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Guideline Series

Control of Volatile Organic Compound Leaks from Petroleum Refinery Equipment

23

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Control of Volatile Organic Compound Leaks from Petroleum Refinery Equipment

Emission Standards and Engineering Division
Chemical and Petroleum Branch

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

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OAQPS GUIDELINE SERIES

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ABBREVIATIONS AND CONVERSION FACTORS

EPA policy is to express all measurements in agency documents in metric units. Listed below are abbreviations and conversion factors for British equivalents of metric units.

Abbreviations	Conversion Factor
kg - kilogram	kg X 2.2 = pound (lb) lb X 0.45 = kg
m^3 - cubic meter	m^3 X 6.29 = barrel (bbl) bbl X 0.16 = m^3
m ton - metric ton	m ton X 1.1 = short ton short ton X 0.91 = m ton
Mg - megagram	Mg = m ton
$kg/10^3m^3$ - kilograms per thousand cubic meters	$kg/10^3m^3$ X 0.35 = $lb/10^3bbl$ $lb/10^3bbl$ X 2.86 = $kg/10^3m^3$
m^3/day - cubic meters per day	m^3/day X 6.29 = bbl/day bbl/day X 0.16 = m^3/day
cm - centimeters	cm X 0.39 = inches

Frequently used measurements in this document

15,900 m^3/day	∿	100,000 bbl/day
\$100.60/m^3	∿	\$16.00/bbl
5 cm	∿	2 inches
61 m	∿	200 feet

1.0 INTRODUCTION AND SUMMARY

This document addresses the control of volatile organic compounds (VOC) from equipment leaks in petroleum refineries. Equipment considered includes pump seals, compressor seals, seal oil degassing vents, pipeline valves, flanges and other connections, pressure relief devices, process drains, and open ended pipes. VOC emitted from equipment leaks are primarily C_3 through C_6 hydrocarbons which are photochemically reactive (precursors to oxidants).

Methodology described in this document represents the presumptive norm or reasonably available control technology (RACT) that can be applied to existing petroleum refineries. RACT is defined as the lowest emission limit that a particular source is capable of meeting by the application of control technology that is reasonably available considering technological and economic feasibility. It may require technology that has been applied to similar, but not necessarily identical, source categories. It is not intended that extensive research and development be conducted before a given control technology can be applied to the source. This does not, however, preclude requiring a short-term evaluation program to permit the application of a given technology to a particular source. The latter effort is an appropriate technology-forcing aspect of RACT.

1.1 NEED TO REGULATE EQUIPMENT LEAKS FROM PETROLEUM REFINERIES

Control techniques guidelines are being prepared for source categories that emit significant quantities of air pollutants in areas of the country where National Ambient Air Quality Standards (NAAQS) are not being attained. Equipment leaks in petroleum refineries are a significant source of VOC and tend to be concentrated in areas where the oxidant NAAQS are likely to be violated.

Nationwide VOC emissions from equipment leaks in petroleum refineries are presently estimated to be 170,000 metric tons per year, or about one percent of the total VOC emissions from stationary sources. The emission factors upon which these estimates are based are presently being updated. The total emission estimate is expected to increase when the new factors become available.

1.2 MONITORING AND MAINTAINING PETROLEUM REFINERY EQUIPMENT

The approach used in this document for controlling VOC leaks from petroleum refinery equipment is dictated by the nature of the emissions. There are many potential leak sources--over 100,000 in a very large refinery--and leak rates range over six orders of magnitude. Leaks from most of the sources are insignificant; a small percentage of the sources account for a majority of the total mass emissions. This situation makes it difficult to quantify the emissions, and highlights the importance of a monitoring plan to effectively locate leaks so that maintenance can be performed.

Recent test data show that when a VOC concentration of over 10,000 parts per million (ppm) is found in proximity to a potential leak source,

the source is leaking from one to ten kilograms per day depending on the type of source. If the leak were not located or repaired for a year, annual emissions from this single source would be from 0.4 to 3.7 metric tons of VOC.

