculated using the equation in Section 8.1.1.

Table 8-31. SPECIFICATIONS FOR SCRUBBER AND FABRIC FILTER CONTROL OPTIONS

I. CENTRIFUGAL FAN WET SCRUBBER

- A. Processes controlled: crusher, ore bin, dryer, product loadout units[a]
- B. Construction material: carbon steel
- C. Air flow rate: determined by individual emission sources

II. & III. VENTURI SCRUBBERS

- A. Processes controlled: crusher, ore bin, dryer, product loadout units[a]
- B. Pressure drop: 3.75 kPa (15 in. W.G.) and 7.50 kPa (30 in. W.G.)
- C. Construction material: carbon steel
- D. Air flow rate: determined by individual emission sources

IV. FABRIC FILTER

- A. Processes controlled: crusher, ore bin, dryer, product loadout units[a]
- B. Bag material: Dacron felt
- C. Air to cloth ratio: 6:1 (ft/min)
- D. Cleaning method: pulse-jet
- E. Pressure drop: 1.5 kPa (6 in. W.G.)
- F. Construction material: carbon steel
- G. Air flow rate: determined by individual emission sources

[a]Separate control is assumed for each process unit (see Chapter 6 for deliniation of process units. Process units may include screens and conveyor transfer points as appropriate.

Table 8-32. DIRECT CAPITAL COST FACTORS FOR A WET SCRUBBER AS A FUNCTION OF EQUIPMENT COST (Q)[a,b]

Component	Material	Labor
Equipment	1.00 Q	0.09 Q
Ductwork	0.10 Q	0.09 Q
Instrumentation	0.05 Q	0.02 Q
Electrical	0.06 Q	0.12 Q
Foundations	0.03 Q	0.05 Q
Structural	0.06 Q	0.03 Q
Sitework	0.02 Q	0.02 Q
Painting	0.005 Q	0.02 Q
Piping	0.09 Q	0.08 Q
Total direct costs	1.42 Q	0.52 Q

[a]Weaver, 1973.

[b]Peters and Timmerhaus, 1968.

Table 8-33. INDIRECT CAPITAL COST FACTORS FOR A WET SCRUBBER AS A FUNCTION OF EQUIPMENT COST (Q)[a,b]

Component	Measure of costs	Factor
Engineering	10% of material and labor	0.19 Q
Contractor's fee	15% of material and labor	0.29 Q
Shakedown	5% of material and labor	0.10 Q
Spares	1% of material	0.01 Q
Freight	3% of material	0.04 Q
Taxes	3% of material	0.04 Q
Total indirect costs		0.67 Q
Contingencies[c]		0.52 Q
Total capital costs		3.13 Q

[a]Weaver, 1973.

[b]Peters and Timmerhaus, 1968.

[c]20% of direct and indirect costs.

Table 8-34. DIRECT CAPITAL COST FACTORS FOR A BAGHOUSE AS A FUNCTION OF EQUIPMENT COST (Q)[a,b]

Component	Material	Labor
Equipment	1.00 Q	0.09 Q
Ductwork	0.14 Q	0.11 Q
Instrumentation	0.05 Q	0.02 Q
Electrical	0.05 Q	0.10 Q
Foundations	0.03 Q	0.05 Q
Structural	0.06 Q	0.03 Q
Sitework	0.02 Q	0.02 Q
Painting	0.005 Q	0.02 Q
Total direct costs	1.36 Q	0.44 Q

[a]Weaver, 1973.

[b]Peters and Timmerhaus, 1968.

Table 8-35. INDIRECT CAPITAL COST FACTORS FOR A BAGHOUSE AS A FUNCTION OF EQUIPMENT COST (Q)[a,b]

Component	Measure of costs	Factor
Engineering	10% of material and labor	0.18 Q
Contractor's fee	15% of material and labor	0.27 Q
Shakedown	5% of material and labor	0.09 Q
Spares	1% of material	0.01 Q
Freight	3% of material	0.04 Q
Taxes	3% of material	0.04 Q
Total indirect costs		0.63 Q
Contingencies[c]		0.49 Q
Total capital costs		2.92 Q

[a]Weaver, 1973.

[b]Peters and Timmerhaus, 1968.

[c]20% of direct and indirect costs.

Table 8-36. BASES FOR SCRUBBER AND FABRIC FILTER ANNUALIZED COSTS (1979 dollars)

Type of cost	Description
Direct operating cost	
Utilities	
Water	Water from the tailings pond is typically used for scrubbers as well as for the ore processing equipment. No cost is assigned to the (small) fraction used for scrubbers.
Electricity	\$0.0302/kWh (Scrubber electricity usage is derived from pump and fan requirements and annual hours of operation. Fabric filter electricity usage is derived from fan and compressor requirements and annual hours of operation.)
Operation and maintenance	
Scrubber	14.85% of capital investment
Fabric filter	15.75% of capital investment
Capital charges	
Capital recovery factor	16.69% of capital investment
Taxes, Insurance, and Administration	4% of capital investment

[a]Based on a 15-year lifetime for either scrubbers or fabric filters, and an interest rate of 14.5 percent.

Table 8-37. FIXED CAPITAL INVESTMENT[a]
(Using fourth-quarter 1979 dollars x 10^6)

Mineral	Plant size (ton/hr)	Mine	Mill	Combined
Aluminum				
	50		145	
	150		430	
	300		870	
	600		1,750	
Copper				
low	150	32	15	47
average	150	44	21	65
high	150	46	23	69
low	300	40	22	60
average	300	55	33	88
high	300	59	35	94
low	600	47	40	87
average	600	52	61	133
high	600	78	66	144
low	1,200	69	72	141
average	1,200	109	114	223
high	1,200	119	124	243
Gold				
	10			10
	50			27
	75			34
	150			52
	300			79

(continued)

Table 8-37. Continued

Mineral	Plant size (ton/hr)	Mine	Mill	Combined
Iron				
	600			345
	1,200			707
	2,400			1,430
Lead/Zinc				
	150	19	16	35
	300	50	45	95
	600	114	100	214
Molybdenum				
low	150			36
average	150			68
high	150			130
low	300			72
average	300			100
high	300			140
low	600			90
average	600			125
high	600			144
low	1,200			245
average	1,200			285
high	1,200			426

(continued)

Table 8-37. Concluded

Mineral	Plant size (ton/hr)	Mine	Mill	Combined
Silver	35			17
	50			25
	150			76
	200			102
Titanium/Zirconium	300			10
	600			17
Tungsten	25			15
Uranium	25			6.8
	75			20

[a]References for this table are found in a bibliography at the end of this section.

Table 8-38. TOTAL CAPITAL REQUIREMENTS FOR A 25 TPH TUNGSTEN PLANT[a]

Unit	Cost (1979 4th quarter (dollars x 10^6)
Mine	
Surface mine plant and buildings	0.5
Underground equipment and construction	0.3
Mine property acquisition	0.1
Mine exploration and development	0.9
Total	1.8
Mill	
Crushing section	0.4
Grinding section	0.3
Flotation section	0.3
Leaching section	0.1
Total	1.1
Plant facilities	0.3
Plant utilities	0.4
Total	0.7
Total plant cost (insurance and tax bases)	3.6
Interest during construction	0.2
Working capital	0.6
Total	4.4

[a]Stefford, 1971.

8.2 OTHER COST CONSIDERATIONS

The cost considerations assessed in this section for the 16 metallic mineral industries are a result of pollution control standards other than this New Source Performance Standard (NSPS). The other air pollution control costs considered include NSPS for primary copper, lead, and zinc smelting industries, and iron and steel plants. In addition, the control costs resulting from the National Ambient Air Quality Standard (NAAQS) for Lead will be considered. The control costs required by the Occupational Safety and Health Administration (OSHA) standards and water pollution control requirements are addressed. The solids wastes (tailings) resulting from the beneficiation of metallic minerals have been exempted from the provisions of the Resource Conservation and Recovery Act.

8.2.1 Other Air Pollution Control Costs

8.2.1.1 NSPS.

8.2.1.1.1 Primary copper smelters. Total capital and operating costs are presented in Table 8-39 for various combinations of emission control processes for the four basic copper smelter type configurations - electric smelting, flash smelting, roaster/reverberatory smelting, and reverberatory smelting. In addition, the overall control of sulfur dioxide emissions, expressed as a percent, achieved with each control alternative is summarized. Table 8-39 also presents control costs and incremental control costs expressed in terms of cents per pound of copper produced and cents per pound of sulfur dioxide controlled.* The baseline control is by single stage acid plant and neutralization.

8.2.1.1.2 Primary zinc smelters. The cost of controlling sulfur dioxide and particulate emissions at a new source zinc smelter depends on both the particular smelting refining process that is utilized in the new source smelter and the control level chosen for the process. Total capital and operating costs are presented in Table 8-40 for various combinations of emission control processes for the three basic zinc smelter type configurations - electrolytic process (roasting and leaching), conventional roasting and sintering, and the Robson process

---

*Incremental cost throughout this section is the difference between the alternative control cost and the appropriate baseline control cost as indicated in the text.

(combined roast/sinter). Table 8-40 also presents control costs and incremental control costs expressed in terms of cents per pound of zinc produced and cents per pound of sulfur dioxide controlled. The baseline control is by single stage acid plant and neutralization.

8.2.1.1.3 Primary lead smelters. The cost of controlling sulfur dioxide and particulate emissions at a new source lead smelter depends on both the smelting process that is used as well as the control level chosen for the process. Three smelting techniques were considered for use in a new source lead smelter. These techniques are recirculating sintering machine, nonrecirculating sintering machine, and electric furnace and converters. The five control systems considered were single-stage sulfuric acid plants, dual-stage sulfuric acid plants, elemental sulfur plants coupled with dimethylamine (DMA) units, elemental sulfur plants coupled with Wellman-Lord scrubbing units, and DMA units only. Various combinations of emission control processes were coupled with the three smelting techniques and are presented in Table 8-41. Table 8-41 presents control costs and incremental control costs expressed in terms of cents per pound of lead produced and cents per pound of sulfur dioxide controlled. The baseline control is by single stage acid plant and neutralization.

8.2.1.1.4 Primary aluminum industry. The NSPS for primary aluminum reduction plants limits emissions of total fluorides and visible emissions from potrooms that house primary aluminum reduction cells and from anode bake plants.

Primary aluminum reduction is carried out in shallow rectangular cells (pots) made of carbon-lined steel with carbon blocks that are suspended above and extend down into the pot. The pots and carbon blocks serve as cathodes and anodes, respectively, for the electrolytical process. Three types of reduction cells or pots are used in the United States: prebake (PB), horizontal stud Soderberg (HSS), and vertical stud Soderberg (VSS). Table 8-42 shows the capital and annual costs for control of pre-bake cells, and vertical and horizontal stud Soderberg cells. The capital cost includes the primary collection system (hoods and ducts), the fans and other auxiliary equipment, the collection device, and wastewater treatment facilities if required. Because the carbon anodes used in the prebake cells are made in a separate operation, the anode baking furnace control equipment costs must be added to the reduction cell emissions in order to determine the total cost for control under this NSPS. Table 8-43 presents the range of control costs for the anode baking furnace. Capital costs are given in terms of dollars/ton of annual capacity of aluminum produced and annualized costs are given in terms of ¢/lb of aluminum produced at full capacity.

The NSPS for the primary aluminum industry was promulgated on January 26, 1976 (40 Federal Register 3826). Since then EPA implemented a Section 111(d) requiring states to adopt fluoride emission standards for existing primary aluminum plants that are subject to the same NSPS as a new plant. The section change under the Clean Air Act from 111(b) to 111(d) will have no effect on the control equipment costs for new plants.

8.2.1.1.5 Iron and steel plants. One NSPS for the iron and steel industry limits emissions of particulate matter from new basic oxygen process furnaces (BOPF's). A review of this NSPS background document (EPA, 1973) indicates that the description of applicable control technologies for BOPF particulate emissions remains unchanged; i.e., closed hood/venturi scrubber, open hood/ESP, or venturi scrubber remain the best demonstrated control technologies. Table 8-44 gives the control costs of meeting the NSPS for new BOPF's.

8.2.1.1.6 Electric arc furnaces in the steel industry. The NSPS for electric arc furnaces in the steel industry limits particulate matter emissions from electric arc furnaces and dust handling equipment. The majority of the electric furnace installations are controlled by fabric filters with a few venturi scrubbers in service. In addition to the variations in control devices, there are three viable methods of collecting the fumes for cleaning. First, in the direct shell evacuation method, fumes are drawn from the shell of the furnace, the carbon monoxide is burned, the fumes are cooled, and then are routed to the control device. The second method incorporates a canopy hood to capture charging and tapping emissions to supplement the direct evacuation system. The third method is total building evacuation. Table 8-45 shows detailed cost estimates for fabric filter control for each collection configuration.

8.2.1.1.7 Electric submerged arc furnaces for production of ferroalloys. The NSPS for electric submerged arc furnaces limits emissions of particulate matter from ferroalloy plants. In ferroalloy production, the major source of pollution is the electric submerged arc furnace which performs the smelting operations. There are three different furnace configurations - open, semi-closed, and sealed. The type of configuration present at the ferroalloy plant affects the efficiency of air pollution control equipment. Costs were developed for open and sealed furnaces for two types of control devices - wet scrubbers and fabric filters. Table 8-46 presents costs for the variable throat venturi scrubber for an open and a sealed furnace. The maximum power rating for this furnace is 33 MW for HC FeMn and 38 MW for SiMn. The use of a fabric filter as a control device on a sealed furnace has not been demonstrated in the United States. The estimated capital cost for a conventional fabric filter control system, consisting of a radiant cooler, cyclone, fan, fabric filter, dust and collected storage equipment is estimated at about $250,000 (1974 dollars).

8.2.1.2 Lead NAAQS. An Economic Impact Assessment for the National Ambient Air Quality Standard for Lead was completed on June 28, 1978 (Environmental Protection Agency, 1978). The final promulgated standard is 1.5 $\mu g/m^3$ with an averaging period of 90 days. The NAAQS for lead could effect the level of emission control required for primary lead smelters and primary copper smelters as well as the lead ore processing units covered in this document. The control costs for meeting the lead NAAQS for primary lead and primary copper smelters are given in Table 8-47. The investment, annualized control cost, and investment and annualized cost as a percent of annual revenue for the model lead smelter and the model copper smelter are presented in Table 8-47. The annual production rates for the model lead smelter and the model copper smelter are 62,000 megagrams per year and 635,000 megagrams per year, respectively. These control costs are based on the best demonstrated control system currently available (building evacuation to a fabric filter).

8.2.2 Control Costs Resulting from OSHA Regulations

OSHA undertook a formal analysis of cost of compliance with the 100 $\mu g/m^3$ permissible exposure limit (PEL) to lead for the lead smelting industry. Since this analysis was done, OSHA decided that the proposed level of 100 μg/m^3 did not provide adequate worker protection and that a 50 μg/m^3 PEL was required. However, OSHA determined that the cost for control to proposed 100 μg/m^3 level adequately estimated the cost for the lower standard for most industries. In addition, OSHA found that compliance with levels below 100 μg/m^3 might require extensive technological development in several industries and long periods of implementation time. This time frame would preclude meaningful quantification of cost. Therefore, the costs presented are for the 100 μg/m^3 concentration level.

To aid in its assessment of economic factors, OSHA contracted with DB Associates Inc. (DBA) to investigate the technological feasibility of compliance with the proposed PEL of 100 μg/m^3 and to estimate compliance costs for the lead smelting industry. A draft of the Lead Industries Association (LIA) study ("Economic Impact of Proposed OSHA Lead Standards") conducted by Charles River Associates ("CRA") was also used for economic data in the smelting industry. Table 8-48 shows the cost estimates for the primary lead sector made by DBA and CRA to meet the 100 μg/m^3 level.

Estimating the cost impact of the lead OSHA standard for lead processing plants is extremely difficult. Contacts with both the Bureau of Mines and the Department of Labor reveal that little data relating to the additional expenditures for this industry to comply with OSHA regulations (43 Federal Register 52952) are available. Furthermore, contacts directly with the industry reveal a general lack of quantitative data. Consequently, at this point a full assessment of the economic impact of OSHA on this industry is not possible. In general, however, qualitative information provided by these contacts indicates limited economic impact due to OSHA, because additional expenditures over and above those normally incurred by the lead processing plants are likely to be small.

8.2.3 Water Pollution Control Requirements

Generalized capital and annual costs for wastewater treatment processes at ore mining and dressing facilities have been established. Costing has been prepared on a unit process basis for each of the metallic minerals. The effluent limitations that must be achieved by 1 July 1984 under the Clean Water Act (CWA) require consideration of costs in the requirements for Best Available Treatment; however, the CWA does not require a balancing of costs against effluent reduction (see Weyerhauser vs. Costle, 11 ERC 2149 (DC Cir. 1978)). The regulations proposed for July 1984 are, in fact, based on the application of what the Agency deems to be Best Available Technology Economically Achievable. New Source Performance Standards (NSPS), required under Section 306 of the CWA, are also based on the application of the Best Available Demonstrated Control Technology. EPA has proposed New Source Performance Standards to be based on Best Available Demonstrated Control Technology for all metallic mineral industries.

A study of existing froth flotation mills in the copper, lead, zinc, gold, silver, and molybdenum ore processing industries reveals that a large percentage of these facilities are already effectively achieving 100 percent recycle of mill water. A number of the facilities practicing 100 percent recycle are located in arid regions.

Tables 8-49 to 8-55 summarize the treatment costs for specific plant sizes for each of the metallic mineral processing industries. These costs are for existing plants. It is probable that the costs for a new plant to meet the New Source Performance Standards (NSPS) are no more than the costs for an existing plant. In the construction of a new plant, in-process modifications can often be made more efficiently and economically than add-on treatment technologies for existing plants.

Table 8-39. CONTROL COSTS FOR MODEL COPPER SMELTING FACILITIES[a,b]

Model No.	Control Equipment	Capital Cost (10^6\$)	Capital Charges (10^6\$/yr)	Operating Cost (10^6\$/yr)	Total Cost (10^6\$/yr)	Overall Control (%)	Control Costs: Cents per lb Copper	Control Costs: Cents per lb SO_2	Incremental Control Costs: Cents per lb Copper	Incremental Control Costs: Cents per lb SO_2
	Electric Smelting									
Ia	Single Stage Acid Plant	10.2	2.31	0.57	2.88		1.68	0.72	—	—
	Neutralization	5.4	0.96	0.97	1.93					
		15.6	3.27	1.54	4.81	97.5	2.79	1.21	—	—
Ib	Dual Stage Acid Plant	11.4	2.59	0.62	3.21		1.87	0.79	0.19	4.34
	Neutralization	5.5	1.00	0.99	1.99					
		16.9	3.59	1.61	5.20	99.5	3.03	1.28	0.24	5.13
Ic	DMA Scrubbing	25.8	5.84	0.96	6.80					
	Sulfur Plant	3.5	0.76	0.73	1.49					
		29.3	6.60	1.69	8.29	99.5	4.82	2.04	—	—
Id	DMA Scrubbing	23.4	5.30	0.86	6.16	99.5	3.58	1.52	—	—
	Flash Smelting									
IIa	Single Stage Acid Plant	8.7	1.98	0.50	2.48		1.45	0.62	—	—
	Neutralization	5.4	0.96	0.97	1.93					
		14.1	2.94	1.47	4.41	97.5	2.56	1.10	—	—
IIb	Dual Stage Acid Plant	9.8	2.23	0.54	2.77		1.61	0.68	0.16	4.15
	Neutralization	5.5	1.00	0.99	1.99					
		15.3	3.23	1.53	4.76	99.5	2.77	1.17	0.21	5.01
IIc	DMA Scrubbing	20.2	4.57	0.73	5.30					
	Sulfur Plant	3.5	0.76	0.73	1.49					
		23.7	5.33	1.46	6.79	99.5	3.95	1.67	—	—
IId	DMA Scrubbing	18.1	4.08	0.63	4.71	99.5	2.74	1.16	—	—

(continued)

Table 8-39. Concluded

Model No.	Control Equipment	Capital Cost (10^6\$)	Capital Charges (10^6\$/yr)	Operating Cost (10^6\$/yr)	Total Cost (10^6\$/yr)	Overall Control (%)	Control Costs: Cents per lb Copper	Control Costs: Cents per lb SO_2	Incremental Control Costs: Cents per lb Copper	Incremental Control Costs: Cents per lb SO_2
	Roaster/Reverberatory Smelting									
IIIa	Single Stage Acid Plant	8.7	1.98	0.44	2.42		1.41	0.75	—	—
	Neutralization	4.8	0.87	0.78	1.65					
		13.5	2.85	1.22	4.07	78.5	2.41	1.27	—	—
IIIb	Dual Stage Acid Plant	9.7	2.21	0.48	2.69		1.57	0.82	0.82	4.84
	Neutralization	4.8	0.87	0.79	1.66					
		14.5	3.08	1.27	4.35	80.0	2.56	1.33	0.15	5.01
IIIc	DMA Scrubbing	11.2	2.54	0.43	2.97					
	Dual Stage Acid Plant	10.2	2.31	0.52	2.83		3.37	1.43	1.80	4.05
	Neutralization	5.5	1.00	0.99	1.99					
		26.9	5.85	1.94	7.79	98.5	4.53	1.93	1.97	4.43
	Reverberatory Smelting									
IVa	Single Stage Acid Plant	8.9	2.02	0.46	2.48		1.45	0.89	—	—
	Neutralization	4.4	0.80	0.68	1.48					
		13.3	2.82	1.14	3.96	69.0	2.30	1.41	—	—
IVb	Dual Stage Acid Plant	9.9	2.25	0.50	2.75		1.60	0.96	0.15	5.48
	Neutralization	4.4	0.80	0.69	1.49					
		14.3	3.05	1.19	4.24	70.0	2.46	1.49	0.16	5.69
IVc	DMA Scrubbing	17.0	3.85	0.84	4.69					
	Dual Stage Acid Plant	10.1	2.23	0.56	2.79		4.36	1.85	2.76	3.99
	Neutralization	5.4	0.96	0.98	1.94					
		32.5	7.04	2.38	9.42	98.5	5.48	2.33	3.02	4.36

[a] Environmental Protection Agency, 1974a.

[b] All costs in 1974 dollars.

Table 8-40. CONTROL COSTS FOR MODEL ZINC SMELTERS[a,b]

Model No.	Control Equipment	Capital Cost (10^6\$)	Capital Charges (10^6\$/yr)	Operating Cost (10^6\$/yr)	Total Cost (10^6\$/yr)	Overall Control (%)	Control Costs: Cents per lb Zinc	Control Costs: Cents per lb SO_2	Incremental Control Costs: Cents per lb Zinc	Incremental Control Costs: Cents per lb SO_2
	Roaster/Sinter Smelting									
Ia	Single Stage Acid Plant	4.8	1.09	0.31	1.40		0.70	0.69	—	—
	Neutralization	3.5	0.63	0.50	1.13					
		8.3	1.72	0.81	2.53	94.5	1.26	1.24	—	—
Ib	Dual Stage Acid Plant	5.5	1.22	0.34	1.56		0.78	0.75	0.08	3.86
	Neutralization	3.6	0.63	0.50	1.13					
		9.1	1.85	0.84	2.69	96.5	1.34	1.29	0.08	3.86
Ic	DMA Scrubbing	21.7	4.16	0.68	4.84					
	Dual Stage Acid Plant	5.5	1.22	0.34	1.56		3.20	3.00	2.42	241
	Neutralization	3.5	0.63	0.50	1.13					
		30.7	6.01	1.52	7.53	98.0	3.76	3.53	2.42	241
Id	Sulfur Plant	6.8	1.52	0.79	2.31					
	Wellman Scrubbing	2.9	0.65	0.25	0.90					
		9.7	2.17	1.04	3.21	96.5	1.60	1.52	—	—
	Electrolytic Smelting									
IIa	Single Stage Acid Plant	4.9	1.11	0.32	1.43		0.71	0.67	—	—
	Neutralization	3.5	0.64	0.51	1.15					
		8.4	1.75	0.83	2.58	97.5	1.29	1.21	—	—
IIb	Dual Stage Acid Plant	5.6	1.28	0.34	1.62		0.81	0.74	0.10	4.44
	Neutralization	3.6	0.64	0.51	1.15					
		9.2	1.92	0.85	2.77	99.5	1.38	1.27	0.09	4.44
IIc	Sulfur Plant	5.5	1.22	0.71	1.93					
	Wellman Scrubbing	2.9	0.65	0.20	0.85					
		8.4	1.87	0.91	2.78	99.5	1.39	1.28	—	—

(continued)

Table 8-40. Concluded

Model No.	Control Equipment	Capital Cost (10^6\$)	Capital Charges (10^6\$/yr)	Operating Cost (10^6\$/yr)	Total Cost (10^6\$/yr)	Overall Control (%)	Control Costs: Cents per lb Zinc	Control Costs: Cents per lb SO_2	Incremental Control Costs: Cents per lb Zinc	Incremental Control Costs: Cents per lb SO_2
	Robson Smelting									
IIIa	Single Stage Acid Plant	7.3	1.65	0.37	2.02		1.01	0.94	—	—
	Neutralization	4.3	0.77	0.50	1.27					
		11.6	2.42	0.87	3.29	96.5	1.64	1.54	—	—
IIIb	Dual Stage Acid Plant	8.4	1.90	0.40	2.30		1.15	1.04	0.14	4.53
	Neutralization	4.3	0.77	0.50	1.27					
		12.7	2.67	0.90	3.57	99.0	1.79	1.62	0.15	4.53
IIIc	DMA Scrubbing	19.4	4.45	0.54	4.99					
	Sulfur Plant	3.4	0.74	0.44	1.18					
		22.8	5.19	0.98	6.17	99.0	3.09	2.80	—	—

[a] Environmental Protection Agency, 1974a.

[b] All costs in 1974 dollars.

Table 8-41. CONTROL COSTS FOR MODEL LEAD SMELTERS[a,b]

Model No.	Control Equipment	Capital Cost (10^6\$)	Capital Charges (10^6\$/yr)	Operating Cost (10^6\$/yr)	Total Cost (10^6\$/yr)	Overall Control (%)	Control Costs: Cents per lb Lead	Control Costs: Cents per lb SO_2	Incremental Control Costs: Cents per lb Lead	Incremental Control Costs: Cents per lb SO_2
	Conventional Sintering Machine Smelting									
Ia	Single Stage Acid Plant	3.2	0.73	0.16	0.89		0.45	1.23	—	—
	Neutralization	1.9	0.33	0.17	0.50					
		5.1	1.06	0.33	1.39	67.0	0.70	1.92	—	—
Ib	Dual Stage Acid Plant	3.7	0.84	0.17	1.01		0.50	1.37	0.05	6.59
	Neutralization	1.9	0.33	0.17	0.50					
		5.6	1.17	0.34	1.51	68.5	0.76	2.04	0.06	6.59
Ic	DMA Scrubbing	20.1	4.63	0.52	5.15					
	Dual Stage Acid Plant	3.6	0.84	0.17	1.01		3.08	6.90	2.58	23.4
	Neutralization	2.3	0.40	0.24	0.64					
		26.0	5.87	0.93	6.80	89.0	3.40	7.61	2.64	24.0
Id	DMA Scrubbing	23.9	5.51	0.66	6.17					
	Dual Stage Acid Plant	3.7	0.84	0.17	1.01		3.59	7.00	0.51	16.4
	Neutralization	2.4	0.42	0.25	0.67					
		30.0	6.77	1.08	7.85	96.5	3.92	7.66	0.52	16.9
	Recirculating Sintering Machine Smelting									
IIa	Single Stage Acid Plant	4.9	1.12	0.21	1.33		0.66	1.39	—	—
	Neutralization	2.2	0.39	0.23	0.62					
		7.1	1.51	0.44	1.95	88.5	0.98	2.03	—	—
IIb	Dual Stage Acid Plant	5.6	1.27	0.23	1.50		0.75	1.52	0.09	6.01
	Neutralization	2.2	0.39	0.23	0.62					
		7.8	1.66	0.46	2.12	91.0	1.06	2.15	0.08	6.01

(continued)

Table 8-41. Concluded

Model No.	Control Equipment	Capital Cost (10^6\$)	Capital Charges (10^6\$/yr)	Operating Cost (10^6\$/yr)	Total Cost (10^6\$/yr)	Overall Control (%)	Control Costs: Cents per lb Lead	Control Costs: Cents per lb SO_2	Incremental Control Costs: Cents per lb Lead	Incremental Control Costs: Cents per lb SO_2
IIc	DMA Scrubbing	8.3	1.90	0.17	2.07					
	Dual Stage Acid Plant	5.7	1.29	0.23	1.52		1.80	3.42	1.05	36.5
	Neutralization	2.4	0.43	0.26	0.69					
		16.4	3.62	0.66	4.28	98.5	2.14	4.08	1.08	37.7
IId	DMA Scrubbing	11.6	2.66	0.22	2.88					
	Sulfur Plant	2.1	0.45	0.24	0.69					
		13.7	3.11	0.46	3.57	91.0	1.79	3.62	—	—
	Electric Smelting									
IIIa	Single Stage Acid Plant	4.4	0.99	0.28	1.27		0.64	1.40	—	—
	Neutralization	2.2	0.39	0.23	0.62					
		6.6	1.38	0.51	1.89	97.5	0.95	2.08	—	—
IIIb	Dual Stage Acid Plant	5.0	1.14	0.30	1.44		0.72	1.55	0.08	8.50
	Neutralization	2.2	0.39	0.23	0.62					
		7.2	1.53	0.53	2.06	99.5	1.03	2.22	0.08	8.50
IIIc	DMA Scrubbing	10.7	2.47	0.32	2.79					
	Sulfur Plant	2.5	0.54	0.43	0.97					
		13.2	3.01	0.75	3.76	99.5	1.88	4.04	—	—

[a]Environmental Protection Agency, 1974a.

[b]All costs in 1974 dollars.

Table 8-42. COST OF POTLINE CONTROLS FOR ALUMINUM REDUCTION SMELTERS[a]

Cell type		Prebake		Vertical stud Soderberg		Horizontal stud Soderberg
Control equipment[b]		1°-FBDS	1°-IADS	1°-FBDS 2°-SS	1°-ST+WESP 2°-SS	1°-ST+WESP
Capital cost ($/ton)		67[c]	59	95[c]	117	193
Annual cost ($/ton)						
Operating and maintenance		5.57	4.35	9.70	11.69	11.89
Depreciation	8%					
Administrative overhead	5%					
Property tax, insurance	2%	10.02	8.80	14.31	17.49	28.91
	15%					
Interest	8%	5.36	4.70	7.64	9.32	15.46
Royalty		.33	--	.33	--	--
Gross annual cost		21.28	17.85	31.98	38.50	56.26
Credits (alumina @ $0.032/lb, and fluoride @ $0.25/lb		(10.54)	(10.54)	(9.19)	--	--
Net annual cost ($/ton)		10.74	7.31	22.79	38.50	56.26
(¢/lb)		0.54	0.37	1.14	1.93	2.81

[a]Singmaster, D. and S. Breyer, 1973. All costs in 1972 dollars.

[b]FBDS - Fluidized Bed Dry Scrubber
IADS - Injected Alumina Dry Scrubber
ST - Spray Tower
WESP - Wet Electrostatic Precipitator
SS - Spray Screen
1° = primary control system
2° = secondary control system

[c]In addition a $100,000 one-time fee is charged per company for this design.

Table 8-43. CONTROL COSTS FOR PREBAKE ANODE BAKING FURNACES[a,b]

Control Equipment	PC+DESP+WS or WS+WESP[c]
Capital cost ($/ton)[d]	6 - 12
Annual cost (¢/lb)[e]	0.088 - 0.20

[a]Environmental Protection Agency, 1974b.

[b]All costs in 1974 dollars.

[c]PC - Precooler
WS - Wet Scrubber
DESP - Dry Electrostatic Precipitator
WESP - Wet Electrostatic Precipitator

[d]$/ton of annual capacity of aluminum.

[e]¢/lb of aluminum produced at full capacity.

Table 8-44. CONTROL COSTS OF MEETING PERFORMANCE STANDARD (0.22 gr/dscf) FOR TYPICAL NEW TWO-VESSEL BASIC OXYGEN PROCESS FURNACES[a,b,c]

Plant size, tons/melt	Required control equipment	Control investment, $	Annual cost, $/yr	Annual cost per unit of production, $/ton
140	Open hood, scrubber	4,700,000	1,950,000	1.52
	Open hood, ESP	5,900,000	1,500,000	1.17
	Closed hood, scrubber	6,800,000	2,140,000	1.67
250	Open hood, scrubber	7,400,000	2,750,000	1.20
	Open hood, ESP	8,000,000	2,000,000	0.89
	Closed hood, scrubber	8,400,000	2,800,000	1.22

[a]Major assumptions: (1) production of 140 tons/melt = 2,300,000 tons/yr; (2) 18-year straight-line depreciation.

[b]Environmental Protection Agency, 1973.

[c]All costs in 1973 dollars.

Table 8-45. ELECTRIC ARC FURNACE CONTROL COSTS FOR SHOP WITH THREE 100 TON FURNACES USING FABRIC FILTER CONTROL DEVICE[a,b]

	Carbon steel		Alloys	
	Direct evacuation & canopy hoods	Building evacuations	Canopy hoods only	Building evacuation
Gas flow, SCFM (design)	600,000	1,500,000	750,000	1,500,000
Investment				
Gas cleaning device, $	$1,038,500	$1,969,700	$1,246,200	$1,969,700
Auxiliary equipment, $	433,000	651,200	440,300	651,200
Ductwork, utilities, $	1,265,500	1,965,200	1,321,400	1,965,200
Engineering, overheads, etc., $	583,000	976,900	700,900	976,900
Total investment, $	$3,320,000	$5,563,000	$3,708,800	$5,563,000
$/annual ton capacity	$9.78	$16.40	$10.93	$16.40
Operating costs				
Operating labor & supervision, $/yr	$ 2,240	$ 2,240	$ 2,240	$ 2,240
Power @ 1.2¢/kWH, $/yr	168,370	294,520	201,600	368,020
Make-up water @ 25¢/1000 gal, $/yr	23,080	-	-	-
Cooling water treatment @ 0.2¢/1000 gal, $/yr	1,850	-	-	-
Maintenance @ 6% inv, $/yr	199,200	333,780	222,530	333,780
Property tax, insur, G & A, @ 6% inv, $/yr	199,200	333,780	222,530	333,780
8% interest (averaged to 5%), $/yr	166,000	278,150	185,440	278,150
Depreciation, 15 yr straight line, $/yr	221,330	370,870	247,250	370,870
Total annualized cost, $/yr	$ 981,270	$1,613,340	$1,081,590	$1,686,840
Tons/yr (7920 hrs/yr, 7 hrs/heat for allows & 3.5 hrs/heat for carbon steel)	678,600	678,600	339,300	339,300
Cost/ton produced, $	$1.45	$2.38	$3.19	$4.97

[a]Environmental Protection Agency, 1974d.

Table 8-46. COMPARISON OF CAPITAL AND ANNUAL COSTS FOR AN OPEN AND SEALED FURNACE[a,b]

Cost item	Open furnace	Totally enclosed furnace
Comparison of total capital costs (thousands of $)		
Basic furnace and associated process equipment	$ 8,500	$ 8,500
Incremental furnace cost	--	1,400
Incremental feed pretreatment	--	3,000
Air pollution control systems	3,500	2,100
	$12,000	$15,000
Comparison of control equipment costs		
Capital costs (thousands of $)		
Primary system	$ 3,500	$ 1,700[c]
Taphole system (see Table VI-7)	(inc. in above)	400
Incremental furnace cost	--	1,400
	$ 3,500	$ 3,500
Annual costs (thousands of $ per year)		
Operating cost	$ 143	$ 135
Maintenance (6%)	210	210
Capital recovery (@ 8% interest)	409[d]	390[e]
Administration (2%)	70	70
Taxes and insurance (2%)	70	70
	$ 902	$ 875
Annual cost per ton ($/ton)		
HC FeMn	$ 9.11	$ 8.84[f]
SiMn	$20.50	$19.89[f]

[a]Environmental Protection Agency, 1974c.

[b]All costs in 1974 dollars.

[c]Includes $900,000 for the cooler, mechanical separator, scrubber, mist eliminator, and water treatment equipment; $420,000 for the furnace cover and mechanical seals; and $380,000 for the prorated share of electrical utility and engineering costs.

[d]Depreciation life: 15 years.

[e]Depreciation lives: 10 years - furnace cover, 15 years - pollution control system, 20 years - incremental furnace costs.

[f]This does not include the annualized investment cost or operating cost of the incremental feed pretreatment equipment. The ferroalloy industry has indicated that the total manufacturing cost per ton of product is about equal for both the open furnace with control and the sealed furnace with control and feed preparation.

Table 8-47. CONTROL COSTS OF THE LEAD NAAQS FOR MODEL PRIMARY LEAD AND PRIMARY COPPER SMELTERS[a,b,c]

Plant	Investment 10^3\$	As a % of annual revenue	Annualized cost 10^3\$	As a % of annual revenue
Primary Lead	1600	5.2%	400	1.2%
Primary Copper	7600	5.2%	1600	1.1%

[a]Environmental Protection Agency, 1978.

[b]Costs based on 1.5 μg/m^3 final standard with an averaging period of one calender quarter.

[c]All costs in 1978 dollars.

Table 8-48. PRIMARY LEAD SMELTING AND REFINING COSTS OF COMPLIANCE TO MEET THE OCCUPATIONAL EXPOSURE TO LEAD REGULATION[a,b]

	Capital costs (10^6\$)		Recurring annual costs (10^6\$)		Annual charge to capital		Pre-tax total annualized cost		After-tax total annualized cost	
	DBA	CRA	DBA	CRA	DBA	CRA	DBA	CRA	DBA	CRA
Bunker Hill	18.400	9.236	2.649	2.233	N.C.	1.439	N.C.	2.672	N.C.	1.389
St. Joe	7.500	10.627	2.211	1.414	N.C.	1.656	N.C.	3.071	N.C.	1.597
Amax	9.540	8.144	1.814	1.365	N.C.	1.269	N.C.	2.634	N.C.	1.370
ASARCO (Total)	20.830	19.247	5.833	1.823	N.C.	2.999	N.C.	4.822	N.C.	2.508
(ASARCO/Omaha)	(4.500)	(4.153)	(1.209)	(0.425)	(N.C.)	(0.647)	(N.C.)	(1.072)	(N.C.)	(0.557)
(ASARCO/East Helena)	(5.900)	(5.499)	(1.444)	(0.491)	(N.C.)	(0.857)	(N.C.)	(1.348)	(N.C.)	(0.701)
(ASARCO/El Paso)	(5.250)	(5.483)	(2.060)	(0.498)	(N.C.)	(0.752)	(N.C.)	(1.250)	(N.C.)	(0.650)
(ASARCO/Glover)	(5.180)	(4.767)	(1.120)	(0.373)	(N.C.)	(0.743)	(N.C.)	(1.116)	(N.C.)	(0.580)
TOTAL	56.270	47.254	12.507	5.836	12.373	7.363	24.88	13.199	12.94	6.864

[a]Occupational Safety and Health Administration, 1978.

[b]All costs in 1978 dollars.

NC - Not calculable from data provided.

Table 8-49. COST FOR THE IRON ORE PROCESSING INDUSTRY FOR VARIOUS TYPES OF WASTE TREATMENT TECHNOLOGIES TO MEET THE BAT STANDARDS[a,b]

Mine	Mill	Mine/Mill	Ore production 1000 tons/yr	Water discharged (MGD)	Treatment technologies and costs: Secondary settling	Flocculation	Mixed media filter
1101[c]			36,376	21.13	340[d] 44.8[e] 0.12[f]	110 160 0.44	2000 310 0.85
1102			9072	0.69	84 19.8 0.21	65 30 0.33	150 47 0.52
		1104	1800	7.0	284 49.2 2.72	160 100 4.98	1006 195 10.78
	1105		9149	12.7	250 35 0.38	100 99 1.08	1400 220 2.40
		1107	5842	6.22	286 49.2 .84	162 85 1.45	955 185 3.16
		1108	9700	12.88	386 59.5 0.61	180 125 1.29	1675 292 3.01
	1109		18,078	5.94	186 29.2 0.61	90 58 0.32	800 140 0.77

(continued)

Table 8-49. Concluded

Mine	Mill	Mine/Mill	Ore production 1000 tons/yr	Water discharged (MGD)	Treatment technologies and costs		
					Secondary settling	Flocculation	Mixed media filter
		1121	1194	7.38	294[d] 50.3[e] 4.22[f]	162 93 7.8	1054 203 17.0
1122			8157	17.8	315 42.3 0.52	105 125 1.53	1750 280 3.43
		1131	3858	16.8	380 56.1 1.45	160 138 3.58	1758 291 7.54
		1143	2648	1.06	98 20.2 0.76	70 32 1.21	200 55 2.08
		1144	1874	3.25	148 25.2 1.34	82 43 2.30	500 95 5.07

[a]Environmental Protection Agency, 1980.

[b]All costs in 1980 dollars.

[c]Mine/Mill Code Index used in the Development Document for Effluent Limitations Guidelines and Standards of Performance for the Ore Mining and Dressing Point Source Category.

[d]Capital cost ($1000).

[e]Annual cost ($1000).

[f]Cost: $/ton of ore mined

Table 8-50. COST FOR THE COPPER ORE PROCESSING INDUSTRY FOR VARIOUS TYPES OF WATER TREATMENT TECHNOLOGIES TO MEET THE BAT STANDARDS[a,b]

Mine	Mill	Mine/Mill	Ore production 1000 tons/yr	Water discharged (MGD)	Treatment technologies and costs: Secondary settling	Flocculation	Mixed media filter	Recycle 25%	Recycle 50%	Recycle 75%	Recycle 100%
		2104[c]	8101	0.18	61[d]	66	60	7	9.6	13	17
					17[e]	27	33	18	18.6	17	18.6
					0.21[f]	0.33	0.41	0.2	0.2	0.21	0.23
	2117		2024	8.50	220	96	1050	60	90	130	170
					32	76	100	31	43	67	70
					1.68	3.71	8.89	1.63	2.12	2.81	3.46
		2120	17,000	9.55	304	143	1178	66	100	146	180
					51	108	218	33	48	82	76
					0.3	0.63	1.3	0.1	0.27	0.36	0.44
		2121	3617	32	400	120	2600	166	270	380	485
					60	210	400	70	125	170	230
					1.38	6.81	11.1	1.94	3.46	4.70	8.36
	2122		36,600	8.60	220	96	1050	68	90	130	170
					32	76	180	70	43	67	70
					0.09	0.21	0.61	0.08	.12	.16	0.20

[a] Environmental Protection Agency, 1980.

[b] All costs in 1980 dollars.

[c] Mine/Mill Code Index used in the Development Document for Effluent Limitations Guidelines and Standards of Performance for the Ore Mining and Dressing Point Source Category.

[d] Capital cost ($1000).

[e] Annual cost ($1000)

[f] Cost: $/ton or ore mined.

Table 8-51. COSTS FOR THE LEAD/ZINC ORE PROCESSING INDUSTRY FOR VARIOUS TYPES OF WATER TREATMENT TECHNOLOGIES TO MEET THE BAT STANDARDS[a,b]

Mine	Mill	Mine/Mill	Ore production 1000 tons/yr	Water discharged (MGD)	Treatment technologies and costs: Secondary settling	Flocculation	Mixed media filter	Recycle 25%	Recycle 50%	Recycle 75%	Recycle 100%
		3101[c]	206	0.38	70[d]	60	90	9.6	140	18	24
					17.5[e]	27	40	16.0	16.6	17.6	19.6
					8.6[f]	13.1	19.4	7.77	8.0	8.6	9.47
		3102	1634	6.94	180	90	800	60	73	100	130
					29	60	140	27	37	47	67
					1.77	3.67	8.67	1.65	2.26	2.88	3.49
		3109	1117	7.60	210	96	930	66	80	126	160
					32	67	166	30	43	66	66
					2.86	8.00	13.8	2.69	3.85	4.92	6.91
		3114	68	0.42	74.0	61	95	11	16	19	24
					18.0	27	41	18	18.6	17.6	20
					28.47	39.71	60.29	23.6	24.3	26.7	29.4
		3116	372	4.7	160	90	640	43	60	84	110
					26	61	120	26	32	39	46
					6.99	13.71	13.26	6.72	8.6	10.48	12.1
		3118	698	14.0	280	100	1600	87	130	170	240
					38	110	230	40	69	80	100
					8.38	18.46	38.6	8.71	9.9	13.4	16.8

[a]Environmental Protection Agency, 1980.

[b]All costs in 1980 dollars.

[c]Mine/Mill Code Index used in the Development Document for Effluent Limitations Guidelines and Standards of Performance for the Ore Mining and Dressing Point Source Category.

[d]Capital costs ($1000)

[e]Annual cost ($1000)

[f]Cost: $/ton or ore mined

Table 8-52. COSTS FOR THE GOLD AND SILVER ORE PROCESSING INDUSTRY FOR VARIOUS TYPES OF WATER TREATMENT TECHNOLOGIES TO MEET THE BAT STANDARDS[a,b]

Mine	Mill	Mine/Mill	Ore production 1000 tons/yr	Water discharged (MGD)	Treatment technologies and costs						
					Secondary settling	Flocculation	Mixed media filter	Recycle 25%	Recycle 50%	Recycle 75%	Recycle 100%
		4102[c]	179	1.36	168[d] 37.8[e] 19.4[f]	130 60 27.6	290 104 44	9.6 16 6.7	16 17 6.9	18 18 6.3	23 20 6.9
4106			1660	3.04	146 24.7 1.58	82 43 2.76	490 92 5.9	NA	NA	NA	NA
4401			181	0.31	63 17.1 9.46	55 28 16.5	67 34 18.78	NA	NA	NA	NA
4402			74.4	0.78	88 19.4 26.0	68 30 40.32	165 60 67.2	NA	NA	NA	NA
	4403		198	0.83	90 19.6 9.85	89 30.6 16.4	176 63 26.77	16 17 8.69	22 19 9.80	29 21 10.61	38 24 12.12
4404			407	1.00	96 20 4.91	70 32 7.66	200 65 13.61	NA	NA	NA	NA

[a]Environmental Protection Agency, 1980. NA = not available from this reference.

[b]All costs in 1980 dollars.

[c]Mine/Mill Code Index used in the Development Document for Effluent Limitations Guidelines and Standards of Performance for the Ore Mining and Dressing Point Source Category.

[d]Capital cost ($1000)

[e]Annual cost ($1000)

[f]Cost: $/ton or ore mined

Table 8-53. COSTS FOR THE ALUMINUM ORE PROCESSING INDUSTRY FOR VARIOUS TYPES OF WATER TREATMENT TECHNOLOGIES TO MEET THE BAT STANDARDS[a,b]

					Treatment technologies and costs		
Mine	Mill	Mine/Mill	Ore production 1000 tons/yr	Water discharged (MGD)	Secondary settling	Flocculation	Mixed media filter
5101[c]			1200	1.9	120[d]	77	340
					22.4[e]	37	75
					1.87[f]	3.08	6.25
5102			872	3.67	152	85	546
					25.0	47	102
					2.96	5.39	11.7

[a] Environmental Protection Agency, 1980.

[b] All costs in 1980 dollars.

[c] Mine/Mill Code Index used in the Development Document for Effluent Limitations Guidelines and Standards of Performance for the Ore Mining and Dressing Point Source Category.

[d] Capital cost ($1000).

[e] Annual cost ($1000).

[f] Cost: $/ton or ore mined.

Table 8-54. COSTS FOR THE FERROALLOY ORE PROCESSING INDUSTRY FOR VARIOUS TYPES OF WATER TREATMENT TECHNOLOGIES TO MEET THE BAT STANDARDS[a,b]

Mine	Mill	Mine/Mill	Ore production 1000 tons/yr	Water discharged (MGD)	Treatment technologies and costs						
					Secondary settling	Flocculation	Mixed media filter	Recycle 25%	Recycle 50%	Recycle 75%	Recycle 100%
	6101[c]		6283	2.90	140[d] 24[e] 0.38[f]	82 43 0.68	480 92 1.46	32 23 0.36	47 28 0.44	62 33 0.52	80 38 0.60
	6102		15,430	2.90	140 24 0.16	82 43 0.28	480 92 0.60	32 23 0.15	47 28 0.18	62 33 0.21	80 38 0.24
6103			2425	2.87	140 24 0.99	82 43 1.77	480 90 3.71	NA	NA	NA	NA
6104			705	8.71	230 32 4.54	97 77 10.92	1071 182 25.82	NA	NA	NA	NA
6107			361	5.54	180 28 7.76	90 56 15.51	750 140 38.78	NA	NA	NA	NA

[a] Environmental Protection Agency, 1980. NA = not available from this reference.

[b] All costs in 1980 dollars.

[c] Mine/Mill Code Index used in the Development Document for Effluent Limitations Guidelines and Standards of Performance for the Ore Mining and Dressing Point Source Category.

[d] Capital cost ($1000)

[e] Annual cost ($1000).

[f] Cost: $/ton or ore mined.

Table 8-55. COSTS FOR THE URANIUM/VANADIUM ORE PROCESSING INDUSTRY FOR VARIOUS TYPES OF WASTE TREATMENT TECHNOLOGIES TO MEET THE BAT STANDARDS[a,b]

					Treatment technologies and costs						
Mine	Mill	Mine/Mill	Ore production 1000 tons/yr	Water discharged (MGD)	Secondary settling	Flocculation	Mixed media filter	Recycle 25%	50%	75%	100%
9401[c]			750	0.85	90[d] 19.5[e] 2.60[f]	68 30 4.00	180 52 6.93	NA	NA	NA	NA
	9401		1270	1.86[g]	120 22 1.72	NA	NA	NA	NA	NA	60 30 2.36
	9402		2409	1.94[g]	120 22 0.91	NA	NA	NA	NA	NA	60 30 1.25
	9403		274	0.41[g]	74 18 6.57	NA	NA	NA	NA	NA	25 30 7.3
9437			96	5.03	180 28 29.17	90 54 56.25	700 130 85.13	NA	NA	NA	NA
	9405		439	1.00	96 20 4.55	NA	NA	NA	NA	NA	40 26 5.92

[a] Environmental Protection Agency, 1980. NA = not available from this reference.

[b] All costs in 1980 dollars.

[c] Mine/Mill Code Index used in the Development Document for Effluent Limitations Guidelines and Standards of Performance for the Ore Mining and Dressing Point Source Category.

[d] Capital cost ($1000).

[e] Annual cost ($1000).

[f] Cost: $/ton or ore mined.

[g] No point discharge - flow indicated is equal to volume discharged to treatment or recycle system.

SELECTED REFERENCES FOR TABLE 8-37

A. Aluminum

Peters, F. A. and J. Johnson. 1974. Revised and Updated Cost Estimates for Producing Alumina from Domestic Raw Materials. United States Bureau of Mines Information Circular 8648. Washington, D.C. 58 p.

B. Copper

Bennett, H. J. and L. Moore. 1973. An Economic Appraisal of the Supply of Copper from Primary Domestic Sources. United States Bureau of Mines Information Circular, 8598. Washington, D.C. 65 p.

Dayton, S. H. 1980. This Month in Mining – New and Expanding Mines and Plants. Engineering and Mining Journal, 181(3):39-63.

Dayton, S. H. 1980. This Month in Mining – Benguet's Dizon Copper Project Goes on Stream. Engineering and Mining Journal, 181(2):36-39.

Dayton, S. H. 1975. This Month in Mining – Hecla Mining is Coming into Production at Lake Shore. Engineering and Mining Journal, 176(11):37.

C. Gold

Dayton, S. H. 1980. This Month in Mining – New and Expanding Mines and Plants. Engineering and Mining Journal, 181(3):55.

Li, T. M. 1980. This Month in Mining – U.S. and International Minerals News Brief. Mining Engineering 32(1):17.

Skillings, D. N. 1980. Atlas Begins Output at Masbate Gold Mine. Skillings' Mining Review, 69(2):5.

Skillings, D. N. 1980. Freeport Minerals Reports Record Earnings. Skillings' Mining Review, 69(9):12.

Skillings, D. N. 1980. IU International to Develop Gold Mine. Skillings' Mining Review, 69(38):13.

D. Iron

Peterson, O., R. J. Michaelson, and H. J. Volta. 1970. Evaluating the Economic Availability of Mesabi Range Taconite Iron Ore with Computerized Models. United States Bureau of Mines Information Circular 8480. Washington, D.C. 60 p.

(continued)

D. Iron (continued)

Dayton, S. H. 1978. This Month in Mining - New and Expanding Mines and Plants. Engineering and Mining Journal, 179(10):25-33.

Dayton, S. H. 1975. This Month in Mining - New and Expanding Mines and Plants. Engineering and Mining Journal, 176(10):36.

E. Lead/Zinc

Cammarota, V. A., U.S. Bureau of Mines. 1980. Telephone conversation with M. Buckwalter, TRW. September 17. Capital cost information for zinc mine and mill.

Dayton, S. H. 1980. This Month in Mining - West Fork Will be First New U.S. Lead/Zinc Mine Since 1974. Engineering and Mining Journal, 181(4):41.

Dayton, S. H. 1980. This Month in Mining - St. Joe will Develop a New Mine and Mill at Virburnum, Missouri. Engineering and Mining Journal, 181(6):43.

Rathjen, J. U.S. Bureau of Mines. 1980. Telephone conversation with M. Buckwalter, TRW. September 17. Capital cost information for lead mine and mill.

F. Molybdenum

Kummer, J., U.S. Bureau of Mines. 1980. Telephone conversation with E. Monnig, TRW. September 16. Capital cost information for molybdenum mine and mill.

Li, T. M. 1980. U.S. and International Mineral News Briefs - U.S. Borax and Chemical Corporation. Mining Engineering 32(2):148.

Schickner, B.C. 1980. U.S. and International Mineral News Briefs - Standard Oil Company (Indiana). Mining Engineering 32(9):1322.

G. Nickel

Sibley, S., U.S. Bureau of Mines. 1980. Telephone conversation with M. Buckwalter, TRW. September 17. Capital cost information for nickel mine and mill.

H. Silver

Drake, H. J., U.S. Bureau of Mines. 1980. Telphone conversation with M. Alexander, TRW. September 25. Capital cost information for silver mine and mill.

Li, T. M. 1980. Industry Newswatch – Asarco's West Fork Lead Mine Sets 1983 Startup Date. Mining Engineering 32(4):377.

Schickner, B. C. 1980. U.S. and International Mineral News Briefs – Wallace Diamond Drilling Company. Mining Engineering 32(9):1320.

I. Titanium/Zirconium

Whittle, E., Humphreys Mining Co. 1980. Telephone conversation with E. Monnig, TRW. December 12. Capital Cost Information for Titanium/ Zirconium Mines and Mills.