The monitoring plan recommended includes annual, quarterly, and weekly inspections. In the monitoring inspections the refinery operator will determine the VOC concentration in proximity to each individual potential leak source with a portable VOC detection instrument. If the VOC concentration at the source exceeds 10,000 ppm, the leak should be repaired within fifteen (15) days. The recommended monitoring intervals are: annual--pump seals, pipeline valves in liquid service, and process drains; quarterly--compressor seals, pipeline valves in gas service, and pressure relief valves in gas service; weekly--visual inspection of pump seals; and no individual monitoring--pipeline flanges and other connections, and pressure relief valves in liquid service. Whenever a liquid leak from a pump seal is observed during the visual inspection and whenever a relief valve vents to atmosphere, the operator must immediately monitor the VOC concentration of that component. If a leak is detected, the leak should be repaired within fifteen days. The manpower required to perform the inspections is approximately 1800 manhours per year for a 15,900 cubic meter per day refinery.

A portion of the components with concentrations in excess of 10,000 ppm will not be able to be repaired within fifteen (15) days. The refinery operator should report quarterly leaks that cannot be repaired within this time frame and should make arrangements for this equipment to be repaired during the next scheduled turnaround or, if unable to bring a component into compliance, apply for a variance on an individual basis.

The approximate manpower required to perform maintenance on leaking equipment is 3800 manhours per year for a 15,900 cubic meter per day refinery.

2.0 SOURCES AND TYPES OF REFINERY EQUIPMENT LEAKS

Petroleum refining represents a large potential source of volatile organic compound (VOC) emissions by virtue of the large quantities of petroleum liquids refined and the intricacy of the refining processes. The major sources of refinery VOC emissions that have been addressed in guideline documents include fixed roof storage tanks; vacuum producing systems, wastewater separators, and process unit turnarounds; and gasoline transfer operations. This chapter discusses equipment leaks, another significant source of VOC emissions for which controls previously have been adequately defined.

2.1 SOURCES OF VOC EMISSIONS FROM EQUIPMENT LEAKS

There are many types of equipment in petroleum refineries that can develop leaks. Among these are pump seals, compressor seals, pipeline valves, open-ended valves, flanges and other connections, pressure relief devices and process drains. Most of these sources maintain their sealing effect through proper mating of two sealing surfaces. These sealing surfaces include compressed packings, gaskets, finely machined surfaces (as in mechanical seals), and seats (as in pressure relief devices). If these seals are not properly designed, constructed, installed, and maintained, they can degrade to the point where their ability to seal is reduced. As this process continues, the leaking equipment becomes a significant source of VOC emissions. In addition to sealing failures, open-ended valves that are not completely shut off (such as a sample tap or bleed valve) and process drains which are not properly designed or operated can also emit VOC to atmosphere.

2.2 MAGNITUDE OF VOC EMISSIONS FROM EQUIPMENT LEAKS

Many studies have been undertaken to determine the magnitude of VOC emissions from equipment leaks. About twenty years ago, a Joint Project[1] was undertaken to quantify all emissions from refineries in the Los Angeles air basin. The emission factors that resulted from this study are currently used to estimate the VOC emissions from refineries.[2] Radian Corporation has been contracted by EPA to update refinery emission factors to the present state of the art.[3] This study is incomplete and thus their preliminary data cannot be cited. Results should be available in late 1978 or early 1979. Limited testing has been performed by KVB, Incorporated;[4] industry;[5] Meteorology Research, Incorporated;[6,7] and EPA, but none of these tests have yielded new emission factors.

Recent tests have shown that most refinery equipment have low leak rates and that the small percentage of equipment with high leak rates accounts for a large part of the total VOC emitted. Table 2-1 presents preliminary data from the Radian study that illustrates this point.[8] In every case a small percentage of the sources emit about 90 percent of the emissions. The test program undertaken by KVB, Incorporated, under contract with California Air Resources Board also found this to be the case.[9] This leads to the conclusion that the key to controlling VOC emissions from equipment leaks is developing an effective monitoring and maintenance program to locate this small percentage of the total equipment with high leak rates so that repairs can be scheduled.