J. Tungsten

Stafford, P., U.S. Bureau of Mines. 1980. Telephone conversation with M. Alexander, TRW. September 25. Capital cost information for tungsten mine and mill.

Larson, L. P. et al. 1971. Cost Analysis for Various Tungsten Mines and Mills. United States Bureau of Mines Information Circular 8500. Washington, D.C. 65 p.

K. Uranium

Klemenic, J., Director Supply Analysis Division, U.S. Department of Energy. 1979. Uranium Production Capability in the United States, p. 205-229.

Pittman, R., Department of Energy. 1980. Telephone conversation with M. Alexander, TRW. September 22. Capital cost information for uranium mine and mill.

8.3 REFERENCES FOR CHAPTER 8

Bennett, H. J. and L. Moore. 1973. An Economic Appraisal of the Supply of Copper from Primary Domestic Sources. United States Bureau of Mines Information Circular 8598. Washington, D.C. 65 p.

Bureau of Mines. 1980. Mineral Commodity Summaries. 200 p.

Butterman, W.C., Bureau of Mines, 1981. Telephone conversation with E. Monnig, TRW. January 8. Price information for metallic mineral processing concentrates.

Cammarota, V.A., Bureau of Mines. 1981. Telephone conversation with M. Buckwalter, TRW. January 7. Price information for metallic mineral processing concentrates.

Dayton, S. H. 1979. Engineering and Mining Journal Markets. Engineering and Mining Journal, 180:(5)19-25.

Environmental Protection Agency. 1973. Background Information for Proposed New Source Performance Standards: Asphalt Concrete Plants, Iron and Steel Plants,...Volume 1. Publication No. APTD-135a. Research Triangle Park, North Carolina. p. 61.

Environmental Protection Agency. 1974a. Background Information for New Source Performance Standards: Primary Copper, Zinc, and Lead Smelters. Volume 1: Proposed Standards. EPA-450/2-74-002a. Research Triangle Park, North Carolina. pp. 6-1 to 6-139.

Environmental Protection Agency. 1974b. Background Information for Standards of Performance: Primary Aluminum Industry. Volume 1: Proposed Standards. EPA 450/2-74-020a. Research Triangle Park, North Carolina. 97 p.

Environmental Protection Agency. 1974c. Background Information for Standards of Performance: Electric Submerged Arc Furnaces for Production of Ferroalloys. Volume 1: Proposed Standards. EPA 450/2-74-018a. Research Triangle Park, North Carolina. 147 p.

Environmental Protection Agency. 1974d. Background Information for Standards of Performance: Electric Arc Furnaces in the Steel Industry. Volume 1: Proposed Standards. EPA 450/2-74-017a. Research Triangle Park, North Carolina. 155 p.

Environmental Protection Agency. 1978. Economic Impact Assessment for the National Ambient Air Quality Standard for Lead. Office of Air Quality Planning and Standards. Research Triangle Park, North Carolina. p. 56.

43 Federal Register 52952. Occupational Exposure to Lead Attachments to the Preamble for the Final Standard. Occupational Safety and Health Administration. Washington, D.C. Office of the Federal Register. November 21, 1978.

Hough, Ruth, Bureau of Mines. 1981. Telephone conversation with M. Buckwalter, TRW. January 7. Price information for metallic mineral processing concentrates.

Kurtz, H., U.S. Bureau of Mines. 1980. Telephone conversation with M. Buckwalter, TRW. October 16. Capital costs for alumina plants.

Neveril, R. B. 1978. Capital and Operating Costs of Selected Air Pollution Control Systems. Gard, Inc., Niles, Illinois. EPA-450/5-80-002.

Peters, M. S. and K. D. Timmerhaus. 1968. Plant Design and Economics for Chemical Engineers. New York, McGraw-Hill. p. 90-142.

Rathjen, J., Bureau of Mines. 1981. Telephone conversation with M. Buckwalter, TRW. January 7. Price information for metallic mineral processing concentrates.

Singmaster, D. and S. Breyer. 1973. Air Pollution Control in the Primary Aluminum Industry. Contract No. CPA 70-21 for the Environmental Protection Agency. Research Triangle Park, North Carolina. pp. 40 to 53.

Valerioti, F., Ducon Company. 1979. Telephone conversation with J. Oatway, GCA Technology Division. October 22 and 24. Capital cost information of the Ducon W-4 Scrubber.

Weaver, J. B. 1973. Cost and Profitability Estimation. In: Chemical Engineer's Handbook, 5th Edition. Perry, R. H. (ed.). New York, McGraw-Hill. p. 25-1 through 25-47.

9. ECONOMIC IMPACT

9.1 INDUSTRY CHARACTERIZATION

As discussed in Chapter 3, the products of the metallic mineral industries range from mineral concentrates to complex compounds to pure metals. The metals included in these industries under discussion, along with the product of each type of processing plant, are listed in Table 9-1. Because of the diversity within the industries, each metal will be treated separately in this profile.

Unless otherwise noted, information on each metal was obtained from the Mineral Commodity Profiles and the Mineral Commodity Summaries (both published by the U.S. Bureau of Mines). The specific references for these two sources are presented under the individual metal statistical tables. Estimates for capacity for new growth were based on an annual survey of mine and plant expansions that appeared in the Engineering and Mining Journal (January 1980) and on personal communications with industry and U.S. Bureau of Mines personnel. The information provided in Section 8.1 (cost of control) and in Section 9.1 form the basis for formal analyses of the economic impact of regulatory alternatives on the various metallic mineral processing industries. These analyses are presented in Section 9.2.

Table 9-1. METALLIC MINERAL PROCESSING PRODUCTS

Metal	Process product
Aluminum	Alumina (aluminum oxide)
Copper	25 percent copper sulfide concentrate
Gold	Refined metal often combined with silver
Iron	Taconite pellets (∿60 to 65 percent iron)
Lead/Zinc	90 to 95 percent lead and zinc sulfide concentrates
Molybdenum	90 to 95 percent molybdenum sulfide concentrate
Silver	Refined metal often combined with gold (dore)
Titanium/Zirconium (sand-type ore)	95 percent ilmenite plus zircon concentrate
Tungsten	65 percent tungsten oxide concentrate
Uranium	Yellowcake (90+ percent uranium oxide, U_3O_8)

9.1.1 Aluminum

Aluminum is made from alumina which is produced when bauxite is processed. This chapter is concerned with the processing of bauxite into alumina; the reduction of alumina into aluminum has been covered elsewhere (see Section 8.2). The United States is the world's largest consumer of aluminum, but domestic producers must depend on imports of bauxite and alumina to meet over 90 percent of their demand for raw material as shown in Table 9-2. The major exporters of bauxite for use in the U.S. are Guinea, Jamaica, and Surinam. Many bauxite mines are captive operations owned by U.S. processers, and so the price data provided by the U.S. Bureau of Mines in Table 9-2 can only be estimates.

There are nine active bauxite processing operations in the United States located primarily in the states of Texas and Louisiana because of the proximity of this region to traditional sources of imported bauxite (see Tables 9-3 and 9-4). The processing plants are typically part of large integrated companies. Frequently the product of these processing plants (alumina) is shipped to reduction plants in other parts of the country which have cheaper or more abundant electrical energy. Eighty-eight percent of bauxite is used to produced aluminum metal with the remainder used in refractories and/or chemicals and abrasives (see Table 9-5).

The domestic aluminum ore mining industry will expand at a very slow rate and imports of aluminum ore and alumina will account for an increasing share of the domestic market. Two new bauxite/alumina processing plants are projected to be built by 1985 with ore capacities of 140 and 270 Mg per hour. These additions represent an annualized growth rate of 2.1 percent for the bauxite/alumina processing capacity. These plants are expected to process bauxite containing approximately 22 percent aluminum.

Domestic aluminum production was approximately 5,300,000 Mg (5,800,000 tons) in 1978 (see Table 9-6), exceeding every metal except iron. The transportation, packaging, construction, and aerospace industries are increasing their use of aluminum as a substitute for steel (see Table 9-7). Aluminum has many of the structural qualities of steel but at the same time is much lighter. These qualities make aluminum particularly important to the transportation industry's effort to increase fuel efficiency by making lighter vehicles.

Possible substitutes for aluminum include wood in the construction industry; plastics, titanium, steel, and graphite in transportation; copper in the electrical industry; plastics, glass, and paper in the container industry; plastics and steel in appliances; and steel, magnesium, titanium, copper-nickel alloys and other composites in machinery. In the manufacturing process, however, substitution of materials often necessitates the purchase or modification of equipment. This not only means that the substituted material must offer improvements in cost and performance, but that such a change most likely would occur very slowly.

The price of aluminum in constant 1976 dollars, shown in Table 9-8, declined until 1974. In constant 1976 dollars, the 1977 price was identical to the 1954 price.

Table 9-2. PRODUCTION PROFILE: BAUXITE[a]

Parameters	Year 1974	1975	1976	1977	1978
Production: Mine, 1000 Mg (1,000 tons) as bauxite	1,980 (2,182)	1,800 (1,984)	1,989 (2,192)	2,013 (2,218)	1,620 (1,785)
Imports of bauxite for consumption, 1,000 Mg (1,000 tons) as bauxite	16,000 (17,632)	12,000 (13,224)	13,500 (14,877)	13,600 (14,987)	14,500 (15,979)
Imports of alumina, 1,000 Mg (1,000 tons) as alumina	3,290 (3,626)	3,182 (3,507)	3,288 (3,623)	3,760 (4,144)	4,000 (4,408)
Exports of bauxite, 1,000 Mg (1,000 tons) as bauxite	16 (18)	20 (22)	15 (17)	26 (29)	23 (25)
Exports of alumina, 1,000 Mg (1,000 tons) as alumina	927 (1,022)	934 (1,029)	1,050 (1,157)	856 (943)	878 (968)
Employment: domestic bauxite mines	350	350	350	350	325
alumina processing	-	-	-	-	7-8,000
Net import reliance[b] as a percent of apparent consumption	92	91	91	91	93
Price $ per Mg ($ per ton) of bauxite	5-15 (5-14)	5-15 (5-14)	5-15 (5-14)	5-15 (5-14)	5-15 (5-14)

[a]U.S. Bureau of Mines, 1980.

[b]Net import reliance = imports-exports+adjustments for Government and industry stock changes.

Table 9-3. BAUXITE INDUSTRY CHARACTERISTICS

Number of leading companies	3
Number of active operations	9
Value of processing plant output	$482.8 million
Percent of output controlled by leading companies	86
Major bauxite processing states	Texas, Louisiana
Ratio of bauxite to aluminum metal	4.5
Ratio of alumina to aluminum metal	2.0

Table 9-4. ALUMINUM ORE (BAUXITE) PROCESSING PLANTS (REFINERIES)[a]

Company	Plant	Location	Start-up[b] year	Ore grade[c] (%)	Other minerals	Ore processed mg/yr (Tons/yr)	Mill capacity[b,d] 10^3 Mg/yr (10^3 Tons/yr)
Aluminum Co. of America	Point Comfort Operations	Point Comfort, Texas	1949	20-25	-	NA	1,210 (1,334)
Aluminum Co. of America	Mobile Works	Mobile, Alabama	1938	24	-	NA	900 (992)
Aluminum Co. of America	Arkansas Operations	Bauxite, Arkansas	1952	NA	-	450,000-900,000 (500,000-1,000,000)	340 (375)
Kaiser Aluminum & Chemical Corp.	Baton Rouge Alumina Works	Baton Rouge, Louisiana	1943	21	-	NA	930 (1,025)
Kaiser Aluminum & Chemical Corp.	Gramercy Alumina Works	Gramercy, Louisiana	1958	21	-	NA	725 (799)
Reynolds Metals Company	Sherwin Alumina Plant	Gregory, Texas	1953	20-25	-	NA	1,256 (1,385)
Reynolds Metals Company	Hurricane Creek Alumina Plant	Saline County, Arkansas	1942	25	-	54,320-63,606 (59,860-70,094)	762 (840)
Martin Marietta Alumina Inc.	Kingshill Aluminum Plant	Kingshill, St. Croix, Virgin Islands	1967	20-25	-	NA	508 (560)
Ormet Corp.	Ascension Operations	Ascension County, Louisiana	1958	24	-	NA	544 (600)

[a] Mining Information Services, 1979.
[b] Stephenson, 1981.
[c] As aluminum (as estimated by Baumgardner, 1981).
[d] As alumina.
NA = Not available.

Table 9-5. PRODUCT USES: BAUXITE[a]

Product uses	Percent
Aluminum metal	88
Refractories, chemicals, abrasives, etc.	12

[a]U.S. Bureau of Mines, 1980.

Table 9-6. PRODUCTION PROFILE: ALUMINUM[a]

Parameters	Year 1974	1975	1976	1977	1978
Production 1,000 Mg (1,000 tons) as metal					
Primary (reduction plants)	4,448 (4,902)	3,519 (3,878)	3,856 (4,249)	4,118 (4,538)	4,355 (4,799)
Secondary (from old scrap)	276 (304)	306 (337)	371 (409)	455 (501)	499 (550)
Imports for consumption 1,000 Mg (1,000 tons) as metal	571 (629)	499 (550)	679 (748)	758 (835)	998 (1,100)
Exports 1,000 Mg (1,000 tons) as metal	475 (523)	399 (440)	439 (484)	373 (411)	435 (479)
Net import reliance as a percent of apparent consumption[b]	4	5	9	7	10
Employment:					
Primary reduction[c]	24,000	19,000	20,800	22,000	23,000
Secondary smelter[c]	4,100	4,000	4,200	4,200	4,300

[a]U.S. Bureau of Mines, 1980.

[b]Net imports reliance = imports-exports+adjustments for Government and industry stock changes.

[c]Estimate.

Table 9-7. PRODUCTS USES: ALUMINUM METAL[a]

Product uses	Percent
Building	25
Packaging	22
Transportation	23
Electrical	11
Consumer durables	8
Other	11

[a]U.S. Bureau of Mines, 1980.

Table 9-8. PRICE HISTORY: ALUMINUM[a]

Year	Actual prices $/kg	Actual prices $/lb	Based on constant 1976 dollars $/kg	Based on constant 1976 dollars $/lb
1954	0.49	0.22	1.08	0.49
1955	0.53	0.24	1.17	0.53
1956	0.57	0.25	1.21	0.56
1957	0.62	0.28	1.28	0.58
1958	0.60	0.27	1.21	0.55
1959	0.60	0.27	1.19	0.54
1960	0.57	0.26	1.12	0.51
1961	0.57	0.26	1.10	0.50
1962	0.53	0.24	1.01	0.46
1963	0.51	0.23	0.95	0.43
1964	0.53	0.24	0.97	0.44
1965	0.55	0.25	0.99	0.45
1966	0.55	0.25	0.97	0.44
1967	0.55	0.25	0.93	0.42
1968	0.57	0.26	0.93	0.42
1969	0.60	0.27	0.93	0.42
1970	0.64	0.29	0.95	0.43
1971	0.64	0.29	0.88	0.40
1972	0.57	0.26	0.77	0.35
1973	0.55	0.25	0.71	0.32
1974	0.75	0.34	0.86	0.39
1975	0.88	0.40	0.93	0.42
1976	0.99	0.45	0.99	0.45
1977	1.15	0.52	1.08	0.49
Oct.[b] 1979	1.43	0.65	--	--

[a]Average annual price of aluminum metal from Stamper and Kurtz (1978).

[b]Average price for October from Engineering and Mining Journal (1979).

9.1.2 Copper

In 1978, the United States was the world's leading producer and consumer of copper. Many copper producers are highly integrated with all operations from mining through smelting and fabrication owned by one corporation. At many plants all operations from processing of ore through the fabrication of final products are located on the mine site. As shown in Table 9-9, approximately 67 percent of the domestic copper supply comes from domestic mines, 21 percent from old scrap, and 12 percent from imports. As shown in Table 9-10, the copper market has undergone wide price fluctuations between 1973 and 1979.

Product uses of copper are profiled in Table 9-11. Over one-half of domestic consumption went into electrical applications such as motors, generators, power distribution, industrial controls, communications equipment, and residential wiring. Non-electrical applications include roofing, plumbing, decorative items, heat exchangers, shell casings, instruments, household utensils, jewelry, and coinage.

Although copper is the preferred material for numerous uses, aluminum, plastics, steel, and other materials are possible substitutes in some cases. Aluminum has replaced copper to some degree in insulated power cable and, to a great extent, in bare conductor applications. Aluminum may also replace copper in the manufacture of automobile radiators.

As summarized in Table 9-12, the eight leading copper companies control approximately three-quarters of the total output. Most companies are highly integrated with operations from mining through smelting and refined metal production often located at one site. Table 9-13 lists 41 copper processing plants, located primarily in Arizona, New Mexico, Utah, and Nevada.

The demand for copper is expected to increase at an annual rate of approximately 3 percent through 1985. Ore capacity is expected to increase at an annualized rate of 1 percent through 1985. New facilities are projected to include one 540 and one 140 Mg per hour plant. The trend in the industry is to utilize lower grade ore as richer deposits become exhausted. Ore grades for larger new processing plants will probably average from 0.4 to 0.5 percent copper while smaller operations will be tailored to less extensive but richer deposits (1 to 2 percent copper). Both new plants were assumed to process 0.45 percent copper ore. The recovery of other minerals, such as molybdenum, zinc, silver, and uranium, will continue to play a significant role in the profitability of some operations.

The development of the copper deposits in Minnesota will significantly increase the domestic supply of nickel with the recovery of this metal as a byproduct from new copper operations. The recoverable nickel reserves in these operations are estimated at 5 million tons of metal. The deposits vary in concentration from 0.3 to over 0.6 percent copper and from 0.1 to 0.2 percent nickel.

AMAX has conducted active exploration and has tentative plans for a pilot plant operation in Minnesota. Commercial development is possible before 1990. A single economical commercial development is expected to require 20 million tons of ore per year (2,100 Mg/hour) from an open pit operation processing ore at 0.45 percent copper and 0.15 percent nickel. These operations are expected to be relatively high cost operations due to the very hard gangue from which the mineral must be recovered (Veith, 1980). Because the nickel concentrations are so low, nickel could not be economically recovered except as a byproduct of copper in these operations. For this reason separate analyses of the impact of emission control alternatives on the nickel industry was not performed. Economic impacts on copper-nickel operations would be less severe than on operations recovering only copper.

Demand for nickel is expected to increase at 3 percent per year through 1985. The United States imports most of its nickel from Canada. Vital to the iron and steel industry, nickel's greatest value is in alloys with other elements, where it provides strength and corrosion resistance. These alloys include stainless steel, superalloys, nickel-copper alloys, and copper-nickel alloys. The domestic nickel ore processing industry currently consists of one integrated processing plant located in Oregon and operated by Hanna Mining Company. AMAX has a nickel refinery located in Louisiana, but it produces nickel metal from imported intermediate (matte) materials.

Table 9-9. PRODUCTION PROFILE: COPPER[a]

Parameters	Year 1974	1975	1976	1977	1978
Production: Mine 1,000 Mg (1,000 tons) as metal	1,449 (1,597)	1,282 (1,413)	1,457 (1,606)	1,364 (1,503)	1,358 (1,497)
Refined copper: 1,000 Mg (1,000 tons) as metal					
Primary	1,501 (1,654)	1,309 (1,443)	1,396 (1,538)	1,357 (1,495)	1,449 (1,597)
Secondary	451 (497)	312 (344)	340 (375)	349 (385)	420 (463)
Imports for consumption 1,000 Mg (1,000 tons) as metal:					
Total	573 (631)	246 (271)	425 (468)	396 (436)	532 (586)
Refined	284 (313)	130 (143)	346 (381)	351 (387)	403 (444)
Exports 1,000 Mg (1,000 tons) as metal					
Total	173 (191)	212 (234)	156 (172)	113 (125)	178 (196)
Refined	115 (127)	156 (172)	102 (112)	47 (52)	92 (101)
Employment: mine and mill	36,300	33,500	29,700	29,400	26,400
Net import reliance[b] as a percent of apparent consumption	20	c	12	13	20

[a]U.S. Bureau of Mines, 1980.

[b]Net import reliance = imports-exports+adjustments for Government and industry stock changes.

[c]Net exports.

Table 9-10. PRICE HISTORY: COPPER[a]

Year	Actual prices ¢/kg	Actual prices ¢/lb	Based on constant 1978 dollars ¢/kg	Based on constant 1978 dollars ¢/lb
1958	58.0	26.3	133.6	60.6
1959	67.7	30.7	152.3	69.1
1960	70.8	32.1	156.5	71.0
1961	66.1	30.0	145.1	65.8
1962	67.9	30.8	146.4	66.4
1963	67.9	30.8	144.2	65.4
1964	71.9	32.6	150.4	68.2
1965	78.0	35.4	159.6	72.4
1966	80.7	36.6	159.8	72.5
1967	85.1	38.6	163.6	74.2
1968	93.0	42.2	171.3	77.7
1969	105.6	47.9	185.2	84.0
1970	128.3	58.2	213.4	96.8
1971	114.6	52.0	181.7	82.4
1972	112.9	51.2	171.5	77.8
1973	131.2	59.5	188.5	85.5
1974	170.4	77.3	223.3	101.3
1975	141.5	64.2	169.3	76.8
1976	153.4	69.6	174.6	79.2
1977	147.3	66.8	158.3	71.8
1978	146.6	66.5	146.6	66.5
1979[b]	199.5	90.5	--	--
1979[c]	218.5	99.1	--	--

[a]Average annual price of copper metal from Schroeder (1979).

[b]Average through May 31, 1979.

[c]Average price for October from Engineering and Mining Journal (1979).

Table 9-11. PRODUCT USES: COPPER[a]

Product uses	1978 (percent)	1979 (percent)
Electrical	58	58
Construction	19	18
Industrial machinery	9	9
Transportation	8	9
Other	6	6

[a]U.S. Bureau of Mines, 1980.

Table 9-12. INDUSTRY CHARACTERISTICS: COPPER

Number of leading companies	8
Number of active operations	34 (6 temporarily inactive, 1 under construction)
Percent of capacity controlled by leading companies	76
Value of processing plant output (as 95 percent concentrate)	$220.8 million
Major processing states	Arizona, Nevada, Utah, New Mexico
Ratio of ore to product	Range: 200 - 250

Table 9-13. COPPER ORE PROCESSING PLANTS[a]

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Anaconda Co. Mineral Resources Group	Anaconda Reduction Dept.	Deer Lodge County, Montana	NA	NA	--	NA	11,794 (13,000)	Flotation
Anaconda Co. Mineral Resources Group	Butte Operations	Silver Bow County, Montana	1955	0.64	Silver, Gold	17,000,000 (18,734,000)	45,360 (50,000)	Flotation
Anaconda Co. Mineral Resources Group	Carr Fork	Tooele, Utah	1979	NA	--	NA	9,000 (10,000)	NA
Anamax Mining Co.	Twin Buttes Operations	Sahuarita, Arizona	NA	NA	Molybdenum	5,824,186 (6,420,000)	36,288 (40,000)	Flotation
Asarco Inc.	Mission Unit	Sahuarita, Arizona	1961	0.60	Silver, Molybdenum	7,107,713 (7,832,700)	20,412 (22,500)	Flotation
Asarco Inc.	Silver Bell Unit	Silver Bell, Arizona	1951	NA	Molybdenum, Silver	EE[b]	9,982 (11,000)	Flotation
Asarco Inc.	Sacaton Unit	Casa Grande, Arizona	1972	0.68	Molybdenum	3,764,855 (4,150,000)	9,979 (11,000)	Flotation
Asarco Inc.	San Xavier Unit	Sahuarita Arizona	1973	0.80	Silver,	EE[b]	NA	Leaching
Cities Service Co.	Pinto Valley Operations	Miami, Arizona	1974	0.49	--	GG[b]	43,100 (47,500)	Flotation
Cities Service Co.	Copperhill Operations	Copperhill, Tennessee	1899	NA	Iron, Zinc	1,898,710 (2,093,328)	7,530 (8,300)	Flotation

(continued)

Table 9-13. Continued

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Cyprus Mines Corp.	Cyprus Bagdad	Bagdad, Arizona	1940	0.50	Molybdenum, Silver	12,247,120 (13,500,000)	36,288 (40,000)	Flotation
Cyprus Pima Mining[c]	Pima Operations	Tucson, Arizona	1957	0.468	--	--	52,164 (57,500)	Flotation
Duval Corp.	Mineral Park Property	Kingman, Arizona	1964	0.262	Molybdenum, Silver	5,911,276 (6,514,226)	16,329 (18,000)	Flotation
Duval Corp.	Esperanza Property	Sahuarita, Arizona	1959	NA	Molybdenum, Silver	EE[b]	17,237 (19,000)	Flotation
Duval Corp.	Sierrita Property	Sahuarita, Arizona	1971	NA	Molybdenum, Silver	30,441,804 (33,556,000)	83,462 (92,000)	Flotation
Duval Corp.	Battle Mountain Properties	Battle Mountain Nevada	1967	0.62	Gold, Silver	707,611 (780,000)	4,173 (4,600)	Flotation
Earth Resources Co.[c]	Nacimiento Copper Mine	Cuba, New Mexico	1971	0.7	Silver	c	4,228 (4,660)	Flotation
Federal Resources[c] Corp.	Bonney-Miser's Chest and '85	Lordsberg, New Mexico	NA	NA	--	c	408 (450)	Flotation
Inspiration Consolidated Copper Company	Inspiration Division	Inspiration, Arizona	1915	0.7	Silver, Gold	EE[b]	18,144 (20,000)	Flotation
Inspiration Consolidated Copper Company	Christmas Division	Inspiration Arizona	1962	0.74	--	DD[b]	5,443 (6,000)	Flotation

(continued)

Table 9-13. Continued

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Kennecott Copper Corp., Metal Mining Division	Ray Mines Division	Hayden, Arizona	1955	0.9	--	GG[b]	24,494 (27,000)	Flotation
Kennecott Copper Corp., Metal Mining Division	Nevada Mines Division	McGill, Nevada	NA	0.74	--	DD[b]	19,505 (21,500)	Flotation
Kennecott Copper Corp., Metal Mining Division	Chino Mines	Hurley, New Mexico	1910	0.87	Molybdenum	EE[b]	20,865 (23,000)	Flotation
Kennecott Copper Corp., Metal Mining Division	Utah Copper Division	Salt Lake City, Utah	1906	0.61	Molybdenum, Gold, Silver	GG[b]	93,441 (103,000)	Flotation
Kerramerican, Inc.[c]	Blue Hill Joint Venture	Blue Hill, Maine	1972	1.1	Zinc	NA	907 (1,000)	NA
Keystone Wallace Resources	Minerals Division	Moab, Utah	1970	1.2	--	AA[b]	2,177 (2,400)	Leaching
Magma Copper Co.	San Manuel Division	San Manuel, Arizona	1956	0.7	Molybdenite, Gold and Silver Electrolytic Slimes	17,884,423 (19,714,000)	58,060 (64,000)	Flotation
Magma Copper Co.	Superior Division	Superior, Arizona	1910	4.5	--	889,050 (980,000)	2,903 (3,200)	Flotation
Micro Copper Corp.	Lisbon Valley Mine	Moab, Utah	1968	1.0	--	NA	227 (250)	Leach and Precipitation
Oracle Ridge Mining Partners	Oracle Ridge Project	Oracle, Arizona	1980	NA	--		41,731 (46,000)	NA

(continued)

Table 9-13. Continued

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Phelps Dodge Corp.	Copper Queen	Bisbee, Arizona	1885	NA	Gold, Silver	NA	18,144 (20,000)	Flotation
Phelps Dodge Corp.	Morenci Branch	Morenci, Arizona	1942	0.81	--	GG[b]	54,432 (60,000)	Flotation
Phelps Dodge Corp.	Morenci Branch/ Metcalf	Morenci, Arizona	1975	0.70	--	GG[b]	36,288 (40,000)	Flotation
Phelps Dodge Corp.	New Cornelia Branch	Ajo, Arizona	1917	0.64	--	FF[b]	30,845 (34,000)	Flotation
Phelps Dodge Corp.	Tyrone Branch	Tyrone, New Mexico	1969	0.78	--	GG[b]	45,360 (50,000)	Flotation
Ranchers Exploration & Development Corp.	Bluebird Mine	Miami, Arizona	1964	0.40	--	5,080 (5,600)	846 (933)	Solvent Extraction
San Pedro Mining Corp.	San Pedro Mine	Albuquerque, N.M.	NA	2.15	Gold, Silver	BB[b]	NA	NA
Toledo Mining Co.	OK Mine	Salt Lake City, Utah	NA	NA	--	NA	NA	NA
UV Industries, Inc.	Continental Mill & Shafts 2,3, and 4	Hanover, New Mexico	1967	NA	Zinc	466,075 (513,755)	7,258 (8,000)	Flotation
Vekol Copper	Vekol Hills Operations	Vekol Hills, Arizona	Under Const.	0.543	Molybdenum	Under Const.	18,000 (20,000)	NA

(continued)

Table 9-13. Concluded

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
White Pine Copper Co.	White Pine Operations	White Pine, Michigan	1953	1.3	Silver	EE[b]	22,680 (25,000)	Flotation

[a]Mining Information Services, 1979.

[b]AA = 907-9072 Mg (1,000-10,000 short tons).
BB = 9072-90,719 Mg (10,000-100,000 short tons).
CC = 90,719-453,597 Mg (100,000-500,000 short tons).
DD = 453,597-907,194 Mg (500,000-1,000,000 short tons).
EE = 907,194-9,071,940 Mg (1,000,000-10,000,000 short tons).
FF = 6,167,800-8,526,000 (6,800,000-9,400,000 short tons).
GG = Greater than 9,071,940 Mg (10,000,000 short tons).
NA = Not available.

[c]Temporarily inactive.

9.1.3 Gold

Gold's unique position in world history and in international financial markets has made the metal as valuable for an investment as for an industrial metallic mineral. Table 9-14 summarizes the product uses of gold. Gold's properties of chemical inertness, malleability, reflectiveness, and thermal and electrical conductivity are the basis for its industrial applications and use in jewelry and dentistry. The electronics industry (which is the major industrial consumer of gold) is, however, decreasing their use of gold due to its current high price. As shown in Table 9-15, the price of gold has risen dramatically from $1.17 per gram ($36.41 per troy ounce) in 1970 to a high of $25.72 per gram ($800 per troy ounce) in January 1980.

The United States mines and reclaims from scrap less than one-half the gold required by domestic fabricators (see Table 9-16). From 1973 to 1978, imported bullion came primarily from Canada, Switzerland, and the USSR.

Although gold use can be reduced by more efficient use and substitution, any substitute brings with it an impairment in performance. Platinum and palladium can be substituted in some instances, but consumers prefer gold. Silver has some of gold's qualities but has less resistance to corrosion. A titanium and chrome-based alloy has been developed for dental applications, but it lacks gold's malleability.

Table 9-17 presents industry characteristics and shows that the industry is dominated by four major companies. The gold industry is located primarily in Nevada, California, Colorado, South Dakota, and Washington. Table 9-18 lists 20 domestic gold ore processing plants.

In the United States, about 60 percent of domestic production comes from primary gold ores, with the remainder produced as a byproduct of copper and other base metals. Domestic lode gold mining has, in the past, been directed towards grades of ores having 0.3 troy ounces of gold per ton of ore or greater, but recent technology and higher gold prices have combined to permit exploitation of much lower grade ores in the range of 0.05 to 0.1 troy ounces per ton.

The demand for gold is expected to increase at an annual rate of 2.7 percent through 1985. If gold prices remain high, production is likely to decline temporarily, because high price levels allow mining of a greater proportion of lower grade ores. On the other hand, higher price levels should also encourage the expansion of existing mines and the opening of additional mines (Etheridge, 1980). Mine production and growth capacity are difficult to estimate through 1985. Two new plants are projected to be built before 1985; one plant at 68 Mg per hour capacity and one plant at 140 Mg per hour capacity. An ore grade of 0.2 troy ounces per ton of ore was assumed for these new plants.

Table 9-14. PRODUCT USES: GOLD[a]

Product uses	1978 (percent)	1979 (percent)
Jewelry and arts	56	58
Industrial (mainly electronic)	27	28
Dental	16	13
Small bars, etc., mainly for investment	1	1

[a]U.S. Bureau of Mines, 1980.

Table 9-15. PRICE HISTORY: GOLD[a]

Year	Actual prices		Based on constant 1977 dollars	
	$/gram	$/troy oz	$/gram	$/troy oz
1956	1.13	35.00	2.47	76.70
1957	1.13	35.00	2.38	73.91
1958	1.13	35.00	3.32	72.08
1959	1.13	35.00	2.28	70.88
1960	1.13	35.00	2.24	69.82
1961	1.13	35.00	2.21	68.89
1962	1.13	35.00	2.19	68.09
1963	1.13	35.00	2.16	67.22
1964	1.13	35.00	2.13	66.27
1965	1.13	35.00	2.09	65.06
1966	1.13	35.00	2.04	63.30
1967	1.13	35.00	1.97	61.29
1968	1.26	39.26	2.12	66.08
1969	1.33	41.51	2.14	66.66
1970	1.17	36.41	1.78	55.46
1971	1.33	41.25	1.93	60.09
1972	1.88	58.60	2.66	82.58
1973	3.14	97.81	4.20	130.52
1974	5.14	159.74	6.23	193.74
1975	5.19	161.49	5.76	179.17
1976	4.03	125.32	4.25	132.30
1977	4.77	148.31	4.77	148.31
1978[b]	5.92	184.00	--	--
1979[c]	12.62	392.73	--	--

[a]Average annual price of gold metal from Butterman (1978).

[b]First 6 months.

[c]Average price for October from Engineering and Mining Journal (1979).

Table 9-16. PRODUCTION PROFILE: GOLD[a]

Parameters	1974	1975	1976	1977	1978
	Year				
Production 1,000 kg (1,000 lbs) as metal					
Mine	35.1 (77.4)	32.7 (72.1)	32.7 (72.1)	34.2 (75.4)	30.2 (66.6)
Refinery:					
New (domestic as metal)	31.7 (69.9)	33.9 (74.7)	29.5 (65.0)	29.9 (65.9)	31.1 (68.6)
Secondary (including toll as metal)	59.1 (130.3)	84.0 (185.2)	77.8 (171.5)	76.2 (168.0)	96.4 (212.5)
General imports 1,000 kg (1,000 lbs) as metal	82.4 (181.7)	82.7 (182.3)	82.7 (182.3)	138.4 (305.1)	145.6 (321.0)
Exports 1,000 kg (1,000 lbs) as metal	17.7 (39.0)	83.7 (184.5)	89.6 (197.5)	218.0 (480.6)	176.0 (388.0)
Employment: mine and mill	2,600	3,000	3,200	3,200	3,200
Net import reliance[b] as a percent of apparent consumption	63	52	60	61	54

[a]U.S. Bureau of Mines, 1980.

[b]Net import reliance = imports-exports+adjustments for Government and industry stock changes.

Table 9-17. INDUSTRY CHARACTERISTICS: GOLD

Number of leading companies	4
Number of active operations	17 (3 inactive)
Percent of capacity controlled by leading companies	70
Value of processing plant output (as metal)	$415.4 million
Major processing states	Nevada, South Dakota, Utah, Arizona
Ratio of ore to product	Range: 100,000 - 640,000

Table 9-18. GOLD ORE PROCESSING PLANTS[a]

Company	Plant	Location	Start up date	Ore grade (%)[c]	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Carlin Gold Mining Co.	Eureka Operations	Carlin, Nevada	1964	.230	Mercury	EE[b]	2,268 (2,500)	Cyanidation
Cash Industries, Inc.	Milford Operations	Milford, California	NA	NA	Silver	240,406 (265,000)	NA	NA
Coronado Silver Corp.[d]	Platoro Project	Rollinsville, Colorado	1966	156g/Mg (5 oz./ton)	Silver	BB[b]	159 (175)	Flotation
Cortez Gold Mines[d]	Cortez Operations	Cortez, Nevada	1969	NA	--	NA[d]	1,996 (2,200)	CCD Cyanidation
DMEX International	American Hill Operations	Forest Hills, California	1977	.21	Tungsten	BB[b]	907 (1,000) to be expanded to 1,814 (2,000)	Sluice, jigs tables, flotation
Day Mines, Inc.	Republic Unit	Republic, Washington	NA	NA	Silver	18,144 (20,000)	227 (250)	NA
Grizzly Corporation	Spring Valley Venture	Reno, Nevada	1979	NA	--	NA	NA	Gravity
Hendricks Mining Co., Inc.	Nederland Operations	Nederland, Colorado	1974	NA	Silver, lead, zinc, copper	4,536 (5,000)	100 (110)	Selective flotation
Homestake Mining Co.	Black Hills Operations	Lead, South Dakota	1876	.193	Silver, lead, zinc	EE[b]	4,990 (5,500)	Cyanidation
Idaho Mining Corp.	Eureka Windfall Gold Mine	Eureka, Nevada	1974	1.25 g/M (.04 oz/ton)	Silver	BB[b]	NA	Cyanide-heap leach

(continued)

Table 9-18. Continued

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Inland Empire Milling & Mining Corporation	San Bernadino Plants	Verdermont, California	1970	NA	Silver	BB[b]	73 (80)	Ion Exchange
Intermountain Exploration Co.	Comstock Gold Exploration	Virginia City, Nevada	NA	NA	Silver	Under construction		Heap cyanide leach
Intermountain Exploration Co.	Intermountain Limited Partners	Boulder City, Nevada	1976	NA	Silver, Copper	43,360 (50,000)	NA	Heap leach (Cyanide)
Jem Trac Mines, Inc.	Placer Mining	Hayfork, California	1978	NA	Silver	NA	NA	Screening concentrating tables, spiral concentrator, amalgamation, retort.
Little Squaw Gold Mining Co.	Chandalar Operations	Chandalar District, Alaska	NA	NA	Silver	BB[b]	91 (100)	NA
Rico Argentine Mining Co.[d]		Rico, Colorado	1974	NA	Silver	NA[d]	160 (175)	Crushing, grinding, flotation
Smoky Valley Mining Co.	Round Mountain Operation	Round Mountain, Nevada	1977	1.88g/Mg (.06 oz/ton)	Silver	NA	NA	Leaching
Standard Metals Corp.	Silverton Operations	Silverton, Colorado	NA	NA	Zinc, lead, silver, copper	CC[b]	907 (1,000)	Flotation
Standard Slag Co.	Atlanta Mine	Pioche, Nevada	NA	NA	Silver	CC[b]	454 (500)	Crushing, grinding, cyanidation

(continued)

Table 9-18. Concluded

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
West Coast Oil & Gas Corp.	Gooseberry Operations	Sparks, Nevada	1977	NA	Silver	63,504 (70,000)	318 (350)	Flotation-cyanide concentrates

[a]Mining Information Services, 1979.

[b]Mine tonnage.
BB = 9072-90,719 Mg (10,000-100,000 short tons).
CC = 90,719-453,597 Mg (100,000-500,000 short tons).
EE = 907,194-9,071,940 Mg (1,000,000-10,000,000 short tons).

NA = Not available.

- = None.

[c]Values as percentage unless otherwise noted.

[d]Temporarily inactive.

9.1.4 Iron Ore

Iron is the most widely used metal in the world. Although the United States is the fourth largest producer of iron ore, imports have grown from less than 5 percent of demand in 1953 to about one-third of the total requirement in 1977 (see Table 9-19). Over one-half of the 1977 imports came from mines owned, operated, or partially owned by United States mining and steel companies.

The domestic iron ore mining and processing industries are dominated by large, integrated steel companies. As shown in Tables 9-20 and 9-21, about 85 percent of total iron ore output in 1977 was produced by 18 out of 45 mines, operated by 8 out of 34 companies. Table 9-21 lists 41 iron ore processing plants. Most are located in Minnesota or Michigan.

Almost all iron ore mined today is beneficiated before shipment. After beneficiation, iron ore particles are usually agglomerated before use in blast furnaces. Agglomeration usually involves sintering and pelletizing. The average grade of crude ore (iron ore in its natural state) is 36 percent and the iron content of the final product of mining and beneficiation operations is typically raised to between 60 and 65 percent.

Table 9-22 lists product uses of iron and steel. In some cases aluminum may take iron's place as a structural support, as a packaging material, and in the transportation industry. Plastics and other polymeric materials have also replaced some uses of steel in the automobile industry due to the recent emphasis on lighter, more fuel-efficent cars.

Table 9-23 presents the price history of iron. Prices have shown a steady rise since the mid-seventies.

The expansion of capacity for the iron ore processing industry is directly related to the financial condition and planned production increases of the steel industry. The steel industry is expected to maintain a good growth rate through 1985, with demand for iron increasing at an annual rate of 2.5 percent. Two new iron ore processing plants are projected between now and 1985, one at 1,100 Mg per hour and one at 2,200 Mg per hour. Crude ore grades were assumed to be 36 percent as iron.

Table 9-19. PRODUCTION PROFILE: IRON ORE[a]

Parameters	Year 1974	1975	1976	1977	1978
Production million Mg (million tons) as metal	85.8 (94.6)	80.2 (88.4)	81.3 (89.6)	56.7 (62.5)	81.8 (90.1)
Imports for consumption million Mg (million tons) as metal	48.8 (53.8)	47.7 (52.6)	45.1 (49.7)	38.5 (42.4)	33.5 (36.9)
Exports million Mg (million tons) as metal	2.3 (2.5)	2.5 (2.8)	2.9 (3.2)	2.1 (2.3)	3.8 (4.2)
Employment: mine and concentrating plant (average)	20,000	19,900	20,500	20,200	19,700
Net import reliance[b] as a percent of apparent consumption (iron in ore)	37	39	31	48	29

[a]U.S. Bureau of Mines, 1980.

[b]Net import reliance = imports-exports+adjustments for Government and industry stock changes.

Table 9-20. INDUSTRY CHARACTERISTICS: IRON

Number of leading companies	8
Number of active operations	36 (5 temporarily inactive)
Percent of capacity controlled by leading companies	85
Value of processing plant output (as taconite pellets)	$88.1 million
Major processing states	Minnesota, Michigan
Ratio of ore to product	2.8

Table 9-21. IRON ORE PROCESSING PLANTS[a]

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
CF&I Steel Corp.	Sunrise Mine	Sunrise, Wyoming	NA	54	--	DD[b]	3,629 (4,000)	Gravity Separation
Cleveland-Cliffs Iron Co.	Canisteo Operations	Taconite, Minnesota	1932	NA	--	EE[b]	27,216 (30,000)	Gravity Separation
Cleveland-Cliffs Iron Co.	Ore Improvement Plant	Ishpeming, Michigan	NA	57	--	1,636,400 (1,800,000)	6,350 (7,000)	Moisture reduction, sizing, and heavy media for underground ore
Dominion Foundries and Steel Limited	Eveleth Expansion Co.	Eveleth, Minnesota	1976	34	--	9,457,948 (10,427,388)	31,498 (34,720)	Rod Mill, magnetic separators, ball mill and finishers
Empire Iron Mining Co.	Palmer Operations	Ishpeming, Michigan	1964	33	--	FF[b]	31,498 (34,720)	Flotation and magnetic separation
Eveleth Mines	Fairlane Plant	Eveleth, Minnesota	NA	35-40	--	15,605,630 (17,202,086)	55,883 (61,600)	Magnetic separation
Halecrest Co., Inc.[d]	Mt. Hope Iron Mine	Mt. Hope, New Jersey	1975	43	--	NA[d]	6,096 (6,720)	Magnetic separation
Hanna Mining Co.	Groveland Mine	Iron Mtn., Michigan	1959	34.77	--	EE[b]	14,530 (16,016)	Flotation

(continued)

Table 9-21. Continued

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Hanna Mining Company	National Steel Pellet Project	Keewatin, Minnesota	1967	31.1	--	EE[b]	24,385 (26,880)	Wet and dry magnetic separation
Hanna Mining Company	Butler Taconite	Nashwauk, Minnesota	1967	32.71	--	EE[b]	22,658 (24,976)	Magnetic separation
Hanna Mining Company[d]	Whitney Mine	Hibbing, Minnesota	1974	49.43	--	NA[d]	24,385 (26,880)	Heavy media
Hanna Mining Company	Pilot Knob Pellet Co.	Ironton, Missouri	1968	36.03	--	EE[b]	5,873 (6,474)	Magnetic separation
Inland Steel Mining Co.	Minerva Operations	Virginia, Minnesota	1977	NA	--	6,127,692 (6,754,555)	25,401 (28,000)	Magnetic separation
Jackson County Iron Co.	Black River Falls Operations	Black River Falls, Wisconsin	1969	65	--	1,907,224 (2,102,333)	2,540 (2,800)	Magnetic separation
Jones & Laughlin Steel Corporation	Hill Annex Mine	Calumet, Minnesota	1917	32.71	--	EE[b]	16,800 (18,816)	Magnetic separation
Jones & Laughlin Steel Corporation[d]	Lind & Greenway Mine	Grand Rapids, Minnesota	1953	NA	--	NA[d]	20,000 (22,040)	Crushing/ screening, washing, high density
Jones & Laughlin Steel Corporation	McKinley Mine	McKinley, Minnesota	1968	54.49	--	EE[b]	13,818 (15,232)	Crushing/ screening, washing

(continued)

Table 9-21. Continued

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Jones & Laughlin Steel Corporation	New York Ore Benson Mine	Star Lake, New York	1944	23	--	EE[b]	13,209 (14,560)	Magnetic separation
Kaiser Steel Corp.	Eagle Mountain Iron Ore Mine	Eagle Mountain, California	1948	35	--	8,060,419 (8,885,000)	45,360 (50,000)	Magnetic separation, jigs, heavy media
Lone Star Steel Co.	Lone Star Mines	Lone Star, Texas	1945	25	--	EE[b]	28,958 (31,920)	Crushing, washing, sizing
Marquette Iron Mining Company	Republic Mine	Ishpeming, Minnesota	NA	NA	--	EE[b]	23,877 (26,312)	NA
NL Industries, Inc.	MacIntyre Development	Tahawus, New York	1942	NA	--	CC[b]	1,200 (1,322)	NA
Picklands Mather & Co.	Erie Mining Co. Hoyt Lakes Operations	Hoyt Lakes, Minnesota	1957	22	--	FF	2,830 (3,120)	Magnetic separation
Picklands Mather & Co.	Hibbing Taconite Co.	Hibbing, Minnesota	1974	22	--	EE[b]	NA	Magnetic separation
Pittsburgh Pacific Co.	Mesabi Division Open Pits	Hibbing, Minnesota	NA	NA	--	203,211[b] (224,000)	7,200 (7,940)	NA

(continued)

Table 9-21. Continued

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Pittsburgh Pacific Co.[d]	Neville Mine	Hibbing, Minnesota	1974	NA	--	NA[d]	7,620 (8,400)	Straight wash
Pittsburgh Pacific Co.	Julia Concentrator	Hibbing, Minnesota	NA	NA	--	482,600 (531,900)	10,160 (11,200)	Gravity separation, washing, screening, crushing
Pittsburgh Pacific Co.	Virginia Concentrator	Crosby, Minnesota	NA	NA	--	NA	7,110 (7,840)	Gravity separation, washing, screening
Pittsburgh Pacific Co.[d]	Knox Extention	Hibbing, Minnesota	1975	54.7	--	NA[d]	11,180 (12,320)	Straight wash
Reserve Mining Co.	Silver Bay Division	Silver Bay, Minnesota	1955	60.5	--	26,775,000 (29,514,000)	30,480 (33,600)	Magnetic separation and hydraulic classification
Rhude & Fryberger, Incorporated	Gross-Nelson Mine	Eveleth, Minnesota	NA	58	--	CC[b]	NA	Washing, jigging, high density
Rhude & Fryberger, Incorporated	Rana Mine	Kinney, Minnesota	1974	58	--	CC[b]	1,090 (1,200)	NA
Standard Slag Company	Beck Iron Mine	Tecopa, California	NA	NA	--	DD[b]	2,000 (2,200)	Crushing, screening, magnetic separation

(continued)

Table 9-21. Continued

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Tex-Iron, Incorporated	Henderson County Operations	La Rue, Texas	NA	49	--	BB[b]	910 (1,000)	Benefication: washing and crushing
Tilden Mining Company	Tilden Mine	Tilden Township, Michigan	1929	NA	--	EE[b]	NA	Selective flocculation and multistage catinoic silica flotation
United States Steel Corporation	Arcturus Mine	Marble, Minnesota	NA	NA	--	EE[b]	12,000 (13,230)	NA
United States Steel Corporation	Sherman Mine	Chisholm, Minnesota	NA	NA	--	2,636,400 (2,900,000)	NA	NA
United States Steel Corporation	Plummer Mine	Taconite, Minnesota	NA	NA	--	1,070,900 (1,200,000)	12,000 (13,230)	Washing, spirals, cyclones
United States Steel Corporation	Minntac Mine and Plant	Mt. Iron, Minnesota	1967	22	--	11,400,000 (12,500,000)	50,880 (56,070)	NA
United States Steel Corporation	Atlantic City Mine	Atlantic City, Wyoming	1962	26	--	4,545,500 (5,000,000)	12,000 (13,230)	Crushing and screening, magnetic separation

(continued)

Table 9-21. Concluded

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Utah International, Incorporated	Iron Springs	Cedar City, Utah	1943	36	--	DD[b]	4,360 (4,800)	Magnetic-hms.

[a]Mining Information Services, 1979.

[b]AA = 907-9072 Mg (1,000-10,000 short tons).
BB = 9072-90,719 Mg (10,000-100,000 short tons).
CC = 90,719-453,597 Mg (100,000 - 500,000 short tons).
DD = 453,597-907,194 Mg (500,000-1,000,000 short tons).
EE = 907,194-9,071,940 Mg (1,000,000-10,000,000 short tons).
FF = Greater than 9,071,940 Mg (10,000,000 short tons).
NA = Not available.
-- = None.

[c]Tons/yr as iron pellets.

[d]Temporarily inactive.

Table 9-22. PRODUCT USES: IRON[a]

Product uses	1979 (percent)
Transportation	31
Construction	27
Machinery	20
Oil and gas	7
Cans and containers	6

[a]U.S. Bureau of Mines, 1980.

Table 9-23. PRICE HISTORY: IRON IN ORE[a]

Year	Actual price		Based on constant 1978 dollars	
	$/Mg	$/ton	$/Mg	$/ton
1957	15.98	14.50	32.85	29.80
1958	15.87	14.40	32.19	29.20
1959	16.09	14.60	31.97	29.00
1960	15.98	14.50	31.20	28.30
1961	16.20	14.70	31.31	28.40
1962	15.87	14.40	30.09	27.30
1963	16.09	14.60	30.09	27.30
1964	16.42	14.90	30.20	27.40
1965	16.42	14.90	29.54	26.80
1966	16.42	14.90	28.66	26.00
1967	16.87	15.30	28.55	25.90
1968	17.09	15.50	27.67	25.10
1969	17.20	15.60	26.57	24.10
1970	18.08	16.40	26.46	24.00
1971	18.96	17.20	26.46	24.00
1972	19.62	17.80	25.23	23.80
1973	20.72	18.80	26.23	23.80
1974	26.34	23.90	30.42	27.60
1975	34.50	31.30	36.27	32.90
1976	38.58	35.00	38.58	35.00
1977[b]	40.67	36.90	42.99	39.00
1979[c]	41.20	37.37	--	--

[a]Average annual price of iron pellets from Klinger (1978).

[b]Preliminary.

[c]Average price for October from Engineering and Mining Journal (1979).

9.1.5 Lead

The United States is both the leading producer and consumer of lead. As shown in Table 9-24, about 40 percent of the lead consumed is reclaimed from old scrap materials, chiefly storage batteries. Approximately 14 percent of the United States lead supply is imported.

Table 9-25 summarizes the product uses of lead. The largest use of lead is for lead storage batteries, which are used in the transportation and communication industries as well as by electric utilities. Lead is also used as an anti-knock additive in gasoline, although this use is decreasing because of the environmental regulations reducing lead in all types of gasoline and eliminating lead from fuel for cars equipped with catalytic converters. In construction, lead is used as a sound barrier and a radiation shield. Lead paint is used to protect steel in highway and building construction and for safety markings on highways. Lead is also used for cables, ammunition, packaging, glass porcelain enamel, and ceramic glazes. The use of lead in some products has been reduced due to the possibility of lead poisoning and potentially adverse environmental impacts.

Alternative materials are available for use in batteries, but they either are limited in supply, cost more than lead, or do not have the electrical characteristics necessary to meet the volume of automotive and industrial power requirements. New anti-knock materials for gasoline are currently under development and may eventually replace lead. Lead has been replaced in exterior house paint by titanium and zinc pigments. Unless extreme corrosion is a problem, underground cables can be made of polyethylene and combinations of metallic and organic materials. Although other materials may sometimes be substituted for lead (e.g., in ammunition and in containers) the growth of lead use in batteries and in newly developing applications assures its continued long-term growth. As shown in Table 9-26, the prices in constant dollars have fluctuated and were actually less in 1976 than in 1954.

The lead processing industry characteristics are summarized in Table 9-27. Processing plants whose primary products are lead and zinc concentrates are listed in Table 9-28. Domestic production of lead continues to come chiefly from ores mined primarily for their lead content; additional lead is derived from ores in which lead and zinc are comparably valued as coproducts. Lead is also recovered as a byproduct from ores mined for copper, gold, silver, zinc, or fluorine. Profitable processing of the complex ores of the Rocky Mountain areas is particularly dependent on the aggregate value of the lead, zinc, silver, and gold content rather than the value of any one metal. In addition to lead, the principal metals recovered in processing lead ores and concentrates are copper, zinc, silver, antimony, tellurium, gold, and bismuth. Significant quantities of sulfur, as sulfuric acid, also are recovered as byproducts of lead production.

The average grade of Missouri ore is 6 percent lead and 1 percent zinc, while the more complex vein ores of Idaho and the Rocky Mountain area average about 3 percent lead and 1 percent zinc.

Demand for lead is expected to increase at an annual rate of 1 to 2 percent through 1985. Growth in processing capacity between 1980 and 1985 is projected to include a 540 Mg per hour plant and two 270 Mg per hour plants. Industry growth is expected primarily in Missouri and Tennessee and ore grades for new plants are presumed to be 4.5 percent lead and 1 percent zinc.