TABLE 2-1. DISTRIBUTION OF EQUIPMENT LEAK VOC EMISSIONS FOR A MODEL REFINERY[a]

COMPONENT	NUMBER OF COMPONENTS	COMPONENTS WITH 90% OF EMISSIONS[b]	PERCENT OF TOTAL REFINERY LEAK EMISSIONS
Pump Seals	250	23	5
Compressor Seals	14	2	2
Pipeline Valves	25,500	765	75
Process Drains	1,400	56	3
Pressure Relief Valves	130	7	11
Flanges	64,000	640	4

a Based on actual sampling of equipment in six refineries by Radian Corporation (Reference 3) and a model 15,900 cubic meter per day refinery.

b Ninety percent of the total mass emissions are emitted by the listed number of the components.

2.3 REFERENCES

1. "Joint District, Federal and State Project for the Evaluation of Refinery Emissions," Los Angeles County Air Pollution Control District, Nine Reports. 1957 - 1958.

2. "Compilation of Air Pollutant Emission Factors," Second Edition, AP-42, U.S. Environmental Protection Agency, April, 1973.

3. "Assessment of Environmental Emissions from Oil Refining," Radian Corporation, EPA Contract No. 68-02-2665, in progress, March, 1976 to March, 1979.

4. Personal communication between Harold J. Taback, KVB, Incorporated, and K.C. Hustvedt, U.S. EPA, memo to the files dated March 10, 1978.

5. Letter with attachments from J.M. Johnson, Exxon Company, U.S.A. to Robert T. Walsh, U.S. EPA, ESED, CPB, July 28, 1977.

6. Letter with attachments from B. F. Ballard, Phillips Petroleum Company, to William Stewart, Texas Air Control Board, September 8, 1977.

7. Personal communication between Paul Harrison, Meteorology Research, Incorporated, and K.C. Hustvedt, U.S. EPA, memo to James F. Durham, dated January 18, 1978.

8. "Assessment of Environmental Emissions from Oil Refining," op cit.

9. Taback, op cit.

3.0 CONTROL OF REFINERY EQUIPMENT LEAKS

There are two phases to controlling volatile organic compound (VOC) emissions from equipment leaks; first, the leaks must be located (monitoring), and then the leak must be repaired (maintenance). This chapter discusses both phases. The manhour requirements of applying the monitoring and maintenance program are presented in Appendix C, costs in Chapter 4, and environmental effects in Chapter 5.

3.1 MONITORING

There are many types of monitoring that may be effective in reducing emissions of VOC to atmosphere. These include individual source monitoring, unit walkthrough monitoring, and multiple fixed-point monitoring. Only individual source monitoring has been evaluated sufficiently to determine its effectiveness and will therefore be the only technique discussed below.

3.1.1 Individual Source Monitoring

Each type of equipment listed in Chapter 2 can be monitored for leaks by sampling the ambient air in proximity to the potential leak point with a portable VOC detection instrument. Both the recommended instrument and monitoring techniques for each type of equipment are described in Appendix B. Routine monitoring of every potential leak source in this manner will ensure that all leaks in the refinery are located, thus allowing maintenance to be scheduled as necessary.

In order to develop a monitoring plan for equipment leaks, one must first define what constitutes an equipment leak. Tests were performed by Radian Corporation in four refineries on equipment that had a VOC

concentration of over 10,000 parts per million (ppm) at the seal interface.[1] In the 166 tests Radian performed, the average leak rate was 5.6 kilograms per day (kg/day) with leak rates ranging from 1.0 to 10.1 kg/day for the different types of equipment. This is a significant leak rate, averaging over 2 metric tons per year per source. If this leaking equipment were located and repaired, an appreciable reduction in VOC emissions would result.

Table 3-1 shows the incidence of leaks for different types of refinery equipment as found in EPA and industry[2] source tests. Here again it is shown that a small percentage of the sources leak. This table is used in Appendix C to determine the manpower requirements for repairing leaking equipment. In the EPA and industry tests a leaking component is defined as one having a VOC concentration over 1000 parts per million (ppm) at a distance of 5 centimeters (cm) from the potential leak source. In this document, however, a leaking component has a VOC concentration of over 10,000 ppm at the potential leak source (0 cm). It has been shown in the tests performed by Radian Corporation[4] and Meteorology Research[5] that these two values are equivalent. Table 3-2 summarizes log-log linear regression analyses that were performed by Radian for equipment total leak rate versus VOC concentration at a given distance from pump seals, compressor seals and valves. Figures 3-1 and 3-2 are the actual relations that the analyses predicts for valves and pumps, respectively. There are fewer sources sampled at the 5 cm distance because this analysis was not initiated until after the sampling was underway. This analysis shows that a VOC concentration of 1000 ppm at 5 cm and 10,000 ppm at 0 cm represent equivalent emission rates so the leak rate incidence data shown in Table 3-1 is valid for both leak definitions.