Table 9-24. PRODUCTION PROFILE: LEAD[a]

Parameters	Year 1974	1975	1976	1977	1978
Production 1,000 Mg (1,000 tons) as metal					
Mine	602 (663)	563 (620)	553 (609)	537 (592)	530 (584)
Refinery	620 (683)	579 (638)	598 (659)	552 (608)	568 (626)
Secondary	634 (699)	597 (658)	660 (727)	757 (834)	769 (847)
Imports for consumption 1,000 Mg (1,000 tons) as metal					
Ores, concentrates, and bullion	85 (94)	80 (88)	69 (76)	73 (80)	66 (73)
Pigs and bars	109 (120)	96 (106)	134 (148)	237 (261)	225 (248)
Exports 1,000 Mg (1,000 tons) as metal	110 (121)	64 (71)	48 (53)	86 (95)	126 (139)
Employment:					
Mine and mill[b]	4,800	4,600	4,700	4,600	4,600
Smelters and refineries	2,400	2,400	2,400	2,400	2,400
Net import reliance[c] as percent of apparent consumption	19	11	15	13	11

[a]U.S. Bureau of Mines, 1980.

[b]Includes all lead and/or lead-zinc processing units.

[c]Net import reliance = imports-exports+adjustments for Government and industry stocks.

Table 9-25. PRODUCT USES: LEAD[a]

Product uses	1978 (percent)	1979 (percent)
Transportation:		
Batteries	51	61
Gasoline additives	15	12
Electrical	8	2
Paints	6	6
Ammunition	4	4
Construction	3	3
Other	13	12

[a]U.S. Bureau of Mines, 1980.

Table 9-26. PRICE HISTORY: LEAD[a]

Year	Actual price ¢/kg	Actual price ¢/lb	Based on constant 1976 dollars ¢/kg	Based on constant 1976 dollars ¢/lb
1954	31.1	14.1	69.7	31.6
1955	33.3	15.1	73.0	33.1
1956	35.3	16.0	75.0	34.0
1957	32.4	14.7	66.6	30.2
1958	26.7	12.1	54.0	24.5
1959	26.9	12.2	53.4	24.2
1960	26.5	12.0	51.6	23.4
1961	24.0	10.9	46.3	21.0
1962	21.2	9.6	40.1	18.2
1963	24.5	11.1	45.6	20.7
1964	30.0	13.6	55.1	25.0
1965	35.3	16.0	63.5	28.8
1966	33.5	15.2	58.4	26.5
1967	30.9	14.0	52.2	23.7
1968	29.1	13.2	47.2	21.4
1969	32.8	14.9	50.7	23.0
1970	34.6	15.7	50.7	23.0
1971	30.6	13.9	42.8	19.4
1972	33.1	15.0	44.3	20.1
1973	35.9	16.3	45.4	20.6
1974	49.6	22.5	56.9	25.8
1975	47.4	21.5	49.8	22.6
1976	50.9	23.1	50.9	23.1
1977	67.7	30.7	--	--
Oct.[b] 1979	134. 4	61.1	--	--

[a]Average annual price of lead metal from Ryan and Hague (1977).

[b]Average price for October from Engineering and Mining Journal (1979).

Table 9-27. INDUSTRY CHARACTERISTICS: LEAD

Number of leading companies (lead/zinc)	8
Number of active operations (lead/zinc)	35 (11 temporarily inactive)
Percent of capacity controlled by leading companies	85
Value of processing plant output (as 95 percent ZnS+PbS concentrate)	$86.9 million
Major processing states	Missouri, Idaho, Colorado, Utah, New Jersey
Ratio of ore to product	Range: 16 - 33

Table 9-28. LEAD AND/OR ZINC PROCESSING PLANTS[a]

Company	Plant	Location	Start up date	Ore grade (%)	Metals mined	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Amalgamated Larder Mines Ltd.	St. Patrick Mining Co., Inc.	Pioche, Nevada	1974	1.17 (Lead) 2.45 (Zinc)	Lead, zinc (Silver)	CC[b]	1,270 (1,400)	Flotation
AMAX Lead & Zinc Division	Buick Mine	Buick, Missouri	1969	9.1 (Lead) 3.1 (Zinc)	Lead, zinc	1,295,500 (1,428,000)	5,443 (6,000)	Flotation, washing/ screening
Anaconda Company Mineral Resources Group[c]	Park City Ventures	Park City, Utah	1975	NA	Zinc, lead (Silver)	CC[b]	680 (750)	Flotation
Asarco, Inc.[c]	Leadville Unit	Leadville, Colorado	1971	13	Zinc, lead (Silver)	172,400 (190,000)	680 (750)	Flotation
Asarco, Inc.	Deming Mill	Deming, New Mexico	1879	12	Zinc, lead (Copper)	117,000 (129,000)	635 (700)	Flotation
Asarco, Inc.	Tennessee Mines Division	Mascot, Tennessee	NA	NA	Zinc	1,496,900 (1,650,000)	3200,8500 (2903,7711) (2 mills)	Heavy media, flotation
Asarco, Inc.[c]	New Market Mine	New Market, Tennessee	1963	3	Zinc	DD[b]	3,084 (3,399)	Flotation
Bunker Hill Co.	Bunker Hill Mine	Kellogg, Idaho	1885	7	Lead, zinc (Silver)	489,900 (540,000)	2,177 (2,400)	Flotation
Bunker Hill Co.[c]	Pioche Operations	Pioche, Nevada	NA	NA	Lead, zinc (Silver)	79,800 (88,000) (3 months)	1,360 (1,500)	Flotation
Bunker Hill Co.[c]	Pend Oreille Mine	Metaline Falls, Washington	NA	4-5	Lead, zinc	NA[c]	2,177 (2,400)	Flotation

(continued)

Table 9-28. Continued

Company	Plant	Location	Start up date	Ore grade (%)	Metals mined	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Callahan Mining Corp.[c]	Washington Zinc Unit	Colville, Washington	NA	4.5	Zinc, lead	NA[c]	953 (1,050)	NA
Clayton Silver Mines	Clayton Mine	Wallace, Idaho	1934	NA	Lead, zinc (Silver)	NA	NA	Flotation
Cominco American, Inc.	Magmont Mine	Bixby, Missouri	1968	8	Lead, zinc (Copper, silver)	957,090 (1,055,000)	3,810 (4,200)	Flotation
Day Mines, Inc.	Sherman Mine and Mill	Leadville, Colorado	NA	NA	Lead (Silver)	89,600 (98,600)	318 (350)	
Eagle-Picher Industries, Minerals Div.	Illinois-Wisconsin Operations	Galena, Illinois	1948	4	Zinc, lead	CC[b]	2,268 (2,500)	Jigging, flotation
Federal Resources	Camp Bird Mine	Ouray, Colorado	NA	NA	Zinc, lead (Silver, copper)	NA	454 (500)	Flotation
Hecla Mining Company	Star Unit Area	Burke, Idaho	1940	5.64 (Zinc) 5.0 (Lead)	Zinc, lead (Silver)	CC[b]	907 (1,000)	Flotation
Frontier Resources[c]	Babb-Barnes Operations	Salem, Kentucky	1974	NA	Lead, zinc (Flourspar)	NA[c]	454 (500)	Flotation, heavy media
Idarado Mining Company	Ouray Operations	Ouray, Colorado	NA	6.34	Zinc, lead (Copper, gold, silver)	CC[b]	1,542 (1,700)	Selective flotation
Homestake Mining Co.	Bulldog Mt. Project	Creede, Colorado	1969	2.3	Lead (Silver)	NA	272 (300)	Flotation

(continued)

Table 9-28. Continued

Company	Plant	Location	Start up date	Ore grade (%)	Metals mined	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Ivey Construction Co.[c]	Graysville Mine	Mineral Point, Wisconsin	1969	4	Zinc, lead (Copper)	NA[c]	327 (360)	Flotation
Jersey Miniere Zinc Company	Elmwood Operation	Elmwood, Tennessee	1975	3.5-4	Zinc	627,800 (692,000)	2,722 (3,000)	Heavy media flotation
Jersey Miniere Zinc Company	Gordonsville Mine	Gordonsville, Tennessee	1978	NA	Zinc	NA	8,165 (9,000)	NA
Kay Mining	Sandy Valley Operation	Las Vegas, Nevada	NA	NA	Zinc, lead	NA	136 (150)	Amonia leach
Kennecott Copper Corp.	Tintic Division	Eureka, Utah	1966	NA	Lead, zinc (Silver)	BB[b]	454 (500)	Flotation
Matthiesen & Hegeler Zinc Company	La Salle	La Salle, Illinois	NA	NA	Zinc	NA	NA	NA
New Jersey Zinc Company, Gulf & Western Natural Resources Group	Friedensville Operations	Center Valley Pennsylvania	NA	5	Zinc, lead	489,900 (540,000)	2,268 (2,500)	Flotation
New Jersey Zinc Company, Gulf & Western Natural Resources Group	Jefferson City Operations	Jefferson City, Tennessee	NA	2.5	Zinc	415,500 (458,000)	1,814 (2,000)	Flotation
New Jersey Zinc Company, Gulf & Western Natural Resources Group	Sterling Operations	Ogdensburg, New Jersey	1956	18.0	Zinc	NA	725 (800)	NA
New Jersey Zinc Company, Gulf & Western Natural Resources Group	Austinville Operations	Austinville, Virginia	NA	3.0	Zinc, lead	476,300 (525,000)	2,359 (2,600)	Flotation

(continued)

Table 9-28. Continued

Company	Plant	Location	Start up date	Ore grade (%)	Metals mined	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Ozark Lead Company	Ozark Operations	Sweetwater, Missouri	1968	NA	Lead, zinc	1,296,200 (1,428,800)	5,443 (6,000)	Flotation
Ozark Mahoning Company		Rosiclare, Illinois	1925	NA	Lead, zinc (Flourspar)	NA	NA	NA
Resurrection Mining Company	Resurrection Mine	Leadville, Colorado	NA	NA	Zinc, lead	CC[b]	NA	NA
St. Joe Lead Company	Brushy Creek Operations	Viburum, Missouri	1973	NA	Lead, zinc (Copper)	1,118,900 (1,233,340)	4,536 (5,000)	Flotation
St. Joe Lead Company	Fletcher Operations	Viburum, Missouri	1967	NA	Lead, zinc (Copper)	1,110,500 (1,224,200)	4,536 (5,000)	Flotation
St. Joe Lead Company	Indian Creek Operations	Viburnum, Missouri	1954	NA	Lead (Copper)	423,400 (466,700)	2,268 (2,500)	Flotation
St. Joe Lead Company	Viburnum Operations	Viburnum, Missouri	1960	4.4	Lead, zinc (Copper)	1,748,300 (1,927,200)	6,804 (7,500)	Flotation
St. Joe Zinc Company	Edwards Mine	Balmat, New York	1915	8.0	Zinc	CC[b]	1,089 (1,200)	Flotation
Shiny Rock Mining Corp.	Ruth Mine	Mehama, Oregon	1978	NA	Zinc, lead (Silver)	NA	91 (100)	NA
Standard Metals Corp.	Silverton Operations	Silverton, Colorado	NA	NA	Zinc, lead (Gold, silver, copper)	NA	910 (1,000)	Flotation
UV Industries, Inc.[c]	Bullfrog Mine	Bayard, New Mexico	NA	NA	Zinc (Copper)	NA[c]	363 (400)	Flotation
UV Industries, Inc.[c]	Princess Operations	Fierro, New Mexico	NA	NA	Zinc	NA[c]	NA[c]	NA

(continued)

Table 9-28. Concluded

Company	Plant	Location	Start up date	Ore grade (%)	Metals mined	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
UV Industries, Inc.[c]	Hanover Operations	Hanover, New Mexico	NA	NA	Zinc, lead	NA[c]	726 (800)	Flotation
UV Industries, Inc.	Continental Mill	Hanover, New Mexico	1967	NA	Zinc (Copper)	467,000 (513,800)	7,270 (8,000)	Flotation
United States Steel Corp.	Zinc Mine	Jefferson City, Tennessee	NA	NA	Zinc	CC[b]	NA	NA
Ward Development		Missoula, Montana			Lead, zinc (Gold, copper)	NA	NA	NA

[a]Mining Information Services, 1979.

[b]Mine tonnage.
CC = 90,719-453,597 Mg (100,000-500,000 sort tons).
DD = 907,194 Mg (500,000-1,000,000 short tons).
NA = Not available.

[c]Temporarily inactive.

9.1.6 Molybdenum

The United States is the world's leading producer of molybdenum and, as shown in Table 9-29, is a net exporter of the metal. About 70 percent of domestic consumption goes to the production of molybdenum-containing steels. Molybdenum in steel improves steel's hardness and resistance to temper embrittlement, abrasion, and corrosion. The steels are used in all major segments of industry. As shown in Table 9-30, molybdenum is also used in lubricants, catalysts, and pigments.

Historically, there has been little incentive to substitute for molybdenum because the price has been low. As shown in Table 9-31, however, the price increased substantially during the middle to late seventies leading to an increased interest in alternatives. A number of alternative materials are available, but their use may result in impaired performance or a cost disadvantage. These materials include boron, chromium, manganese, and nickel, all of which can be used in steel. Molybdenum-containing steel could occasionally be replaced by plastics and ceramics. Tungsten, tantalum, and graphite may be substituted in various other areas. The domestic availability of molybdenum, plus the fact that it represents only a small percentage of the composition of many steels, tends to discourage most substitution efforts.

The molybdenum ore processing industry is dominated by the Climax Division of AMAX, Incorporated, which controls over 80 percent of the total domestic processing capacity (see Tables 9-31 and 9-33). The company opened the Henderson Mine in Colorado during 1976 and expects the mine's output to reach 23,000 Mg (25,000 tons) of metal per year by 1980. Duval Copper and Kennecott Copper, which recover molybdenum from their copper mining operations, are also large producers of the metal. They are listed in Table 9-13 with the copper processors.

Approximately 70 percent of molybdenum is recovered from molybdenum ores, principally low grade deposits of the mineral molybdenite. Ore grades range from 0.2 to 0.5 percent as MoS_2, representing ore-to-product ratios of 500 and 200, respectively. The remainder of the molybdenum supply is obtained as a byproduct from copper, tungsten, or uranium processing. In some cases the recovery of molybdenum from copper processing significantly improves the profitability of these operations.

The demand for molybdenum is expected to increase at an annual rate of approximately 5 percent through 1985. The growth in processing capacity is expected to include construction of one 270 Mg per hour plant and two 1100 Mg per hour plants by 1985. Ore grades of 0.4 percent were assumed for these plants.

Table 9-29: PRODUCTION PROFILE: MOLYBDENUM[a]

Parameters	Year 1974	1975	1976	1977	1978
Production: mine 1,000 Mg (1,000 tons) as metal	50.8 (56.0)	48.1 (53.0)	51.4 (56.6)	55.5 (61.2)	59.9 (66.0)
Imports for consumption, concentrate 1,000 Mg (1,000 tons) as metal	0.1 (0.1)	1.2 (1.3)	0.9 (1.0)	0.9 (1.0)	1.2 (1.3)
Exports, molybdenum concentrate and oxide 1,000 Mg (1,000 tons)	35.7 (39.3)	28.4 (31.3)	28.3 (31.2)	29.8 (32.8)	31.4 (34.6)
Employment:					
Mine and mill recovering molybdenum as the principal product	2,600	2,700	3,700	4,300	4,500
Net import reliance[b] as a percent of apparent consumption	c	c	c	c	c

[a]U.S. Bureau of Mines, 1980.

[b]Net import reliance = imports-exports+adjustments for Government and industry stocks.

[c]Net exporter.

Table 9-30. PRODUCT USES: MOLYBDENUM[a]

Product uses	1978 (percent)	1979 (percent)
Transportation	21	22
Machinery	34	32
Oil and gas industry	15	17
Chemicals	12	13
Electrical	8	8
Other	10	8

[a]U.S. Bureau of Mines, 1980.

Table 9-31. PRICE HISTORY: MOLYBDENUM[a]

Year	Actual prices $/kg	Actual prices $/lb	Based on constant 1977 dollars $/kg	Based on constant 1977 dollars $/lb
1954	2.31	1.05	5.49	2.49
1955	2.43	1.10	5.62	2.55
1956	2.60	1.18	5.86	2.66
1957	2.60	1.18	5.67	2.57
1958	2.76	1.25	5.91	2.68
1959	2.76	1.25	5.78	2.62
1960	2.76	1.25	5.69	2.58
1961	3.09	1.40	6.31	2.86
1962	3.09	1.40	6.19	2.81
1963	3.09	1.40	6.11	2.77
1964	3.42	1.55	6.66	3.02
1965	3.42	1.55	6.50	2.95
1966	3.42	1.55	6.31	2.86
1967	3.57	1.62	6.39	2.90
1968	3.57	1.62	6.13	2.78
1969	3.79	1.72	6.19	2.81
1970	3.79	1.72	5.89	2.67
1971	3.79	1.72	5.60	2.54
1972	3.79	1.72	5.38	2.44
1973	3.79	1.72	5.07	2.30
1974	4.45	2.02	5.45	2.47
1975	5.47	2.48	6.08	2.76
1976	6.48	2.94	6.86	3.11
1977	8.11	3.68	8.11	3.68
Oct.[b] 1979	19.48	8.84	--	--

[a]Average annual price per pound of molybdenum contained in concentrate (95% MoS_2) from Kummer (1979).

[b]Average price for October from Engineering and Mining Journal (1979).

Table 9-32. INDUSTRY CHARACTERISTICS: MOLYBDENUM

Number of leading companies	2
Number of active operations	3
Percent of capacity controlled by leading companies	Not Available
Value of processing plant output (as 95 percent MoS_2 concentrate)	$133.9 million
Major processing states	Colorado, New Mexico
Ratio of ore to product	Range: 200 - 500

Table 9-33. MOLYBDENUM ORE PROCESSING PLANTS[a]

Company	Plant	Location	Start up date	Ore grade (%)[b]	Other products	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Climax Molybdenum Co., Division AMAX	Climax Operations	Climax, CO	1916	.3522	Tungsten	15,059,400 (16,600,000)	39,000 (43,000)	Flotation
Climax Molybdenum Co., Division AMAX	Henderson Operations	Empire, CO	1976	.49		3,628,800 (4,000,000)	27,200 (30,000)	Flotation
Molycorp, Inc.	Questa Mine	Questa, N.M.	1965	.172		3,937,200 (4,340,000)	14,500 (16,000)	Grinding & Flotation

[a]Mining Information Services, 1979.
[b]Percentage as MoS_2.

9.1.7 Silver

Silver, like gold, is valued both as an investment property and as an industrial metallic mineral. As shown in Table 9-34, the photographic industry is the major consumer of silver, using 38 percent of the domestic supply in 1978. Jewelry, arts and crafts, batteries, and electrical and electronic components are the other major use categories for silver. The qualities that make silver valuable in industry are its superior thermal and electrical conductivity; high reflectivity, malleability and ductility; and corrosion resistance.

As a result of the silver price boom in 1979 (see Table 9-35), substitutes for silver should become more prevalent. Stainless steel is used in the manufacture of flatware; aluminum and rhodium can replace silver in mirrors; and tantalum may be substituted in surgical plates, pins, and sutures. Many countries are making coins from cupronickel, cuprozinc, nickel, and aluminum. Substitutes for silver in the photographic development process are being investigated, but to date, these efforts have not been successful.

As shown in Table 9-36, the United States imports 45 percent of its silver while producing 12 percent of the world's supply. There are 12 processing plants whose primary product is silver located in Idaho, Colorado, and Montana (see Tables 9-37 and 9-38).

Silver ores typically contain from 1 to 25 troy ounces of silver per ton of ore. A recently developed mine contains 2.5 to 5.0 troy ounces per ton (Carter, 1978). The recovery of gold and other metals in the processing of silver ore significantly added to the profitability of several operations.

Demand for silver in the United States was forecasted in 1978 to increase at an annual rate of around 3 percent through 1985. A revised estimate taking into account the unanticipated rise in silver's price is not yet available. Growth in processing capacity is projected to include two 45 Mg per hour plants and one 140 Mg per hour plant by 1985. These plants are assumed to process ore containing 5 troy ounces of silver per ton of ore.

Table 9-34. PRODUCT USES: SILVER[a]

Product uses	1978 (percent)	1979 (percent)
Photography	38	39
Electrical and electronic components	26	25
Sterlingware and electroplated ware	17	15
Brazing alloys and solders	7	8
Other	12	13

[a]U.S. Bureau of Mines, 1980.

Table 9-35. PRICE HISTORY: SILVER[a]

Year	Actual prices		Based on constant 1977 dollars	
	$/kg	$/troy oz	$/kg	$/troy oz
1955	28.94	0.90	67.20	2.09
1956	28.94	0.90	64.94	2.02
1957	28.94	0.90	63.02	1.96
1958	28.94	0.90	62.05	1.93
1959	28.94	0.90	60.44	1.88
1960	28.94	0.90	59.48	1.85
1961	29.58	0.92	60.44	1.88
1962	34.72	1.08	69.45	2.16
1963	40.83	1.27	80.70	2.51
1964	41.47	1.29	80.70	2.51
1965	41.47	1.29	78.77	2.45
1966	41.47	1.29	76.20	2.37
1967	49,83	1.55	89.06	2.77
1968	68.80	2.14	117.67	3.66
1969	57.55	1.79	93.88	2.92
1970	56.91	1.77	88.09	2.74
1971	49.51	1.54	72.98	2.27
1972	54.01	1.68	76.20	2.37
1973	82.31	2.56	109.96	3.42
1974	151.43	4.71	184.55	5.74
1975	142.11	4.42	157.86	4.91
1976	139.86	4.35	147.57	4.59
1977	148.54	4.62	148.54	4.62
1978	171.04	5.32	--	--
Oct.[b] 1979	539.67	16.78	--	--

[a]Average annual price of silver metal from Drake (1978).

[b]Average price for October from Engineering and Mining Journal (1979).

Table 9-36. PRODUCTION PROFILE: SILVER[a]

Parameter	Year 1974	1975	1976	1977	1978
Production, 1,000 kg (1,000 lbs) as metal					
Mine	1,086 (2,394)	1,122 (2,474)	1,102 (2,429)	1,228 (2,707)	1,228 (2,707)
Refinery: New	2,035 (4,486)	2,038 (4,493)	1,749 (3,856)	1,446 (3,188)	1,696 (3,739)
Secondary (old scrap)	1,739 (3,834)	1,594 (3,514)	1,614 (3,558)	1,540 (3,395)	1,156 (2,549)
Imports for consumption[b] 1000 kg (1,000 lbs) as metal	3,035 (6,691)	2,138 (4,713)	2,337 (5,152)	2,543 (5,606)	2,593 (5,717)
Exports[b], 1000 kg (1,000 lbs) as metal	591 (1,303)	1,048 (2,310)	469 (1,034)	720 (1,587)	768 (1,693)
Employment: mine and mill	1,350	1,250	1,450	1,450	1,500
Net import reliance[c] as a percent of apparent consumption	44	12	45	31	48

[a]U.S. Bureau of Mines, 1980.

[b]Excludes coinage.

[c]Net import reliance = imports-exports+adjustments for Government and industry stock changes.

Table 9-37. INDUSTRY CHARACTERISTICS: SILVER

Number of leading companies	5
Number of active operations	11 (1 temporarily inactive, 1 under construction)
Percent of capacity controlled by leading companies	85
Value of processing plant output (as metal)	$103.1 million
Major processing states	Idaho, Colorado
Ratio of ore to product	Range: 1,150 - 30,000 Typical: 8,400

Table 9-38. SILVER ORE PROCESSING PLANTS[a]

Company	Plant	Location	Start up date	Ore grade	Other products	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Asarco Incorporated	Northwest Mining Dept-Coeur	Wallace, Idaho Unit	1976	NA	Cooper	136,079 (150,000)	408 (450)	Flotation
Asarco Incorporated	Northwest Mining Dept-Galena	Wallace, Idaho Unit	NA	625 g/Mg (20oz/t)	Copper	CC[b]	680 (749)	Flotation
Bunker Hill Co.	Crescent Mine	Kellogg, Idaho	1952	625-930g/Mg (20-30oz/t)	Copper	29,030 (32,000)	2,180 (2,400)	Flotation
Clayton Silver Mines	Clayton Mine	Clayton, Idaho	1934	NA	Lead, zinc	BB[b]	227 (250)	Flotation
Day Mines, Inc.	Sherman Mine and Mill	Leadville, Colorado	NA	63g/Mg (20oz/t)	Lead	89,450 (98,600)	318 (350)	NA
Earth Resources Company	DeLamar Silver Mine	Jordon Valley, Idaho	1976	15.6g/Mg (5.0oz/t)	Gold	523,870 (577,300)	1,542 (1,700)	CN-Agitation leach
Federal Resources Corp.	Camp Bird Mine	Ouray, Colorado	NA	NA	Lead, copper zinc	BB[b]	454 (500)	Flotation
Hecla Mining Company	Lucky Friday	Mullan, Idaho	1950	15.6oz/t	Lead, zinc	143,900 (158,600)	726 (800)	Flotation
Homestake Mining Company	Bulldog Mt. Project	Creede, Colorado	1969	594g/Mg (19.0oz/t)	Lead	CC[b]	272 (300)	Flotation
Rico Argentina Mining Co.[c]	Rico Operations	Rico, Colorado	NA	NA	Gold	NA	159 (175)	Flotation

(continued)

Table 9-38. Concluded

Company	Plant	Location	Start up date	Ore grade	Other products	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Sunshine Mining Company	Sunshine Mine	Kellogg, Idaho	1884	0.1%	Copper, antimony, lead	182,210 (200,850)	1,090 (1,200)	Flotation
Ward Development Co.	Dick Creek Operations	Missoula, Montana	1978	NA	Lead, zinc, gold, copper	NA	NA	NA

[a]Mining Information Services, 1979.

[b]BB = 9072-90,219 Mg (10,000-100,000 short tons).
CC = 90,719-453,597 Mg (100,000-500,000 short tons).
NA = Not available.

[c]Temporarily inactive.

9.1.8 Titanium

Most titanium is consumed as titanium dioxide pigment (see Table 9-39). The pigment has a high refractive index and is used in surface coatings, paints, paper coatings, photographic papers, paper boxes, and plastics to add whiteness and opacity. Titanium metal is used mainly in aircraft and guided missile assemblies, spacecraft, and aircraft turbine engines. It is also used by the chemical and electrochemical processing industry, and in steel and other alloys. Table 9-40 profiles the production statistics of this industry.

Possible substitutes for titanium pigments include zinc oxide, talc, clay, silica, and alumina. However, they cost more and do not perform as well. High strength, low alloy steels, aluminum or other metals can replace titanium metal in some structural applications, but they usually do not perform as well and require redesigning of products and manufacturing methods. Nickel steels are somewhat competitive in structural applications. When titianium metal is chosen for its resistance to corrosion, stainless steel, Hastelloy, 90 copper-10 nickel, and certain nonmetals may be substituted.

The mineral sources of titanium are rutile and ilmenite. Concentrates of these minerals are made at relatively few operations in the world. These deposits (rutile and ilmenite) may be either sand or rock. Both rutile and ilmenite occur together in sand deposits, but ilmenite is the main constituent of rock deposits. Large deposits of rutile are found on Australia's east and west coast, and the United States demand for rutile is met largely by imports. Domestic sand deposits contain approximately 1.0 to 2.0 percent titanium as titanium dioxide.

Processing of titanium ores is controlled by the three major companies shown in Table 9-41. Titanium processors are listed in Table 9-42. Most United States processing of titanium ores is a part of an integrated operation. Over 95 percent of the world's natural rutile production is from Australia.

Table 9-43 includes the price history for titanium, both as rutile pigment and sponge metal. Both forms were characterized by current dollar price stability until 1974 when prices began to rise. In constant dollars, prices were falling through 1974.

Demand for titanium is expected to increase by about 4.3 percent per year through 1985. A 270 Mg per hour expansion to an existing plant and a 540 Mg per hour new plant are projected by 1985. These plants are assumed to process sand-type ore with a titanium content of 1.5 percent as titanium dioxide and 0.9 percent zirconium.