3.1.2 Visual Inspection

As a supplement to individual source monitoring with a portable VOC detection device, visual inspections can be performed to detect evidence of liquid leakage from pump seals. When visual evidence of liquid leakage from a pump seal is observed, the operator should immediately obtain a portable VOC detection instrument and monitor the component as outlined in Appendix B. If the component is found to be leaking, i.e., a VOC concentration over 10,000 ppm, maintenance should be scheduled. All liquid leaks will not necessarily result in a reading greater than 10,000 ppm.

3.2 MAINTENANCE

When leaks are located by either monitoring method described in Section 3.1, the leaking component must then be repaired or replaced. Many components can be serviced on-line and this is generally regarded as routine maintenance to keep operating equipment functioning properly. Equipment failure, as indicated by a leak which servicing does not eliminate, requires isolation of the faulty equipment for either repair or replacement. This will normally result in a temporary increase in emissions to atmosphere.

TABLE 3-1. SUMMARY OF EPA[a] AND INDUSTRY[b] EQUIPMENT LEAK SOURCE TEST DATA

Emission Source	Number of Sources Tested	Percent[c] Leaking
Pump Seals	521	12
Compressor Seals	29	7
Pipeline Valves	1350	6
Drains	369	6
Pressure Relief Devices	15[d]	7[e]

a Four EPA source tests described in Appendix A.

b One industry test (Reference 1).

c Concentration over 1000 ppm at 5 centimeters (equivalent 10,000 ppm at the source).

d Not a representative sample.

e In the Joint Project (Reference 3) a leak was defined as a concentration over the lower explosive limit inside the horn and in that study 20 percent of the sources leaked. This value is used in the analysis in Appendix C.

TABLE 3-2. SUMMARY OF EQUIPMENT LEAK VOC CONCENTRATION VERSUS LEAK RATE LINEAR REGRESSION ANALYSIS [a]

Emission Source	Concentration [b] (ppm)	Predicted [c] Emissions (kg/day)	Number of Sources Sampled	Correlation Coefficient
Pump Seals	10,000 @ 0 cm	1.11	51	0.591
	1,000 @ 5 cm	1.14	31	0.691
Compressor Seals	10,000 @ 0 cm	0.70	19	0.551
	1,000 @ 5 cm [d]	-	-	-
Valves	10,000 @ 0 cm	0.19	191	0.635
	1,000 @ 5 cm	0.21	73	0.620

a Based on data from four refinery tests by Radian Corporation (Reference 4)

b The maximum concentration found at the listed distance from the potential leak source

c The emission rate predicted by the linear regression equation for a leak at the given concentration. The average emission rate for all leaks greater than the given concentration would be approximately one order of magnitude higher.

d A valid sample of VOC concentrations at 5 cm from compressor seals was not available.

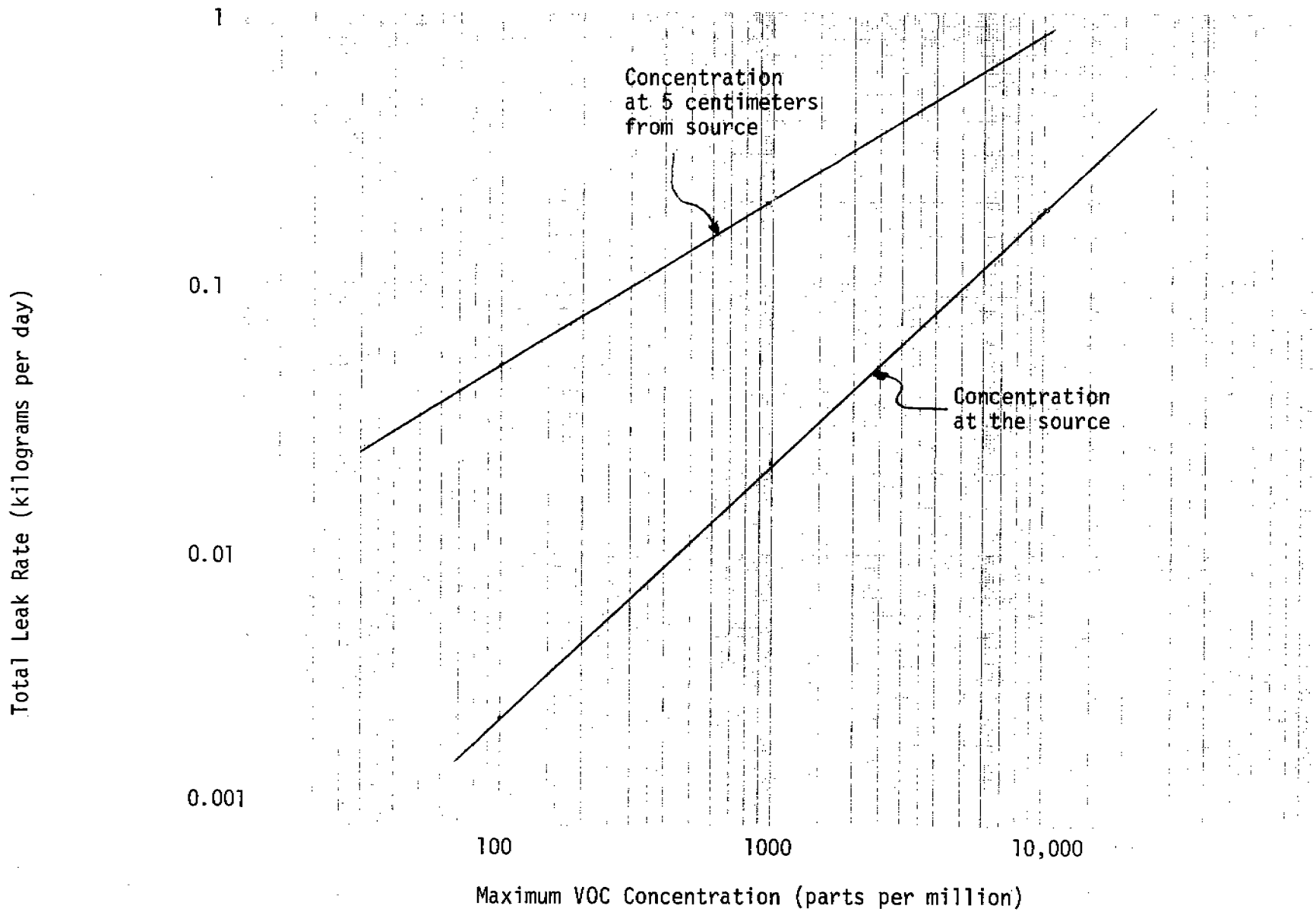

FIGURE 3-1. VOC CONCENTRATION VERSUS LEAK RATE FOR REFINERY VALVES

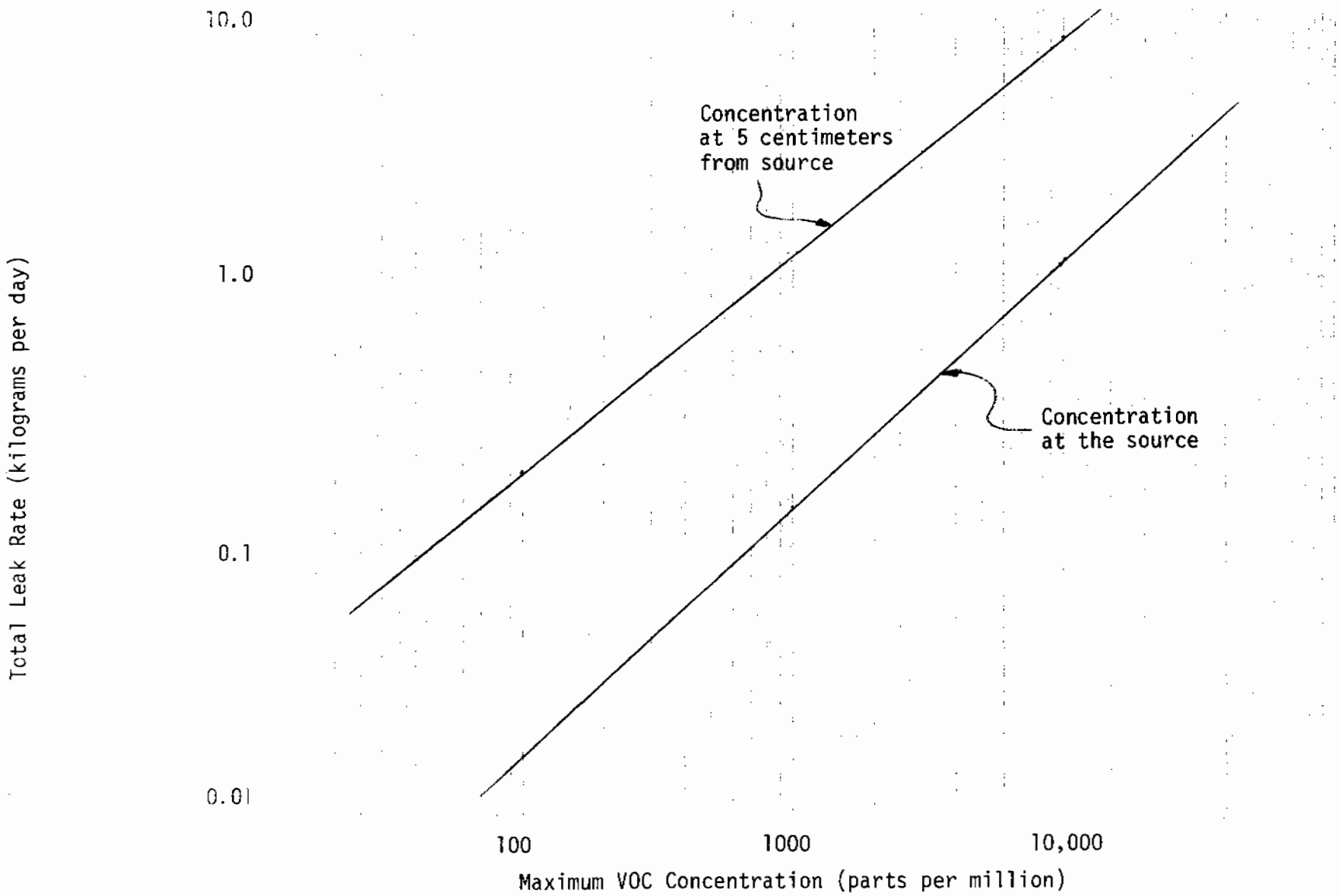

FIGURE 3-2. VOC CONCENTRATION VERSUS LEAK RATE FOR REFINERY PUMP SEALS

3.3 REFERENCES

1. "Assessment of Environmental Emissions from Oil Refining," Radian Corporation, EPA Contract No. 68-02-2665, Interim Report entitled, "Emission Data - Four Refineries," November 30, 1977.

2. Letter with attachments from J. M. Johnson, Exxon Company, U.S.A. to Robert T. Walsh, U.S. EPA, July 28, 1977.

3. "Joint District, Federal and State Project for the Evaluation of Refinery Emissions," Los Angeles County Air Pollution Control District. Nine Reports. 1957 - 1958.

4. "Assessment of Environmental Emissions from Oil Refining," Radian Corporation, EPA Contract No. 68-02-2665, Interim Report entitled, "Data Analysis and Summaries," January 19, 1978.

5. Personal communication between Paul Harrison, Meteorology Research, Incorporated, and K.C. Hustvedt, U.S. EPA, memo to James F. Durham, dated January 18, 1978.

4.0 COST ANALYSIS

4.1 INTRODUCTION

4.1.1 Purpose

The purpose of this chapter is to present estimated costs for control of volatile organic compound (VOC) emissions from equipment leaks at existing petroleum refineries.