Table 9-39. PRODUCT USES: TITANIUM[a]

Product uses	1978 (percent)
Paints	50
Paper	21
Plastic	12
Sponge metal	2
Other uses	15

[a]Lynd, 1978 and U.S. Bureau of Mines, 1980.

Table 9-40. PRODUCTION PROFILE: TITANIUM[a]

Parameters	Year 1975	1976	1977	1978	1979
Production (Mg as metal)	b	b	b	b	b
Imports for consumption, Mg (ton) as sponge metal	3,800 (4,190)	1,613 (1,778)	2,165 (2,387)	1,339 (1,476)	2,177 (2,400)
Exports (mainly scrap), Mg (ton)	5,647 (6,226)	6,538 (7,209)	4,031 (4,444)	7,065 (7,789)	6,984 (7,700)
Price: sponge, per pound year end	$2.70	$2.70	$2.98	$3.28	$3.98
Stock: Sponge, industry, year end	5,669	3,617	3,546	2,642	1,300
Net import reliance[c] as a percent of apparent consumption	b	b	b	b	b
Titanium Dioxide:					
Production	603,429	712,940	687,103	720,223	724,000
Imports for consumption, Mg (ton)	23,562 (25,918)	62,270 (68,497)	104,373 (114,810)	107,000 (117,708)	105,450 (116,000)
Exports, Mg (ton)	14,337 (15,807)	18,912 (20,850)	14,817 (16,336)	34,296 (37,812)	44,444 (49,000)
Employment	5,800	4,900	4,900	4,200	4,800
Net import reliance[c] as a percent of apparent consumption	Net exporter	5	12	12	12

[a]U.S. Bureau of Mines, 1980.

[b]Withheld to avoid disclosing company proprietary information.

[c]Net import reliance = imports-exports+adjustments for Government and industry stock.

Table 9-41. INDUSTRY CHARACTERISTICS: TITANIUM

Number of leading companies (titanium and zirconium)	3
Number of active operations (titanium and zirconium)	5 (2 inactive)
Percent capacity controlled by leading companies	98
Value of processing plant output (as ilmenite/zircon concentrate)	\$70.5 million
Major processing states	Florida, New Jersey
Ratio of ore to product	75 to 100 (as TiO_2 in sand-type ores)

Table 9-42. TITANIUM/ZIRCONIUM ORE PROCESSING PLANTS[a]

Company	Plant	Location	Start up date	Ore grade (%)	Type	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Asarco, Inc.[b]	Manchester Unit	Lakehurst, New Jersey	1973	2.25 (Titanium)	Sand	8,128,460 (8,960,000)	22,350 (24,640)	Gravity separation
Humphreys Mining Company[c]	Folkston Plant	Folkston, Georgia	1974	5.0 (Titanium, Zirconium)	Sand	97,980 (108,000)	454 (500)	Spiral concentration, high tension separation
N.L. Industries	MacIntyre Development	Tahawas, New York	1941	NA	Hard rock	770,000 (850,000)	NA	
E.I. DuPont de Nemours & Co., Inc.	Highland Plant	Lawtey, Florida	NA	1.0 (Titanium) 1.0 (Zirconium)	Sand	EE[d]	21,773 (24,000)	Humphreys spiral, high tension, magnetic
E.I. DuPont de Nemours & Co., Inc.	Trail Ridge Plant	Starke, Florida	NA	1.0 (Titanium) 1.0 (Zirconium)	Sand	EE[d]	21,773 (24,000)	Humphreys spiral, high tension, magnetic
Associated Minerals	Green Cove Springs	Green Cove Springs, Florida	1980	1.3-2.0 (Titanium) 0.5-1.0 (Zirconium)	Sand	EE[d]	21,800 (24,000)	Spiral concentration

[a]Mineral Information Services, 1979.

[b]Inactive, 1982.

[c]Permanently closed, 1980.

[d]Mine tonnage.
EE = 907,194-9,071,940 Mg (1,000,000-10,000,000 short tons).

Table 9-43. PRICE HISTORY: TITANIUM[a]

Year	Actual price		Based on constant 1976 dollars	
	Rutile pigment $/lb	Sponge metal $/lb	Rutile pigment $/lb	Sponge metal $/lb
1954	0.41	4.80	0.92	10.76
1955	0.41	3.90	0.90	8.57
1956	0.44	3.20	0.94	6.80
1957	0.46	2.50	0.95	5.14
1958	0.46	2.05	0.93	4.16
1959	0.46	1.66	0.91	3.29
1960	0.46	1.60	0.90	3.12
1961	0.46	1.60	0.89	3.09
1962	0.46	1.60	0.87	3.04
1963	0.46	1.60	0.86	2.99
1964	0.46	1.32	0.85	2.43
1965	0.46	1.32	0.83	2.38
1966	0.46	1.32	0.80	2.30
1967	0.46	1.32	0.78	2.24
1968	0.48	1.32	0.78	2.14
1969	0.48	1.32	0.74	2.04
1970	0.45	1.32	0.66	1.94
1971	0.45	1.32	0.63	1.84
1972	0.45	1.32	0.60	1.77
1973	0.50	1.42	0.63	1.80
1974	0.72	2.25	0.83	2.60
1975	0.73	2.70	0.77	2.84
1976	0.78	2.70	0.78	2.70
1977	0.81	2.98	0.77	2.82
1978	0.85	3.28	--	--
1979	1.02	3.98	--	--
1980	1.15	7.02	--	--

[a]Year-end price as rutite pigment (Ti content) and sponge metal from Lynd (1978).

9.1.9 Tungsten

Tungsten's unique high temperature properties make it suitable for many industrial uses. As a carbide, its hardness makes it useful as a cutting edge or facing material in industrial equipment. As an alloy constituent, tungsten is used in steels that require resistance to wear, abrasiveness, shock, and corrosion or that need strength at high temperatures. Mill products made from pure tungsten metal powder are used in the electrical and electronic industries, furnaces, aircraft, and in the aerospace industry. Tungsten is also used in various chemicals and compounds. Product uses are presented in Table 9-44.

The increasing price of tungsten, as shown in Table 9-45, has resulted in the expanded use of secondary scrap. Tungsten demand in the United States is linked to major end uses that depend on wear-resisting materials, and these uses constitute about 72 percent of tungsten consumption. Alumina may substitute for tungsten in some instances where an abrasive, wear-resistant material is required. However, in most cases substitution brings impaired performance. An early breakthrough in ceramic technology, in applications involving high temperatures and oxidation resistance could affect demand for tungsten. However, this technology has not been commercially developed.

Most tungsten ore has come from the Bishop mine of the Union Carbide Company, which is the leading company noted on Table 9-46, and the Climax mine of AMAX, Incorporated (listed in Table 9-33). Five tungsten ore processing plants are listed in Table 9-47. Because of tungsten's partial association with molybdenum, about 25 percent of future domestic production may be determined by the level of molybdenum mining operations. Although United States tungsten reserves are relatively small, research on tungsten recovery and utilization continues. Anticipated improvements in tungsten processing would allow more effective development of high volume, low-grade deposits. Domestic tungsten deposits are usually less than 1 percent tungsten and are typically in the range of 0.4 to 0.5 percent. For the near future the United States will continue to depend heavily on imports as shown in Table 9-48.

Demand for tungsten is expected to increase by approximately 5 percent per year through 1985. Tungsten ore processing capacity is projected to increase as a result of a new 23 Mg per hour plant processing ore containing 0.5 percent tungsten. These growth projections may be disrupted if the General Services Administration continues its sales of large quantities of ferrotungsten from the government's strategic materials stockpile.

Table 9-44. PRODUCT USES: TUNGSTEN[a]

Product uses	1978 (percent)	1979 (percent)
Metalworking and construction machinery	75	77
Transportation	11	10
Lamps and Lighting	7	6
Electrical	4	4
Other	3	3

[a]U.S. Bureau of Mines, 1980.

Table 9-45. PRICE HISTORY: TUNGSTEN[a]

Year	Actual prices $/kg	Actual prices $/lb	Based on constant 1976 dollars $/kg	Based on constant 1976 dollars $/lb
1956	8.05	3.65	17.13	7.77
1957	3.44	1.56	7.08	3.21
1958	2.45	1.11	4.96	2.25
1959	2.87	1.30	5.69	2.58
1960	3.09	1.40	6.02	2.73
1961	2.98	1.35	5.75	2.61
1962	3.20	1.45	6.06	2.75
1963	2.95	1.34	5.51	2.50
1964	2.82	1.28	5.20	2.36
1965	3.79	1.72	6.83	3.10
1966	4.63	2.10	8.07	3.66
1967	4.10	1.86	6.94	3.15
1968	4.94	2.24	8.00	3.63
1969	5.22	2.37	8.07	3.66
1970	5.62	2.55	8.25	3.74
1971	6.53	2.96	9.10	4.13
1972	5.64	2.56	7.56	3.43
1973	5.97	2.71	7.56	3.43
1974	10.52	4.77	12.13	5.50
1975	11.55	5.24	12.17	5.52
1976	14.42	6.54	14.42	6.54
1977	21.54	9.77	20.39	9.25
Oct.[b] 1979	17.97	8.15	--	--

[a]Average annual price per pound of tungsten contained in concentrate (65% WO_3).

[b]Average price for October from Engineering and Mining Journal (1979).

Table 9-46. INDUSTRY CHARACTERISTICS: TUNGSTEN

Number of leading companies	1
Number of active operations	4 (1 temporarily inactive)
Percent capacity controlled by leading companies	71
Value of concentrate production (as 65 percent WO_3 concentrate)	\$45 thousand
Major processing states	California, Nevada
Ratio of ore to product	Range: 150 - 250 Typical: 200

Table 9-47. TUNGSTEN ORE PROCESSING PLANTS[a]

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Kennemetal Inc., Nevada Division	Fallon Plant	Fallon, Nevada	NA	NA	--	NA	NA	NA
Ranchers Exploration & Development Corp.[c]	Tungsten Queen Mine	Townsville, North Carolina	1970	NA	--	NA	NA	NA
Tungsten Properties, Ltd.	Tungsten Group	Imlay, Nevada	1976	NA	--	NA	363 (400)	Flotation gravity
Union Carbide Corp., Metals Division	Emerson Operations	Alamo, Nevada	NA	NA	--	CC[b]	907 (1,000)	NA
Union Carbide Corp., Metals Division	Bishop Plant	Bishop, California	NA	NA	Molybdenum, Copper	DD[b]	NA	NA

[a]Mineral Information Services, 1979.

[b]CC = 90,719-453,597 Mg (100,000-500,000 short tons).
DD = 453,597-907,194 Mg (500,000-1,000,000 short tons).
NA = Not available.
-- = None.

[c]Temporarily inactive.

Table 9-48. PRODUCTION PROFILE: TUNGSTEN[a]

Parameters	Year				
	1974	1975	1976	1977	1978
Production; mine shipments, 1,000 Mg (1,000 Tons) as metal	3.55 (3.91)	2.49 (2.74)	2.66 (2.93)	2.73 (3.01)	3.14 (3.46)
Imports for consumption; as concentrate, 1,000 Mg (1,000 Tons)	5.03 (5.54)	2.98 (3.28)	2.40 (2.64)	3.14 (3.46)	4.15 (4.57)
Exports; as concentrate, 1,000 Mg (1,000 Tons)	0.54 (0.60)	0.60 (0.66)	0.78 (0.86)	0.58 (0.64)	0.84 (0.93)
Employment: mine and mill	540	525	540	945	875
Net import reliance[b] as a percent of apparent consumption	57	46	53	52	56

[a]U.S. Bureau of Mines, 1980.

[b]Net import reliance = imports-exports+adjustments for Government and industry stocks.

9.1.10 Uranium

In its natural state, uranium contains about 0.7 percent of isotope U-235, the critical isotope in the generation of nuclear fision processes. Most uranium is purchased by utilities to fuel nuclear reactors as indicated in Table 9-49. Depleted uranium (a byproduct of the enrichment of natural uranium) is used primarily in ordnance, as well as for containers of spent nuclear reactor residues and other radiation shields for counterweights and ballast for aircraft and ships, and in research. The supply of this byproduct greatly exceeds demand.

There are no substitutes for uranium in the production of nuclear energy, although thorium and plutonium are supplements. Lead, tungsten, and other metals can replace uranium in nonnuclear applications.

Industry characteristics are presented in Table 9-50. The major oil companies, such as Kerr-McGee, Exxon, Gulf, and Getty, dominate all phases of the domestic uranium industry. Union Carbide, United Nuclear, and Lucky McMines (an independent subsidiary of General Electric) are other large processors of uranium. Thirty-two uranium processing plants are listed in Table 9-51.

During the sixties and seventies, many uranium mines and mills operated with ore that contained approximately 0.2 percent uranium. Because the richer deposits have been exhausted, the ore grade in new mines has fallen to 0.10 to 0.15 percent uranium. Ore grades for new mining sites are projected at 0.13 percent uranium.

Demand for uranium has been projected to increase by 15 percent per year through 1985. The controversy surrounding the nuclear industry following the Three Mile Island incident and the accelerating cost of nuclear construction coupled with the decreasing growth in demand for electrical power may reduce the growth rate in the uranium industry. In addition, the price of uranium has declined as shown in Table 9-52. Growth in capacity in the uranium industry is expected to include two 23 Mg per hour plants and three 68 Mg per hour plants by 1985.

Table 9-49. PRODUCT USES: URANIUM[a]

Product uses	1978 (percent)
Fuel	98
Nonnuclear	2

[a]U.S. Bureau of Mines, 1980.

Table 9-50. INDUSTRY CHARACTERISTICS: URANIUM

Number of leading companies	10
Number of active operations	31 (1 temporarily inactive)
Percent of capacity controlled by leading companies	74
Value of processing plant output (as yellowcake U_3O_8)	$1608.7 million
Major processing states	New Mexico, Wyoming, Colorado
Ratio of ore to product	Range: 500 - 1,000 850 (future growth)

Table 9-51. URANIUM ORE PROCESSING PLANTS[a]

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Anaconda Company Mineral Resources Group	New Mexico Operations	Grants, New Mexico	NA	NA	--	NA	2,449 (2,700)	Acid leach, solvent extraction
Atlas Minerals, Div. of Atlas Corp.	Moab Mill	Moab, Utah	NA	NA	Vanadium	NA	1,361 (1,500)	Carbonate leach, solvent extraction
Bokum Resouces Corp.	Marquez Operations	Marquez, New Mexico	1979	NA	--	NA	1,814 (2,000)	NA
Chevron Resources Co.	Panna Maria Operations	Hobson, Texas	1978	0.06-0.08	--	27,216[b] (30,000)	2,268 (2,500)	Solvent extraction
Continental Oil Co., Minerals Department	Conquesta Operations	Falls City, Texas	1971	NA	--	CC[b]	1,588 (1,750)	Acid leaching, solvent extraction
Cotter Corporation	Canon City Mill	Canon City, Colorado	NA	NA	Molybdenum	98,936 (109,057)	454 (500)	Alkaline leach
Cotter Corporation	Schwartzwalder Mine	Golden, Colorado	1956	.30	Molybdenum	102,658[b] (113,160)	907 (1,000)	NA
Dawn Mining Company	Pinit-Ford Operations	Ford, Washington	1955	0.226	--	CC[b]	454 (500)	Acid leach, ion exchange
Exxon Minerals Co., U.S.A.	Highland Uranium Operations	Casper, Wyoming	NA	NA	--	EE[b]	2,721 (3,000)	Acid leach, solvent extraction

(continued)

Table 9-51. Continued

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Federal Resources Corp.	Federal-American/Partners Gas Hills	Riverton, Wyoming	NA	NA	--	57,153 (63,000)	862 (950)	Leaching, R.I.P.
Kerr-McGee Nuclear Corp.	New Mexico Uranium Operations	Ambrosia Lake, New Mexico	NA	.214	Molybdenum	EE[b]	6,350 (7,000)	Acid leaching, column ion exchange
Mines Development, Inc.	South Dakota Operations	Edgemont, South Dakota	NA	NA	--	NA	NA	NA
Mobil Oil Corp., Energy Minerals Division	Loredo Plant	Loredo, Texas	NA	NA	--	589,676 (650,000)	181 to 272 (200 to 300)	Leaching, column ion exchange
Pathfinder Mines Corp.	Lucky McMine	Riverton, Wyoming	NA	.20	--	549,660 (606,000)	2,540 (2,800)	Acid leach, resin, column ion exchange
Pathfinder Mines Corp.	Shirley Basin Mine	Shirley Basin, Wyoming	1970	.11	--	558,378 (615,500)	1,632 (1,800)	Acid leach, resin ion exchange
Petrotomics Company (Getty Oil Company)	Shirley Basin Uranium Operations	Shirley Basin, Wyoming	1976	NA	--	362,878 (400,000)	1,361 (1,500)	Leaching, agitation, acid-solvent extractor

(continued)

Table 9-51. Continued

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
Reserve Oil & Minerals Corporation	L-Bar Project	Bibo, New Mexico	NA	NA	--	CC[b]	1,450 (1,600)	Sulfuric acid leach
Rio Algom Corporation	Lisbon Mine	Moab, Utah	1972	NA	--	CC[b]	635 (700)	Basic leach, caustic precipitation
Rocky Mountain Energy Company	Bear Creek Uranium Project	Douglas, Wyoming	1977	NA	--	306,600 (338,000)	910 (1,000)	Acid leach
Sohio Natural Resources Company	L-Bar Operations	Seboyeta, New Mexico	1976	NA	--	479,900 (528,950)	1,360 (1,500)	Acid leach, solvent extraction
Union Carbide Corp., Metals Division	Uravan Operations	Uravan, Colorado	NA	NA	--	CC[b]	1,090 (1,200)	Acid leach, column ion exchange
Union Carbide Corp., Metals Division	Gas Hills Operations	Riverton, Wyoming	NA	NA	--	CC[b]	1,000 (1,100)	NA
United Nuclear Corp., Mining and Milling Division	New Mexico Operations	Gallup, New Mexico	NA	NA	--	CC[b]	2,720 (3,000)	Acid leach, solvent extraction
United Nuclear Homestake Partners	New Mexico Operations	Grants, New Mexico	1958	NA	--	CC[b]	3,180 (3,500)	Carbonate caustic leaching, precipitation

(continued)

Table 9-51. Concluded

Company	Plant	Location	Start up date	Ore grade (%)	Other metals	Ore processed Mg/yr (Tons/yr)	Concentrator capacity Mg/day (Tons/day)	Concentrator process
United States Steel Corp.	Texas Uranium Operations Burns Branch	Corpus Christi, Texas	NA	NA	--	136,079 (150,000)	NA	Ion exchange
Uranium Recovery Corp.	URC Facility	Mulberry, Florida	NA	NA	--	NA	NA	Solvent extraction
Western Nuclear, Inc.	Sherwood Mine and Mill	Wellpinit, Washington	1978	NA	--	240,406 (265,000)	1,814 (2,000)	Acid leach, solvent extraction
Western Nuclear, Inc.	Jeffrey City Operations	Gas Hills & Crooks Gap, Wyoming	1979	NA	--	544,316 (600,000)	1,542 (1,700)	Ion exchange
Wyoming Mineral Corp.	Copperton Unit	Bingham Canyon, Utah	NA	NA	--	FF[b]	4,082 (4,500)	Ion exchange
Wyoming Mineral Corp.	Bruni Unit	Bruni, Texas	NA	NA	--	NA	NA	Ion exchange
Wyoming Mineral Corp.	Sulfur Creek Unit	Sulfur Creek, Texas	1979	NA	--	NA	NA	Ion exchange
Wyoming Mineral Corp.	Irigaray Unit	Irigaray Ranch, Wyoming	NA	NA	--	NA	726 (800)	Ion exchange

[a]Mineral Information Services, 1979.

[b]CC = 90,719-453,597 Mg (100,000-500,000 short tons).
EE = 907,194-9,071,940 Mg (1,000,000-10,000,000 short tons).
FF = Greater than 9,071,940 Mg (10,000,000 short tons).
NA = Not available.
-- = None.

Table 9-52. PRODUCTION PROFILE AND PRICE HISTORY: URANIUM[a,b]

Parameters	Year				
	1974	1975	1976	1977	Oct. 1979[c]
Production					
Ore, 1,000 Mg (1,000 tons)	6,456 (7,115)	6,681 (7,362)	8,344 (9,195)	NA	NA
Uranium content Mg (tons)	11,261 (12,410)	11,158 (12,296)	12,701 (13,997)	13,608 (14,996)	NA NA
Imports, concentrate, Mg (tons) as metal	1,665 (1,835)	1,112 (1,225)	5,023 (5,535)	3,629 (3,999)	NA NA
Employment[d] (reduction plants)	--	100	200	300	NA
Average annual price (U_3O_8) Dollars per kg	25.24	52.20	87.52	93.03	66.12
Dollars per pound	11.45	23.68	39.70	42.20	30.00

[a]U.S. Bureau of Mines, 1980.

[b]American Metal Markets, 1978.

[c]$ per pound U_3O_8 as of October 31, 1980 from the Engineering and Mining Journal (1979).

[d]For nonenergy applications.

9.1.11 Zinc

Zinc is extremely versatile and has a number of uses as an alloy ingredient, a protective coating, and a chemical compound. Table 9-53 summarizes product uses of zinc. Most zinc goes to the construction industry where it is used in the galvanization of many materials. The transportation industry also uses zinc for galvanization, in die castings for automotive components, and in rubber for tires. Zinc is used in electrical equipment, office equipment and machinery, in sensitizing photocopying paper, as well as in a number of other applications.

Aluminum, magnesium, and plastics replace zinc in diecasting where weight limitations or surface finishes are important factors. The price of substitutes and zinc's superior durability affect the degree to which these substitutions are made. In many cases, the automobile industry has moved to lighter weight materials. Aluminum, magnesium, titanium oxides, and zirconium compounds are competitive in the chemical and pigment applications of zinc.

Zinc prices (covered in Table 9-54) and demand are correlated with general economic activity due to zinc's use in the construction and transportation industries. The producers of zinc also face competition from imports as indicated on Table 9-55. Lead and zinc are often processed in the same plant. Forty-three of the plants listed in Table 9-28 process zinc either alone or as a coproduct with lead. Table 9-56 lists additional industry characteristics. When mined in conjunction with lead, the concentration of zinc typically averages 1 percent.

Demand for zinc is expected to increase at about 2 percent per year through 1985. The three prospective new zinc processing plants were covered under the section on lead (Section 9.1.5). These facilities are expected to process both lead and zinc with a zinc ore grade of 1 percent.

Table 9-53. PRODUCT USES: ZINC[a]

Product uses	1978 (percent)	1979 (percent)
Construction materials	41	40
Transportation equipment	27	26
Electrical equipment	10	12
Machinery and chemicals	8	10
Other	14	12

[a]U.S. Bureau of Mines, 1980.

Table 9-54. PRICE HISTORY: ZINC[a]

Year	Actual prices ¢/kg	Actual prices ¢/lb	Based on constant 1976 dollars ¢/kg	Based on constant 1976 dollars ¢/lb
1954	23.57	10.69	52.91	24.00
1955	27.12	12.30	59.52	27.00
1056	29.74	13.49	63.27	28.70
1957	25.13	11.40	51.81	23.50
1958	22.73	10.31	46.08	20.90
1959	25.26	11.46	50.04	22.70
1960	28.55	12.95	55.56	25.20
1961	25.46	11.55	49.16	22.30
1962	25.64	11.63	48.50	22.00
1963	26.48	12.01	49.38	22.40
1964	29.92	13.57	55.12	25.00
1965	31.97	14.50	57.54	26.10
1966	31.97	14.50	55.78	25.30
1967	30.53	13.85	51.59	23.40
1968	29.76	13.50	48.28	21.90
1969	32.30	14.65	49.82	22.60
1970	33.77	15.32	49.38	22.40
1971	35.56	16.13	49.60	22.50
1972	39.13	17.75	52.25	23.70
1973	45.64	20.70	57.54	26.10
1974	79.26	35.95	91.05	41.30
1975	85.89	38.96	90.39	41.00
1976	81.59	37.01	81.57	37.00
1977	75.82	34.39	71.87	32.60
Oct.[b] 1979	79.84	36.21	--	--

[a]Average annual price of zinc metal from Cammarota (1978).

[b]Average price for October from Engineering and Mining Journal (1979).

Table 9-55. PRODUCTION PROFILE: ZINC[a]

Parameters	Year 1974	1975	1976	1977	1978
Production 1,000 Mg (1,000 tons) as metal					
Mine	453 (499)	426 (469)	440 (485)	408 (450)	303 (334)
Primary slab zinc	504 (555)	397 (437)	453 (499)	408 (450)	407 (449)
Secondary redistilled slab zinc	71 (78)	53 (58)	62 (68)	46 (51)	35 (39)
Imports for consumption, 1,000 Mg (1,000 tons) as metal					
Ore and concentrates	121 (133)	389 (429)	141 (155)	109 (120)	106 (117)
Slab zinc	493 (543)	340 (375)	631 (695)	504 (555)	622 (685)
Exports: Slab zinc, 1,000 Mg (1,000 tons) as metal	17 (19)	6 (7)	3 (3)	b	1 (1)
Employment:					
Mine and mill[c]	6,700	6,700	6,700	6,600	5,700
Smelter	4,500	4,100	4,100	4,100	4,100
Net import reliance[d] as a percent of apparent consumption	59	61	58	57	66

[a]U.S. Bureau of Mines, 1980.

[b]Less than one-half unit.

[c]Includes all zinc and/or lead-zinc producing units.

[d]Net import reliance = imports-exports+adjustments for Government and industry stock changes.

Table 9-56. INDUSTRY CHARACTERISTICS: ZINC

Number of leading companies (lead/zinc)	8
Number of active operations (lead/zinc)	46 (11 temporarily inactive)
Percent of capacity controlled by leading companies (as 95 percent ZnS + PbS concentrate)	$86.9 million
Major processing states	Missouri, Idaho, New Jersey
Ratio of ore to product	Range: 10 - 100 Average: 25 New lead/zinc plants: 100

9.1.12 Zirconium

Zirconium, covered by Tables 9-57 through 9-60, is consumed in two basic forms: zircon (zirconium silicate) which represents over 90 percent of production tonnage, and zirconium metal. As indicated in Table 9-59, zircon is used in foundry sands, refractories, abrasives, ceramics, and as a source of zirconium metal. Zirconium metal is used in nuclear reactors, corrosion resistant industrial equipment, flash bulbs, and as a refractory alloy. Commercial nuclear generating plants consume over 90 percent of nonmilitary zirconium metal production. Zircon may be replaced in certain foundry applications by chromite and some aluminum silicate minerals. There are no ready substitutes for zirconium in its nuclear uses.

Plants that process zirconium and titanium as their main product are listed in Table 9-42. Demand for zircon is expected to increase at an annual rate of around 3 percent through 1985 (United States Bureau of Mines, 1980). New demand will be met from the production of zirconium as a coproduct of titanium from sand-type ores (see Section 9.1.8). Based on the ore grades of existing plants, an ore grade of 0.9 percent (as zircon) was assumed for new plants.

9.1.13 Strategic Stockpile

Many of the metals or metallic minerals under consideration for this NSPS are stockpiled in various forms by the United States government for strategic reasons. Table 9-61 lists the metals and the metallic form stockpiled. Actual quantities stockpiled and the respective stockpile goals are also given. The stockpiling efforts of the United States government have sometimes been characterized as erratic and stockpiling activities do not necessarily follow articulated policies. For the year 1979, the only two metals subject to government sales were tungsten and gold. Tungsten sales amounted to 4,250,000 pounds of ores and concentrates.

Table 9-57. PRODUCTION PROFILE: ZIRCONIUM[a]

Parameters	Year 1974	1975	1976	1977	1978
Production Mg (tons)					
Zircon	b	b	b	b	b
Zirconium metal	b	b	b	b	b
Imports Mg (tons)					
Zircon	56,703 (62,487)	36,474 (40,194)	58,644 (64,626)	59,153 (65,187)	82,730 (91,168)
Zirconium metal	332 (366)	738 (813)	452 (498)	580 (639)	900 (992)
Exports Mg (tons)					
Zircon	19,493 (21,481)	17,024 (18,760)	8,553 (9,429)	13,029 (14,358)	6,974 (7,685)
Zirconium, alloys, and scrap	748 (824)	1,202 (1,325)	1,045 (1,152)	891 (982)	936 (1,031)
Employment					
Mine and mill	500	550	550	550	500
Metal plant	900	850	800	800	750
Net import reliance[c] as a percent of apparent consumption	b	b	b	b	b

[a]U.S. Bureau of Mines, 1980.

[b]Withheld.

[c]Net import reliance = imports-exports+adjustments for Government and industry stock changes.

Table 9-58. PRICE HISTORY: ZIRCONIUM[a]

Year	\$/Mg	\$/Short ton
1974	331	300
1975	232	210
1976	165	150
1977	165	150
1978	201	183
1979	165	150

[a]Average annual price of Zirconium concentrate (65 percent ZrO_2) from Engineering and Mining Journal.

Table 9-59. PRODUCT USES: ZIRCONIUM[a]

Product uses	1978 (percent)	1979 (percent)
Foundry sands	42	42
Refractories	30	30
Ceramics	12	12
Abrasives	4	4
Miscellaneous uses, including nuclear	12	12

[a]U.S. Bureau of Mines, 1980.

Table 9-60. INDUSTRY CHARACTERISTICS: ZIRCONIUM

Number of leading companies (titanium and zirconium)	3
Number of active operations	5 (1 temporarily inactive)
Precent capacity controlled by leading companies	98
Value of processing plant output (as ilmenite/zircon concentrate)	70.5
Major processing states	Florida, New Jersey
Ratio of ore to product (as zircon)	100

Table 9-61. STRATEGIC STOCKPILES[a]

Metal	Stockpile form	Stockpile goals	(year)	Stockpile actual	(year)
Aluminum	Bauxite				
	Jamaica grade	523,000[b]	(1977)	8,900,000[b]	(1977)
	Surinam grade	0	(1977)	5,300,000[b]	(1977)
	Refractory grade	2,100,000[c]	(1977)	173,000[c]	(1977)
	Aluminum oxide				
	Alumina	11,500,000	(1977)	0	
	Abrasive grain	75,000	(1977)	50,900	(1977)
	Crude	148,000	(1977)	250,000	(1977)
	Primary metal	0		1,700	(1977)
Copper	Refined copper	1,300,000	(1979)	22,000	(1979)
Gold	Bullion			278,000,000 oz	(1977)
Iron[d]					
Lead	Metal	865,000	(1979)	600,000	(1979)
Molybdenum[d]					
Silver	Metal	0	(1977)	139,500,000 oz	(1977)
Titanium	Rutile ore	132,000[e]	(1976)	39,000	(1976)
	Sponge metal	132,000	(1979)	21,500	(1979)

(continued)

Table 9-61. Concluded

Metal	Stockpile form	Stockpile goals (year)	Stockpile actual (year)
Tungsten	Ores & concentrates	8,800,000 lbs (1979)	60,000,000 lbs (1979)
	Carbide powder	12,900,000 lbs (1979)	1,900,000 lbs (1979)
	Ferrotungsten	17,800,000 lbs (1979)	840,000 lbs (1979)
	Metal powder	3,300,000 lbs (1979)	1,600,000 lbs (1979)
Uranium	NA[f]		
Zinc	Slab zinc	1,313,000 (1979)	372,000 (1979)
Zirconium[d]			

[a]All data in short tons, unless otherwise noted. From Mineral Commodity Profiles and Mineral Commodity Summaries for each individual metal.

[b]Long dry tons.

[c]Long calcine tons.

[d]No government stockpiles.

[e]Pending Congressional approval (as of 1976).

[f]NA - No information available.

9.1.14 REFERENCES FOR SECTION 9.1

American Metal Market. 1978. Metal Statistics. Fairchild Publications. New York. p. 253-254.

Baumgardner, L. United States Bureau of Mines. 1981. Telephone conversation with M. Buckwalter, TRW. February 11. Discussion of ore grades for bauxite processing plants.

Butterman, W. C. 1978. Gold: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D. C. 17pp.

Carter, R. A. 1978. Nations Newest Silver Mine Uses Open-Pit Methods. Mining Engineering. p. 41-44.

Cammarota, V. A. 1978. Zinc: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D. C. 25pp.

Drake, H. J. 1978. Silver: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D. C. 14pp.

Engineering and Mining Journal. 1979. Engineering and Mining Journal Markets. 180(5): p. 19-25.

Engineering and Mining Journal. 1980. 1980 Survey of Mine and Plant Expansion. 181(1): p. 76-90.

Etheridge, D. A. 1980. Gold. Engineering and Mining Journal. 181(3): p. 120-23.

Klinger, F. L. 1978. Iron Ore: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D. C. 27pp.

Kornhauser, B. A. and Philip T. S. 1978. Tungsten: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D. C. 22pp.

Kummer, J. T. 1979. Molybdenum: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D. C. 23pp.

Lynd, L. F. 1978. Titanium: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D. C. 19pp.

Mining Information Services. 1979. International Directory of Mining and Mineral Processing Operations. Engineering and Mining Journal (McGraw Hill). New York. p. 11-242.

Ryan, J. P. and J. M. Hague. 1977. Lead: Mineral Commodity Profile. U.S. Bureau of Mines. 23pp.

Schroeder, H. J. 1979. Copper: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D. C. 20pp.

Stamper, J. W. and H. F. Kurtz. 1978. Aluminum: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D. C. 29pp.

Stephenson, P. U.S. Bureau of Mines. 1981. Telephone conversation with M. Alexander, TRW. February 11. Discussion of start-up dates and mill capacity for bauxite processing plants.

United States Bureau of Mines. 1980. Mineral Commodity Summaries.

Veith, D. Minnesota Bureau of Mines. 1980. Telephone conversation with E. Monnig, TRW. July 23. Discussion of nickel mining in Minnesota.

9.2 ECONOMIC IMPACT ASSESSMENT

9.2.1 Introduction and Summary

9.2.1.1 Introduction. This section assesses the economic impact of the regulatory alternatives on the metallic mineral processing industries. Economic profile information on the industries presented in Section 9.1 is a principal input to this assessment. For the purpose of economic analysis the 12 metals are divided into ten industries. In the economic analysis lead and zinc are treated as coproducts of a single industry, as are titanium and zirconium. Various financial analysis techniques are applied to the model plants to determine potential impacts on control affordability and control capital availability. These findings are assessed, based on the industry profile, to determine the industry-wide impacts that will be presented in Section 9.3.

As noted in previous chapters the facilities of interest, located at the crude ore milling stage of the production process, are: crushers, screens, ore bins, hammer mills, dryers, product transfer points and product loadout facilities. Model plants for some of the metals contain all of the facilities of interest, but not every model plant contains every facility of interest.

9.2.1.2 Summary. Table 9-62 lists the percentage price increases, the percentage capital cost increases, and the affordability conclusions, using the most costly regulatory alternative for all industries and model plant sizes. The most costly regulatory alternative for each model plant refers to the regulatory alternative that has the highest net annualized cost, which is alternative 3b.

A screening analysis shows that none of the ten industries is likely to experience a significant impact for any model plant size when the most costly regulatory alternative is added. Each of the ten products would require a sales price increase, usually at the refined metal stage of processing, of two percent or less when the most costly regulatory alternative is added.

Because the most costly regulatory alternative (3b) is likely to be affordable, the less costly alternatives (2 and 3a) are also affordable and therefore a separate analysis of these alternatives is not provided.

Table 9-62. SUMMARY OF PRICE INCREASE FOR THE MOST STRINGENT REGULATORY ALTERNATIVE

Metal	Plant Size (TPH)	Cents Per Pound Increase	Percentage Price Increase	Capital Percent Increase	Control Affordability Conclusion
1. Aluminum	(150)	0.02	Ins.	Ins.	affordable
	(300)	0.02	Ins.	Ins.	affordable
2. Copper	(150)	1.6	1.7	0.2	affordable
	(600)	0.8	0.8	0.2	affordable
3. Gold	(75)	84. (troy oz)*	0.2	0.2	affordable
	(150)	52. (troy oz)	0.1	0.2	affordable
4. Iron Ore	(1200)	0.16 (LTU)**	0.2	0.1	affordable
	(2400)	0.18 (LTU)	0.3	0.1	affordable
5. Lead/Zinc***	(300)	0.1	0.2	0.2	affordable
	(600)	0.1	0.2	0.2	affordable
6. Molybdenum	(300)	1.1	0.1	0.2	affordable
	(1200)	0.6	0.1	0.2	affordable
7. Silver	(50)	7. (troy oz)	0.5	0.4	affordable
	(150)	3. (troy oz)	0.2	0.2	affordable
8. Titanium/	(300)	0.1	0.8	0.9	affordable
Zirconium	(600)	0.1	0.8	1.2	affordable
(sand)					
9. Tungsten	(25)	3.6	0.5	1.0	affordable
10. Uranium	(25)	8.8	0.2	0.8	affordable
	(75)	3.6	0.1	0.3	affordable

Ins. = insignificant (< .1 percent)

*14.5 Troy Ounces = 1 pound avoirdupois

**1 Long Ton Unit (LTU) = 22.4 pounds

***Note the discussion in Section 8.1 on the possible effects of the NAAQS for lead on the calculation of the control costs for lead/zinc processing plants.

9.2.2 Methodology

This section describes the methodology used to assess the economic impact of the regulatory alternatives on the ten industries that include 19 model plants. The principal economic impact which is assessed is the effect of incremental control costs on the profitability of new grassroots plants, or expansions of existing plants. Expansions of existing plants are represented by the smaller model plant sizes and therefore a separate analysis for expansions is not necessary.

Since each state implementation plan (SIP) contains particulate emission control standards, any new plant would have to meet SIP standards even in the absence of a NSPS. Incremental control costs are the control costs above those baseline costs required to meet the various SIP standards.

In the analysis which follows, each model plant is evaluated as if it stands alone, that is, the firm is not associated with any other business activity nor is it associated with any larger parent company. This assumption has the effect of isolating the control cost without any assistance from other business activities or firms. This is a conservative assumption because many of the companies in the metallic mineral processing industries are large corporations with substantial management, financial, and other resources, any or all of which could be used to aid other product lines or subsidiaries. For example, a parent corporation could lend money to a subsidiary, or a parent corporation could guarantee repayment of a subsidiary's loan.

This analysis assumes that a plant is profitable in the absence of a NSPS. Therefore, the focus of this analysis is on incremental costs to determine if a plant which would otherwise be profitable is now rendered unprofitable as a result of the incremental control costs.

Economic impact is evaluated on model plants whose description is based on representative characteristics of new or expanded plants, such as production capabilities, asset size, and other financial measures. The model plants provide an indication of the degree of impact on all new plants in the industry by incorporating into the models the major characteristics prevailing in various size segments of the metallic mineral processing industry. They do not represent any particular existing plant as any individual plant may differ in one or more of the above characteristics.

The methodology employs a screening analysis based on the percentage price increase necessary to completely pass-through to customers the added cost of the most costly regulatory alternative for each plant size.

9.2.2.1 Screening Analysis. The screening analysis is based on the percentage price increase necessary to completely pass through to customers the added cost of the most costly regulatory alternative. The prices used are typically those prices shown in Section 9.1 for the individual price histories of the metals. Prices are as of October 1979, the same date as for the control costs. The price cited for each metal is for the first product form that is normally sold in significant quantities and has a published price. The prices cited are at the refined metal stage of the production process, or contained metal, for, aluminum, copper, gold, lead/zinc, and silver. The price for iron ore is in the form of pellets at Lake Superior mines. The prices for molybdenum, titanium/zirconium, tungsten, and uranium are in the concentrate form rather than the refined metal form. The differences are a reflection of the differences in the degree of integration of the producers of the various metals and the related commercial activity of the marketplace. For example, approximately 62 percent of the copper that is smelted domestically is part of an integrated operation (U.S. E.P.A., 1980 p. 9-5).

The model plant parameters are described in Chapter 6. For each model plant the total hours of operation per year is multiplied by the capacity utilization rate to provide the effective annual hours of operation. The effective annual hours of operation are then multiplied by the hourly capacity of the plant to provide the tons of ore processed annually at the plant. The tons of ore processed annually is then multiplied by the ore grade and recovery rate and the result is the product output, or "yield", of the plant. In order to simplify the analysis and to be conservative, a single ore grade is employed for each metal, and no byproducts or coproducts are included (except lead/zinc and titanium/zirconium).

The calculations for a copper model plant are provided as an example:

Copper (150) TPH

8,500	total hours of annual operation
x 96%	capacity utilization rate
8,160	effective hours of annual operation
150	tons per hour (TPH)
x 8,160	hours of operation per year
1,224,000	tons of ore processed per year

1,224,000	tons per year
x .45%	ore grade
5,508	tons of product (contained copper metal)

5,508	tons of contained copper
x 93%	recovery rate
5,122	yield

The yield is calculated for each model plant. The control costs are described in Section 8.1. The net incremental annualized control cost above the SIP for the most costly regulatory alternative is then divided by the yield to provide the dollar cost increase per unit of product. The cost increase per unit of product is then divided by the product sales price to provide the percentage increase in sales price. The earlier copper (150) TPH model plant illustration is again used as an example:

<u>Copper (150) TPH</u>

5,122	yield in tons
x 2,000	pounds per ton
10,244,000	pounds

\$372,100	Alternative #3b
-204,700	less Alternative #1 (SIP)
\$167,400	net incremental annualized cost of Alternative #3b

$$\frac{\$167{,}400}{10{,}244{,}000} = \text{net incremental annualized cost per pound} = 1.6¢ \text{ per pound}$$

$$\frac{1.6¢}{95.3¢} = \frac{\text{incremental cost of Alternative \#3b}}{\text{copper sales price per pound as of October 1979}} = 1.7\%$$

1.7% = incremental cost of Alternative #3b.

The percentage price increases for all model plants are shown in Table 9-62.

It is not unusual for the product prices of many of the ten industries to fluctuate by substantially more than two percent. Further, prices quoted among producers of the same metal may frequently vary by two percent or more due to differences in production costs, transportation costs, inventory levels, contract terms, and so on. For example, two major copper producers follow an announced pricing policy of charging a 2.5 cent premium over the Comex quoted copper price (which is greater than 2.5 percent based on a 1979 price of less than $1.00 per pound). Also, even in the "worst case" situations two percent is considerably lower than the five percent industry average rate which is one of the EPA review guideline criteria for major economic impact. Additionally, a two percent cutoff limit was used in the nonmetallic minerals NSPS. Therefore, it appears that a price increase of two percent or less could be passed through without adverse impacts on the plants.

9.2.3 Findings

This section describes the findings for each of the metals. Various economic factors have different degrees of significance among the ten metals, for example imports may be highly significant for one mineral and insignificant for another. Therefore, each of the ten metals is discussed individually, with emphasis on those economic factors that are most significant to an assessment of the economic impact of incremental control costs for the particular metal at hand.

9.2.4 Aluminum

Section 9.1.1 has provided a profile of the aluminum industry and Section 9.2.1.2 has noted that the addition of the most costly regulatory alternative will require price increases of less than two percent, or specifically .03 and .03 percent for the 150 and 300 TPH aluminum model plants. Also, the increase in capital for the model plants as a result of the incremental controls is insignificant for the model plants. The increased capital required for control equipment will add $63,000 and $130,000 to total investments of $430,000,000 and $870,000,000 for the 150 and 300 TPH model plants, respectively. If an investment in an aluminum processing plant would otherwise be accepted, neither the additional price increase nor the additional capital requirement is likely to cause that investment to now be rejected.

9.2.4.1 Ownership, Location, Concentration. There are three principal corporations in the domestic aluminum industry: Aluminum Co. of America, Reynolds Metals Co., and Kaiser Aluminum and Chemical Corp. These three producers are fully integrated and as a group accounted for 86 percent of domestic primary aluminum capacity in 1979. The principal processing states are Texas and Louisiana.

The large size of the corporations in the aluminum industry, as well as the small sizes of the control capital requirements for the model plants, indicates that the necessary capital for the incremental controls will be available.

9.2.4.2. Pricing. The price of aluminum metal has increased from 55 cents per pound in early 1979 to 58 cents in mid 1979. During early 1980 the price continued to increase to 66 cents per pound.

The incremental control costs will require a price increase for the 150 and 300 TPH aluminum model plants, of less than .1 cent per pound, based on an October 1979 sales price of 60 cents per pound.

In past years during periods of over capacity the industry has experienced some discounting from the quoted price as well as some premium pricing when supply is constrained.

Beyond the normal elements that influence the price of any product, an additional element influencing the price of aluminum is that the industry's domestic prices are currently subject to the voluntary wage and price guidelines and as a result there is some disparity between domestic prices and world prices (The Wall Street Journal, May 6, 1980 p. 2). (As of this writing the guidelines are due to expire on December 31, 1980).

9.2.4.3 Supply. The aluminum industry is dominated by a relatively small number of major participants. Also, government actions play a substantial role in the aluminum industry and the supply of aluminum. Six international corporate groups (three domestic and three foreign) own or control approximately 50 percent of the world's productive capacity. Another 50 firms, most nonintegrated and many associated with one of the above six groups or with a government, own or control 25 percent of the world's capacity. Governments of 24 countries own or control the remaining 25 percent of capacity.(Stamper and Kurtz, 1978 p. 1).

The activity of governments may also influence the aluminum industry through changes in stockpiles. The U.S. Government maintains a stockpile of various forms of aluminum and through 1977 made sales from the stockpile. By the end of 1977 the stockpile of primary metal was essentially depleted. (Aluminum Association, 1978, Stamper and Kurtz, 1978 p. 20).

The United States has large quantities of aluminum resources; however, the costs to use these domestic resources exceed the costs to use foreign bauxite. Therefore, domestic producers import 90 percent of bauxite requirements.

An additional important source of aluminum in the total supply of aluminum is the recycling of aluminum scrap. Domestic secondary recovery of aluminum accounted for approximately 22 percent of the total supply of domestic aluminum in 1978.

Primary aluminum metal production requires large amounts of electrical energy, particularly at the smelting stage of the production process. The cost of electrical energy has risen considerably in recent years, particularly in the Northwestern United States. The domestic cost and availability of electricity will play an increasingly important role in the continued operation of existing facilities and in the location of new facilities, both domestic and foreign (Chemical Week, 1980 p. 17).

9.2.4.4 Demand. Roughly 88 percent of the total aluminum consumption in 1978 was in the form of metal.

The aluminum industry is currently experiencing renewed financial strength after several years of surplus capacity and depressed earnings. A principal reason for the improved outlook for the industry is the increased substitution of aluminum for steel by the transportation industry in order to reduce vehicle weight and increase fuel efficiency.

From 1968 to 1977 domestic demand for primary aluminum grew at an average annual rate of 3.3 percent. As noted in Section 9.1.1 the domestic demand for aluminum is projected to increase at the rate of 2.1 percent per year through 1985.

9.2.5 Copper

A profile of the copper industry was provided in Section 9.1.4. Table 9-83 shows that the addition of the most costly regulatory alternative requires price increases of 1.7 and 0.8 percent for the 150 and 600 TPH model plants, respectively. The increase in capital for the model plants as a result of the incremental controls is .2 percent for both model plant sizes. The increased capital required for control equipment will add $161,000 and $323,000 to total investments of $65,000,000 and $133,000,000 for the 150 and 600 TPH model plants, respectively. If an investment in a copper ore processing plant would otherwise be accepted, neither the additional cost increase nor the additional capital requirement is likely to cause that investment to now be rejected. Although both plants are below the two percent limit, the percentage price increase for the 600 TPH is substantially lower than the percentage price increase for the 150 TPH. This suggests that the added control costs may influence new investments toward larger plant sizes.Also, a higher ore grade, or the addition of byproduct revenues such as nickel or silver, or both, would increase revenues and profits for the model plants and reduce the impact of the control costs.

9.2.5.1 Ownership, Location, Concentration. As noted in Section 9.1.2, there are eight leading companies in the copper industry which control 76 percent of the capacity. The leading companies are major corporations, most of which are fully integrated from mining through refining. Also, several of the leading companies are prominent in the mining of other metals discussed here. Other major corporations, such as major oil companies, either directly or through subsidiaries, maintain considerable ownership interests in the primary copper producing companies both in the United States and in foreign countries. A partial list of leading copper companies that are owned by parent corporations would include: Anaconda Company -- a subsidiary of ARCO; Duval Corporation -- a subsidiary of Pennzoil Company; Magma Copper Company -- a subsidiary of Newmont Mining Company; and Cyprus Mines Corporation -- a subsidiary of Standard Oil Company (Indiana). The major copper-producing states are Arizona, Nevada, New Mexico, and Utah.

9.2.5.2 Pricing. The price of copper can be volatile. During December 1978 the price of copper metal averaged 70.9 cents per pound while one year later during December 1979 the price averaged $1.05 per pound for a gain of 48.7 percent. Also, during early 1980 the price of copper rose to a record high price of $1.41 per pound and then declined to 88 cents per pound by April 1980, a decline of 37.5 percent.

Copper is a widely-traded world metal with the bulk of trading taking place on two major international exchanges: the New York Commodity Exchange (Comex) and the London Metal Exchange (LME).

Prior to 1978, U.S. producers followed a pricing policy not tied directly to the major exchanges. The U.S. producer price was intended to be more stable than the exchange price and thereby promote improved business planning by participants in the industry. When the exchange price was high, the producer price was normally lower, and when the exchange price was low, the producer price was normally higher.

In May 1978 two major U.S. copper producers, Kennecott and Anaconda, introduced a new pricing policy for their companies and began basing their price directly on the exchange price and charging a 2.5 cent premium above the Comex price. The new pricing policy permits these two producers to compete more effectively with foreign imports by introducing greater flexibility into their pricing policy. The domestic price of copper was subject to price controls from June 1973 until May 1974. Another result of the change in pricing policy is that domestic copper prices are less likely to be subject to federal wage and price guidelines, since the price of copper is determined as a widely-traded commodity.

9.2.5.3 Supply. The average U.S. dependence on imports of copper is 12 percent. However, the U.S. dependence on foreign imports has varied from a position of 20 percent dependence in 1974 to net exporter in 1975, back to a position of 19 percent dependence in 1978.

An important source of copper in the total supply of copper is the recycling of copper scrap. During 1979 total scrap (new and old) provided approximately 20 percent of total refined copper production at domestic primary plants (U.S. Bureau of Mines, MIS).

Over 40 percent of the Free World's primary copper production is government-owned or controlled. (Kennecott Copper Corporation, 1979, p.4). Therefore, international political and economic events can have a significant impact on the price and supply of copper both in the United States and world-wide. For example, some less-developed countries that are copper exporters have a critical need for foreign currency such that these countries are willing to continue to sell copper on the world market even during periods of over-supply or slack demand (The Wall Street Journal, February 25, 1980). Another example of the influence of political events on the supply of copper is provided by the fact that in the past U.S. companies have experienced partial or complete nationalization of their interests in a number of countries, including Chile, Zambia, and Peru.

9.2.5.4 Demand. Electrical applications account for more than half of domestic copper consumption. Other major applications are in the construction, industrial machinery, and transportation industries.

As noted in Section 9.1.4, the demand for copper is projected to increase at an annual rate of approximately three percent through 1985.

9.2.6 Gold

Section 9.1.5 has provided a profile of the gold industry and Section 9.2.1.2 has noted that the addition of the most costly regulatory alternative will require price increases of less than 2 percent, or specifically .2 and .1 percent for the 75 and 150 TPH gold model plants, respectively. The increase in capital for each of the model plants as a result of the incremental controls is .2 percent. The increased capital required for control equipment will add $65,000 and $93,000 to total investments of $34,000,000 and $52,000,000 for the 75 and 150 TPH model plants, respectively. If an investment in a gold ore processing plant would otherwise be accepted, neither the additional price increase nor the additional capital requirement is likely to cause that investment to now be rejected.

9.2.6.1 Ownership, Location, Concentration. As noted in Section 9.1.5 there are 17 domestic gold ore processing plants. The plants are located principally in the states of Nevada, California, Colorado, South Dakota, and Washington. There are four leading companies in the industry and these four companies own 70 percent of the industry's capacity.

9.2.6.2 Pricing. Gold's unique position in international financial markets has been accompanied by a history of substantial government control over and involvement in the gold market. This has the effect of making the price of gold relatively more dependent on political developments and relatively less dependent on economic fundamentals.

In recent years the price of gold has been volatile. Gold is widely regarded as a hedge against economic uncertainty and international political turmoil, and therefore during such times the price of gold frequently experiences sharp price increases, due to speculation. The price of gold has risen from $36.41 per troy ounce in 1970 to $800 per troy ounce in early 1980 while later declining to about $500 per troy ounce. During this time daily price fluctuations of $20 per ounce or more have not been uncommon.

These price fluctuations can be viewed in relation to the incremental control cost price increases of 84 cents per troy ounce and 52 cents per troy ounce, which is equivalent to .2 and .1 percent for the 75 and 300 TPH model plants, respectively. These price increases are based on a gold price of $353.44 per troy ounce in October 1979 which is a conservative price when compared to a more recent price of approximately $553 in March of 1980.

9.2.6.3 Supply. Government activities play a significant role in the supply of gold. It is estimated that nearly half of all the gold that has been mined in the world, or 1.3 billion ounces, is in government vaults.

In the United States roughly 40 percent of total output is a byproduct of base metal mining, particularly copper. This byproduct relationship creates a degree of dependence for the domestic supply of gold on the outlook for copper and other base metals.

The U.S. relies on imports to supply approximately 50 to 60 percent of domestic consumption. The major source of supply of imported gold into the United States is the Republic of South Africa. The Republic of South Africa produced 72 percent of the output of the market economy countries. The political controversy surrounding the Republic of South Africa introduces an element of uncertainty into the supply of gold.

9.2.6.4 Demand. Jewelry is the dominant fabricated use for gold, followed by industrial uses, principally in the manufacture of electronic components, and dentistry. This pattern is likely to continue into the future.

As stated in Section 9.1.5 the industrial demand for gold is projected to grow at an annual rate of 2.7 percent through 1985. Speculative demand, in addition to industrial demand, is likely to remain an important element in the total demand for gold.

9.2.7 Iron Ore

Section 9.1.6 has provided a profile of the iron ore industry, and Section 9.2.1.2 has noted that the addition of the most costly regulatory alternative will require price increases of .2 and .3 percent for the 1,200 and 2,400 TPH iron ore model plants, respectively. The increase in capital for the model plants as a result of the incremental controls is less than .1 percent. The increased capital required for control equipment will add

$444,000 and $1,013,000 to total investments of $707,000,000 and $1,430,000,000 for the 1200 and 2400 TPH model plants, respectively. If an investment in an iron ore plant would otherwise be accepted, neither the additional control costs nor the additional capital requirement is likely to cause that investment to now be rejected.