4.1.2 Scope

Estimates of capital and annualized costs are presented for controlling emissions from equipment leaks at existing petroleum refineries. The major sources of VOC emissions that are considered in this chapter include process drains; pipeline valves, flanges, connections and fittings; pump and compressor seals; pressure relief devices; and sampling connections. The recommended control technique to substantially reduce equipment leaks is a monitoring and maintenance program. Control costs are developed for a model existing medium size refinery with a throughput of 15,900 m^3/day. These costs are based on the use of two (2) monitoring instruments and the leak detection and maintenance procedures specified in Chapter 6. Costs are also presented for a typical seal oil reservoir degassing vent control system, which may be required to bring this source of VOC emissions into compliance. Since emission reductions are not presently quantifiable, recovered product credits and cost-effectiveness measures have not been determined. However, a simple procedure is presented that may be used to determine recovery credits and cost-effectiveness when new refinery emission factors become available.

4.1.3 Use of Model Refinery

Petroleum refineries vary considerably as to size, configuration and age of facilities, product mix, and degree of control. Because of the variation among plants, this cost analysis is based on a model medium size

refinery that has a throughput of 15,900 m^3/day. Table 4-1 presents the technical parameters that pertain to the model refinery. The parameters were selected as being representative of existing medium sized refineries based on information from an American Petroleum Institute publication,[1] petroleum refineries and equipment vendors. Although model plant costs may differ, sometimes appreciably, with actual costs incurred, they are the most useful means of determining and comparing emission control costs.

4.1.4 Bases for Capital and Annualized Cost Estimates

Capital cost estimates represent the investment required to purchase and calibrate monitoring instruments for leak detection surveys and the installed costs of a seal oil reservoir degassing vent control system. Annualized control cost estimates include annualized capital charges and annual materials, maintenance and calibration cost of monitoring instruments, annual monitoring labor cost, annual leak repair and maintenance labor cost, annual administrative and support cost of the monitoring and maintenance program, and annual operating and maintenance cost of a degassing vent control system. Cost estimates were obtained from petroleum refineries, equipment vendors, a major refinery contractor, a national survey of current salary rates, and an oil industry journal. All costs reflect fourth quarter 1977 dollars. Costs for research and development, production losses during downtime, and other highly variable costs are not included in the estimates.

The annualized capital charges are sub-divided into capital recovery costs (depreciation and interest costs) and costs for property taxes and insurance. Depreciation and interest costs have been computed using a capital recovery factor based on a 6 year replacement life of the monitoring

Table 4-1. TECHNICAL PARAMETERS USED IN DEVELOPING CONTROL COSTS[a]

I. Refinery Throughput:

15,900 m^3/day

II. Operating Factor:[b]

365 days per year

III. Monitoring and Maintenance Program:

A. Recommended Emission Monitoring Procedures per Section 6.3 and Appendix B.

B. Recommended Monitoring Instruments per Appendix B.

C. Number of Monitoring Instruments:[c] 2

D. Estimated Monitoring Manhours per year:[d,e] 1800

E. Estimated Maintenance and Repair Manhours per year:[d,f] 3800

IV. Seal Oil Reservoir Degassing Vent Control System:[b]

Piping: 61.0 m length, 5.1 cm dia., carbon steel.

Valves: 3 plug type, 5.1 cm dia., cast steel.

Flame Arrestor: One metal gauze type, 5.1 cm dia.

V. Average Density of Recovered Product:[g]

671 Kg/m^3

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[a]Except as noted, parameter values are taken from Chapters 2 and 3.

[b]EPA estimate.

[c]Reference 2; one monitoring instrument needed for the refinery, and one instrument needed for the tank farm and as a back-up instrument.

[d]Per Reference 3 and EPA estimate as discussed in Appendix C.

[e]Based on two person teams (except for the visual pump seal inspection) performing the leak detection surveys.

[f]Includes initial leak repair and on-going maintenance.

[g]Reference 4, product that would have leaked but does not escape because the leaks are repaired; saved product assumed to be equivalent to gasoline.

instruments and a 10 year life of the degassing vent control system and an interest rate of 10% per annum. Costs for property taxes and insurance are computed at 4% of the capital costs. All annualized costs are for one year periods commencing with the first quarter of 1978.

4.2 CONTROL OF VOC LEAKS FROM REFINERIES

4.2.1 Model Cost Parameters

The major sources of VOC leaks from petroleum refinery equipment include process drains; pipeline valves, flanges and other pipe connections; pump and compressor seals; pressure relief devices; and sampling connections. The recommended control techniques to reduce VOC emissions from equipment leaks are a monitoring (leak detection) and maintenance (leak repair) program, and, when necessary, a seal oil reservoir degassing vent control system. Cost parameters used in computing emission control costs are shown in Table 4-2. These parameters pertain to the medium size model refinery and are based on actual cost/price data from petroleum refineries,[3,5,6,7,8,9] equipment vendors,[10,11,15,16] a survey of current salary rates,[12] an oil industry journal,[13] a major refinery contractor,[14] and EPA estimates.

4.2.2 Control Costs of Monitoring and Maintenance Program

Table 4-3 presents the estimated costs of controlling VOC leaks from equipment of the model medium size petroleum refinery. The costs are based on the use of two (2) portable organic vapor analyzers that are suitably equipped and calibrated for monitoring VOC emission leaks. These devices operate on the flame ionization detection principle and are certified safe for use in hazardous locations by Factory Mutual Research Corporation.[11] Except for the visual pump seal inspections, the estimated monitoring labor costs are calculated assuming two (2) person survey teams. For the purpose of determining costs, an Instrument Technician and a Junior Chemical

Table 4-2. COST PARAMETERS USED IN COMPUTING CONTROL COSTS

I. Monitoring Instruments:[a]

Purchased Equipment Cost:	$8,800
Annual Materials, Maintenance, and Calibration Cost:[b]	$2,500
Equipment Replacement Life:[c]	6 years
Battery Pack Replacement Life:	1 year

II. Annualized Capital Charges Factors:[c]

Annual Interest Rate:	10%
Property Taxes and Insurance Charge:	4% of Capital Cost

III. Monitoring (Leak Detection) Labor Costs:

Annual Monitoring Manhours:[d]	1800
Weighted Average Labor Rate:[e]	$14.00/hour

IV. Leak Repair and Maintenance Labor Costs:

Annual Leak Repair and Maintenance Manhours:[d]	3800
Average Labor Rate:[f]	$14.00/hour

V. Annual Administrative and Support Cost of Monitoring and Maintenance Program:[g]

40% of the sum of III. and IV. costs.

VI. Seal Oil Reservoir Degassing Vent Control System:

Carbon Steel Piping:[h]

Installed Capital Cost: $2400

Annual Operating and Maintenance Cost:[c]
5% of Installed Capital Cost

Life: 10 years

Table 4-2 (continued)

Plug Type Valves:[i]

Specification:	WCB ASTM A216-60
Purchase Price:	$140 each
Installation Cost:[c]	10 hr each @ $14.00/hr.

Annual Operating and Maintenance Cost:
15% of Installed Capital Cost

Life: 10 years

Metal Gauze Flame Arrestor:[j]

Specification:	Model 4950; ductile iron with 4.8 mm stainless steel grid
Purchase Price:	$260
Installation Cost:	10 hr @ $14.00/hr

Annual Operating and Maintenance Cost:[i]
15% of Installed Capital Cost

Life: 10 years

VII. Recovered Product Value:[k]

$100.60/m^3

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[a]References 2, 10 and 11; costs based on the use of two (2) Century Systems Corp. Model OVA-108 Portable Organic Vapor Analyzers.

[b]Based on the following usages per monitoring instrument per year: one (1) battery pack, and two (2) filter packs.

[c]EPA estimate.

[d]Reference 3 and EPA estimate as discussed in Appendix C.

[e]References 3, 5, 6, 7, 8, 9 and 12; weighted average labor rate of two (2) person survey team(s), consisting of an Instrument Technician and a Junior Chemical Engineer; includes wages and salary plus an additional 40% for labor related costs to refineries. An Instrument Technician and a Junior Chemical Engineer are assumed for cost purposes; the number and types of personnel actually assigned the monitoring functions will be determined by the respective refineries.

[f]References 3, 5, 6, 7, 8 and 9; average labor rate of refinery maintenance personnel; includes wages plus an additional 40 percent for labor related costs to refineries.

Table 4-2 (continued)

[g]Reference 3 and EPA estimate; includes costs of data reduction and analysis and report preparation.

[h]Reference 14.

[i]Reference 15.

[j]Reference 16.

[k]Average gasoline value based on price data from Reference 13 and the Wall Street Journal, October 20, 21, and 24, 1977 and February 15, 16, and 17, 1978