9.2.7.1 Ownership, Location, Concentration. As noted in Section 9.1.6 there are five leading companies in the iron ore industry which control 56 percent of the capacity.

The steel companies are a dominant force in the iron ore industry. The steel companies are essentially the only consumers of iron ore and they maintain considerable ownership in the iron ore companies.

The two major producing states are Minnesota and Michigan and particularly Minnesota's Mesabi Range.

9.2.7.2 Pricing. The standard unit of weight for iron ore is the long or gross ton which is 2,240 pounds. Published prices for pellets are for a long ton unit (LTU) which is one percent of a long ton, or 22.4 pounds. The price of an LTU as of October 1979 was 65.5 cents. The cost of controls will add .16 and .18 cents to the price of an LTU for the 1200 and 2400 TPH model plant sizes, respectively.

9.2.7.3 Supply. Foreign imports of iron ore have grown from less than five percent of demand in 1953 to approximately one-third in 1977. Over half of the imports in 1977 came from mines owned, operated, or partially owned by U.S. mining and steel companies. Therefore, the major U.S. companies in the iron ore industry are important not only in terms of domestic operations, but also in foreign operations, which is indicative of their significance throughout the marketplace for iron ore.

In addition to the actions of U.S. companies, availability or price of iron ore from abroad may be influenced by foreign political developments. Companies owned or controlled by foreign governments produced about 60 percent of the estimated 785 million tons of iron ore produced outside of the United States in 1977. For example, nationalization of U.S.-owned mines in Chile in 1971 and in Venezuela and Peru in 1975 affected about one-third of U.S. imports of iron ore. Imports from Chile dropped to a small fraction of their original level for several years; imports from Peru ceased for a year and a half; imports from Venezuela in 1977 were less than 50 percent of their volume in 1975. (Klinger, 1978 p. 3, 19).

9.2.7.4 Demand. More than 98 percent of the iron ore consumed in the United States is used in the production of iron and steel. Therefore the financial condition of the iron ore industry is dependent upon the financial condition and production plans of the steel industry.

As stated in Section 9.1.6 the steel industry is projected to maintain good growth through 1985, with demand for iron and steel increasing at an annual rate of 2.5 percent.

9.2.8 Lead/Zinc

A profile of the lead and zinc industries was provided in Sections 9.1.7 and 9.1.1.5. As in earlier sections, lead and zinc are considered jointly for this discussion since they are often mined as byproducts and coproducts. Table 9-83 shows that the addition of the most costly regulatory alternative will require a price increase of .2 percent for both the 300 and 600 TPH lead/zinc plants. The increase in capital for the model plants, as a result of the incremental controls, is .2 percent for both model plant sizes. The increased capital required for control equipment will add $212,000 and $323,000 to total investments of $95,000,000 and $214,000,000 for the 300 and 600 TPH model plants, respectively. If an investment in a lead/zinc ore processing plant would otherwise be accepted, neither the additional control costs nor the additional capital requirements are likely to cause that investment to now be rejected.

9.2.8.1 Ownership, Location, Concentration. As noted in Sections 9.1.7 and 9.1.1.5, there are eight leading companies in the lead/zinc industry. These eight companies control 85 percent of the industry's capacity.

The major lead and zinc primary producers are large corporations that are vertically integrated from mining through refining. Several of the major producers are also prominent in the mining of other metals among the fifteen metals discussed here. Many of the leading producers also have substantial foreign interests.

Except for the lead deposits in the Virburnum Trend in southeastern Missouri, the largest lead-producing area in the United States, the value of associated metals often exceeds the value of the lead. The principal processing states are Missouri, Idaho, Colorado, Utah, and New Jersey.

9.2.8.2 Pricing. During early and mid-1979, both lead and zinc experienced increasing prices with lead rising from 40.8 to a high of 61.1 cents per pound and zinc rising from 34.6 to a high of 39.4 cents per pound. Late in 1979 and during early 1980, prices of both metals began to decline, with lead falling below 49 cents per pound and zinc falling below 38 cents per pound.

Both metals are commonly traded internationally, with the LME serving as the most widely followed exchange.

United States government actions can be a significant force in the market for both lead and zinc. Lead was subject to domestic price controls from June 1973 to December 1973. Zinc was subject to price controls from August 1971 to December 1973.

The price increases are .1 cent per pound for both the 300 and 600 TPH model plants. This price increase is equivalent to .2 percent.

9.2.8.3 Supply. Foreign imports of lead comprise roughly 10 to 20 percent of consumption. Foreign imports of zinc account for roughly 60 percent of domestic consumption (Commorata, 1978 p. 1). The composition of zinc imports has changed over the past decade from predominantly ore and concentrate with metal playing a lesser role, to zinc imports which are now predominantly metal, with ores and concentrates now accounting for the lesser share.

The significance of the change in the composition of zinc imports is that as less of the product's value is added in the U.S., less domestic zinc smelting and refining capacity is needed. From December 1968 to May 1975, eight primary zinc smelters or refineries closed in the United States due to either obsolescence, or lack of concentrate feed materials, or environmental costs, or some combination of these elements (one plant was converted to an eletrolytic process and a second plant was purchased by another company and reopened in 1973) (International Trade Commission, 1978 p. A-24). These closings represented a decline in domestic capacity of about 570,000 short tons, or approximately 50 percent of domestic capacity (International Trade Commission, 1978 p. A-24, Commorata, 1978 p. 1). An additional zinc smelter closed in December 1979 (The Wall Street Journal, April 16, 1980).

Recycled lead is an important component of supply accounting for about 35 to 40 percent of lead consumption (Ryah and Hague, 1977 p. 1). Relative to recycled lead, recycled zinc is less important accounting for only about five percent of the total U.S. supply because much of zinc's consumption is in dissipative uses (Commorata, 1978 p. 1)

The U.S. government maintains a stockpile of both lead and zinc. Sales from the stockpile have had a substantial impact on both industries, particularly from 1972 through 1974 when sales from the stockpile accounted for 3, 13.2, and 17.4 percent of total domestic lead demand and 12.4, 16.5, and 18.7 percent of total domestic zinc demand (Ryan and Hague, 1977 p. 11, Commorata, 1978 p. 14).

9.2.8.4 Demand. The largest use of lead is in storage batteries (61 percent), particularly automobile batteries which contain about 20 pounds of lead. Other major uses of lead are as a gasoline additive (12 percent), electrical uses (2 percent), paints (6 percent), ammunition (4 percent), construction (3 percent), with the remainder divided among a variety of other uses.

The principal uses of zinc are in galvanized steel products for the construction industry (40 percent) and transportation industry (26 percent) in electrical equipment (12 percent), in machinery and chemicals (10 percent) and other uses (12 percent). The demand for zinc in galvanizing has been growing, while the demand for zinc in diecasting has been declining in favor of aluminum and plastic.

Lead is faced with environmental problems in several areas relating to both its production and consumption. For example, lead smelters have a number of environmental problems. The increased use of "unleaded" gasoline is lowering demand for lead in this application. Also, lead is no longer used in interior paints due to its harmful effects when children ingest the paint. Additionally, the use of lead shot for waterfowl hunting is being replaced by the use of steelshot in order to prevent lead poisoning of aquatic life.

Over the past decade the demand for lead has grown by 3 percent per year while the demand for zinc has been stable. Through 1985 the demand for lead and zinc is projected to increase at an annual rateof one to two percent per year due primarily to the growth in demand for lead-acid storage batteries.

9.2.9 Molybdenum

Section 9.1.8 has provided a profile of the molybdenum industry, and Section 9.2.1.2 has noted that the addition of the most costly regulatory alternative will require price increases of less than 2 percent, or specifically .1 percent for both the 300 and 1200 TPH molybdenum model plants. Also, the increase in capital for both of the model plants as a result of the incremental controls is .2 percent. The increased capital required for control equipment will add $213,000 and $464,000 to total investments of $100,000,000 and $285,000,000 for the 300 and 1200 TPH model plants, respectively. If an investment in a molybdenum ore processing plant would otherwise be accepted, neither the additional price increase nor the additional capital requirement is likely to cause that investment to now be rejected.

9.2.9.1 Ownership, Location, Concentration. As noted in Section 9.1.8 two corporations mine deposits primarily for molybdenum. The principal firm is the Climax Molybdenum Co., a division of Amax Inc. and the other firm is Molycorp. Inc., which was acquired in 1977 by Union Oil Co. of California. Additionally, Duval Copper, a subsidiary of Pennzoil Co., and Kennecott Corp. recover a significant amount of molybdenum from their copper mining operations.

Two major corporations, neither of which has historically been a significant participant in the molybdenum industry, have recently begun ambitious expansion programs in the molybdenum industry. The two companies are Standard Oil Company (Indiana), through its Cyprus Mines subsidiary, at the Thompson Creek molybdenum mine in Idaho; and Atlantic Richfield, through its Anaconda subsidiary, at the Liberty mine in Nevada.

9.2.9.2 Pricing. The price of molybdenum has increased twelve times since early 1974 and each price increase has been from 5 to 16 percent over the previous level. The actual price has risen considerably for molybdenum concentrate to $8.84 as of October 1979. The incremental cost price increases are 1.1 and .6 cents per pound for the 300 and 1200 TPH model plants respectively. The control cost price increases are equivalent to percentage price increases of .1 percent for both model plants, which can be viewed in relation to historical percentage price increases of from 5 to 16 percent.

9.2.9.3 Supply. In 1977 the world mine output of molybdenum contained in concentrate was an estimated 206 million pounds. Three countries, the United States, Canada, and Chile provided 89 percent of the total of which the United States provided approximately 60 percent. Historically, the United States is the world's leading producer and is a net exporter of molybdenum. Approximately one-half of the U.S. domestic production is exported.

In the past the U.S. Government has maintained a stockpile of molybdenum. By yearend 1977 the U.S. Government stockpile was fully depleted. Domestic reserves and production capacity are currently considered adequate to supply national emergency needs and thus no new government stockpile purchases are anticipated.

The dominant position of the United States in the world molybdenum industry and the element of stability associated with a domestic source of supply creates a favorable set of circumstances for both the producers and consumers of molybdenum.

9.2.9.4 Demand. The major end use for molybdenum is in the production of molybdenum containing steels. The steel industry consumes approximately 70 percent of domestic molybdenum production.

The molybdenum industry is experiencing a tight supply/demand balance. Molybdenum demand exceeded supply in 1979 for the sixth time in the last seven years, although the expansion programs noted above plus others, should serve to moderate the tight supply demand balance. As discussed in Section 9.1.8 the demand for molybdenum is projected to increase at a rate of approximately five percent annually through 1985.

9.2.10 Silver

Section 9.1.10 has provided a profile of the silver industry, and Section 9.2.1.2 has noted that the addition of the most costly regulatory alternative will require price increases of .5 and .2 percent for the 50 and 150 TPH model plants, respectively. The increase in capital for the model plants as a result of the incremental controls is .4 and .2 percent, respectively. The increased capital required for control equipment will add $92,000 and $126,000 to total investments of $25,000,000 and $76,000,000 for the 50 and 150 TPH model plants, respectively. If an investment in a silver processing plant would otherwise be accepted neither the additional price increase nor the additional capital requirement is likely to cause that investment to now be rejected.

9.2.10.1 Ownership, Location, Concentration. As noted in Section 9.1.10, there are five leading companies in the silver industry which control 85 percent of the capacity. The two principal producing states are Colorado and Idaho, particularly the Coeur d'Alene mining district in Idaho.

9.2.10.2 Pricing. The price of silver has experienced sharp fluctuations recently. During December 1978 the price of silver averaged $5.93 per troy ounce while one year later, during December 1979, the price averaged $21.79 per troy ounce for a gain of more than 350 percent. The price of silver continued to rise during early 1980 to more than $40 per ounce and then declined over a period of weeks to approximately $13 per ounce. The sharp price fluctuations were largely the result of the trading activity of speculators on the commodity exchange.

The incremental control costs will require price increases of 7 cents and 3 cents per troy ounce for the 50 and 150 TPH silver model plants. The price increases are equivalent to percentage price increases of .5 and .2 percent based on an October 1979 silver price of $13.89 per troy ounce.

9.2.10.3 Supply. About 70 percent of silver mined is produced as a byproduct of copper mining as well as lead and zinc mining (Drake, 1978 p. 10). As a result, the supply of silver provided by domestic production is dependent on the outlook for other metals.

A second important source of supply of silver is foreign imports. Foreign imports normally supply approximately 40 percent of consumption.

The United States government maintains a silver stockpile although sales from or purchases for the stockpile have not been significant for a number of years (Drake, 1978 p. 1, 9).

9.2.10.4 Demand. As mentioned above, the trading activity of speculators on the commodity exchange can play a major role in the price and demand for silver. The major industrial use of silver is for photography, consuming 39 percent of domestic demand in 1979. Other principal uses are electrical and electronic components which accounted for 25 percent, and silverware, which accounted for 15 percent, with the remainder used in a variety of other products.

In spite of progress in some special areas to develop substitutes for silver, no satisfactory substitute exists for most of silver's uses (Drake, 1978 p. 12, Chemical Week, February 27, 1980 p. 15). Also, the demand for silver has risen faster than the world supply for most of the last decade (Drake, 1978 p. 8). Therefore, the general lack of close substitutes for silver, plus the fact that demand is outpacing supply suggests that the incremental control costs could be passed through to consumers (Chemical Week, 1980).

Demand for silver is projected to increase at an annual rate of three percent through 1985.

9.2.11 Titanium/Zirconium

A profile of the titanium industry was provided in Section 9.1.11 and a profile of the zirconium industry was provided in Section 9.1.16. Table 9-83 shows that the addition of the most costly regulatory alternative will require price increases of .8 percent each for the 300 and 600 TPH titanium/zirconium model plants. Also, the increase in capital for the model plants as a result of the incremental controls is .9 and 1.2 percent, respectively. The increased capital required for control equipment will add $92,000 and $203,000 to total investments of $10,000,000 and $17,000,000 for the 300 and 600 TPH model plants, respectively. If an investment in a titanium/zirconium processing plant would otherwise be accepted, neither the additional price increase nor the additional capital requirement is likely to cause that investment to now be rejected.

9.2.11.1 Ownership, Location, Concentration. As noted in Section 9.1.11 there are essentially only three companies in the titanium/zirconium (sand) industry, Asarco, Inc., Humphreys Mining Company, and E.I. DuPont deNemours & Co., Inc. These three companies own four ore processing plants. The principal processing states are Florida, Georgia, and New Jersey.

9.2.11.2 Pricing. The price for rutile ore was $375-$400 per short ton, as of October 1979, or 18.8 cents to 20 cents per pound. The price for zirconium ore (65 percent ZrO_2) was $150 per short ton, or 7.5 cents per pound (EMJ Nov. 79 p. 21). Assuming 50 percent of the processing plant's output is titanium and 50 percent of the processing plant's output is zirconium, the average price of the two products combined is approximately 13.2 cents per pound (18.8 + 7.5 = 26.3 ÷ 2 = 13.2).

9.2.11.3 Supply. As discussed in Section 9.1.11 the mineral sources of titanium are rutile and ilmenite. Australia has large desposits of rutile that supply much of the United States demand (the exact percent of demand supplied by imports is proprietary). The large Australian rutile deposits present formidable economic competition for domestic deposits.

9.2.11.4 Demand. Approximately 98 percent of the demand for titanium is for consumption in the form of titanium dioxide pigment for use in paint and paper coatings. The remaining demand for titanium is consumed in the form of titanium sponge metal for use primarily in aerospace applications.

9.2.12 Tungsten

A profile of the tungsten industry was provided in Section 9.1.12. Table 9-62 shows that the addition of the most costly regulatory alternative will require a price increase of .5 percent for the 25 TPH tungsten plant. The increase in capital for the model plant as a result of the incremental controls is one percent. The increased capital required for control equipment will add $46,000 to a total investment of $4,400,000 for the 25 TPH model plant. If an investment in a tungsten processing plant would otherwise be accepted, neither the additional cost increase nor the additional capital requirement is likely to cause that investment to now be rejected.

9.2.12.1 Ownership, Location, Concentration. As noted in Section 9.1.1.2 there are four active tungsten operations. There is one leading firm, Union Carbide Corporation, which owns 71 percent of the industry's capacity. The principal tungsten operations are located in California and Nevada.

9.2.12.2 Pricing. The standard industry unit of measure is the short ton unit (STU) which is one percent of a ton or twenty pounds. The price of tungsten expressed on a per pound basis has risen from $4.77 in 1974 to a high of $9.77 in 1977 and then declined to $6.74 in 1979. The incremental control costs will require a price increase of 3.3 cents per pound.

9.2.12.3 Supply. Production of domestic tungsten concentrate generally supplies from one-third to two-thirds of US. demand (Kornhauser and Stafford, 1978 p. 1). Another important source of supply of tungsten is the U.S. government tungsten stockpile. Sales from the stockpile have been a significant factor in the marketplace over recent years. For example, during 1979 the General Services Administration sold 5.6 million pounds of tungsten from the government stockpile and released an additional 0.2 million pounds directly to consumers for use in government programs. This 5.8 million pounds released from the government stockpile represents approximately 29 percent of the total U.S. consumption, estimated at 20.0 million pounds, during 1979, and is also typical of the five year average percentage of 27 percent (Thurbur, 1980 p. 187).

9.2.12.4 Demand. Tungsten's extreme hardness at high temperatures is its most important characteristic.

Its major end uses are in cutting and wear-resisting materials, high-speed and tool and die steels, superalloys, and nonferrous alloys.

Demand is projected to increase at a rate of five percent per year through 1985.

9.2.13 Uranium

Section 9.1.13 has provided a profile of the uranium industry, and Section 9.2.1.2 has noted that the addition of the most costly regulatory alternative will require price increases of less than two percent, or specifically .2 and .1 percent for the 25 and 75 TPH uranium model plants, respectively. Also the increase in capital for the model plants as a result of the incremental controls is .8 and .3 percent, respectively. The increased capital required for control equipment will add $28,000 and $38,000 to total investments of $3,700,000 and $11,200,000 for the 25 and 75 TPH model plants, respectively. If an investment in a uranium processing plant would otherwise be accepted, neither the additional price increase nor the additional capital requirement is likely to cause that investment to now be rejected.

9.2.13.1 Ownership, Location, Concentration. As described in Section 9.1.13 there are 31 operations located primarily in the Western states, particularly, Colorado, New Mexico, Wyoming, Utah, and Texas. There are 10 leading companies which own 74 percent of the industry's capacity. Several major oil companies are significant participants in the industry, as well as other major corporations, some of which are prominent in the mining of several metals discussed earlier.

9.2.13.2 Pricing. Uranium is marketed, and prices are quoted for uranium, in the concentrate form which is uranium oxide (U_3O_8), commonly referred to as yellowcake.

From 1972 to 1979 the price of uranium rose 700 percent from roughly $6 per pound to over $40 per pound. The sharp increase in prices which began in 1972 led to widespread allegations that an international uranium cartel was causing the price increases. Uranium is normally sold through long term contracts. A major domestic corporation experienced considerable financial loss as a result of the price increase which the corporation alleges was due to the existence of a cartel. Several years ago the corporation signed long term contracts to supply uranium that it expected to purchase and deliver in the future. Subsequently, in 1976, the allegations that an international uranium cartel was causing the price increases led to litigation. The final outcome of the litigation is still pending; however, it is possible that the price of uranium is not primarily the result of the free interaction of supply and demand.

A perspective on the relative size of the incremental control cost price increases can be gained by comparing historical price increases to the incremental control cost price increases. The incremental control costs represent price increases of 8.8 and 3.8 cents per pound for the 25 and 75 TPH model plants, which is equivalent to .2 and .1 percent based on a uranium sales price of $42.70 per pound in mid-1979.

During late 1979 and through the middle of 1980 the price of uranium experienced weakness, declining to approximately $30.00 per pound. At a more current price of $30.00 per pound, few domestic operations are profitable, regardless of pollution controls. However, at a price of $30.00 per pound the incremental control costs continue to represent modest price increases of .3 and .1 percent, respectively.

9.2.13.3 Supply. The sharp increases in the price of uranium over recent years, from $6 to $40 per pound, has stimulated new uranium mining activity. Also world inventories of uranium are high; currently at a level sufficient to meet requirements for two years. Both Canada and Australia contain substantial deposits of low cost uranium, and Africa is increasing its production capacity. An indication of the high level of inventories and the certainty of supplies is provided by the fact that when prices were recently at higher levels some utilities were liquidating portions of their inventories. Therefore supplies of uranium should be more than adequate through 1985.

A significant additional element that determines the supply of uranium for domestic uses is United States Government policy. Congress is discussing the idea of reducing imports of uranium. Imports are approximately 8 percent of total U.S. consumption and growing. Imports of uranium were banned from 1964 to 1976 when there also were large supplies. Currently, imports are restricted to 30 percent of the uranium that is enriched to become nuclear fuel, but imports will be allowed to rise to 100 percent by 1984 (The Wall Street Journal, May 28, 1980).

9.2.13.4 Demand. Roughly 98 percent of the demand for uranium is for use in the production of nuclear energy. There are no substitutes for uranium in the production of nuclear energy and since nuclear power provides about 12.5 percent of total U.S. electricity needs this suggests a continuing demand for uranium.

Current issues concerning the future of nuclear energy production, underscored by the accident at Three Mile Island, plus slower growth in the total demand for electricity, create considerable uncertainty in projections of the demand for uranium. Projections made in July 1978 of the annual uranium requirements of U.S. utilities for the years 1980 through 1986, were reduced as of December 1979 by an average annual amount of approximately 18 percent (White, 1980).

9.3 SOCIO-ECONOMIC IMPACT ASSESSMENT

The purpose of Section 9.3 is to address those tests of macroeconomic impact as presented in interim guidelines for Executive Order 12291 and, more generally, to assess any other significant macroeconomic impacts that may result from the NSPS.

The economic impact assessment is concerned only with the costs or negative impacts of the NSPS. The NSPS will also result in benefits or positive impacts, such as cleaner air and improved health for the population, potential increases in worker productivity, increased business for the pollution control manufacturing industry, and so forth. However, the NSPS benefits will not be discussed here.

There are three principal review criteria to determine significant macroeconomic impact.

1. Additional annual costs of compliance, including capital charges (interest and depreciation), total $100 million (i) within any one of the first five years of implementation, or (ii) if applicable within any calendar year up to the date by which the law requires attainment of the relevant pollution standard.
2. Total additional cost of production of any major industry product or service exceeds 5 percent of the selling price of the product.
3. The Administrator requests such an analysis (for example when there appear to be major impacts on geographical regions or local governments).

The metallic minerals NSPS will not trigger any of the above tests. The metal that will experience the highest annual costs of compliance is iron ore with one projected 1,200 TPH plant and one projected 2,400 TPH plant. The plants will have costs of compliance of $420,100 and $872,400 or a total of $1,292,500, which is far below the $100 million test. Further, Table 9-63 shows that even if the costs of compliance for each of the ten metals are summed, the grand total is $4,555,000; or far below the $100 million test. Also, Table 9-62 has shown that all of the metals are well below the test of an increase in costs of 5 percent of the selling price. Finally, new plants that are subject to the NSPS will be diversified geographically. Therefore, for the reasons given above, no significant macroeconomic impacts are likely.

Table 9-63. SUMMARY OF INDUSTRY ANNUALIZED COST FOR THE MOST STRINGENT REGULATORY ALTERNATIVE ($ in 000's)

Metal	Plant size (Mg/hr)	(ton/hr)	Projected number of new sources	Annualized cost of NSPS increment	Total
Aluminum	140	(150)	1	$ 53	$ 53
	270	(300)	1	95	95
Copper	140	(150)	1	167	167
	540	(600)	1	303	303
Gold	68	(75)	1	66	66
	140	(150)	1	82	82
Iron ore	1,100	(1,200)	1	441	441
	2,200	(2,400)	1	867	867
Lead/Zinc*	270	(300)	2	174	348
	540	(600)	1	264	264
Molybdenum	270	(300)	1	218	218
	1,100	(1,200)	2	464	928
Silver	45	(50)	2	76	152
	140	(150)	1	108	108
Titanium/Zirconium (sand)	270	(300)	1	102	102
	540	(600)	1	156	156
Tungsten	23	(25)	1	41	41
Uranium	23	(25)	2	28	56
	68	(75)	3	36	108
GRAND TOTAL					$4,555

*Note the discussion in Section 8.1 on the possible effects of the NAAQS for lead on the calculation of the control costs for lead/zinc processing plants.

REFERENCES

Aluminum Statistical Review in 1978. The Aluminum Association p. 29.

Chemical Week. For Precious metals, it's a mad, mad world. February 27, 1980. p. 15.

Chemical Week. Power crisis eases in the Pacific Northwest. November 5, 1980 p. 17.

Commorata, V. Anthony. May 1978. Zinc: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D.C. P. 1.

Drake, Harold J., September 1978. Silver: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D.C. p. 1, 8, 9, 10, 12.

International Trade Commission. Unalloyed, Unwrought Zinc. USITC Publication 894, June 1978 p. A-24, A-4.

Kennecott Copper Corporation. SEC Form 10-K. December 31, 1979, p. 4.

Klinger, F.L. May 1978. Iron Ore: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D.C. p. 3 and 19.

Kornhauser, Ben A. and Philip T. Stafford. September 1978. Tungsten: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D.C. p. 1.

Ryan, J.P. and J.M. Hague. December 1977. Lead: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D.C. p. 1, 11.

Stamper, John W. and Horace F. Kurtz. 1978. Aluminum: Mineral Commodity Profile. U.S. Bureau of Mines. Washington, D.C. p. 4, 1.

Thurbur, W.C., Engineering and Mining Journal. March 1980. Tungsten: Demand Tops Supply Despite GSA Releases. p. 187.

United States Bureau of Mines. Mineral Industry Surveys - Copper. July 1980 p. 2.

United States Environmental Protection Agency. Arsenic Emissions from Primary Copper Smelters - Background Information. Section 9.1, p. 9-5.

Wall Street Journal, The. Poland's Copper and Silver Ore Earning Nation Critically Needed Hard Currency. February 25, 1980.

Wall Street Journal, The. St. Joe Won't Replace Zinc Smelter It Closed Recently in Monaca, Pa. April 16, 1980.

Wall Street Journal, The. Reymonds Metals and Kaiser Aluminum Roll Back Price Boosts on Some Products. May 6, 1980 p. 2.

Wall Street Journal, The. Uranium Producers Hope Price Will Rise On Output Cutbacks, Import Restrictions. May 28, 1980.

White, George Jr., Engineering and Mining Journal. March 1980. Uranium: Improving Supplies Weaken Price Structure. P. 195.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/3-81-009a and -009b	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Metallic Mineral Processing Plants - Background Information for Proposed Standards		5. REPORT DATE August 1982
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Air Quality Planning and Standards U.S. Environmental Protection Agency Research Triangle Park, North Carolina 27711		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-3063
12. SPONSORING AGENCY NAME AND ADDRESS DAA for Air Quality Planning and Standards Office of Air, Noise, and Radiation U.S. Environmental Protection Agency Research Triangle Park, North Carolina 27711		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE EPA/200/04

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Standards of performance for the control of particulate matter emissions from metallic mineral processing plants are being proposed under the authority of Section 111 of the Clean Air Act. These standards would apply to facilities at processing plants for which construction or modification began on or after the date of proposal of the regulation. This document contains background information and environmental and economic impact assessments of the regulatory alternatives considered in developing proposed standards.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air pollution Pollution control Standards of performance Metallic mineral processing plants Particulate matter	Air pollution control	13B

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 822
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE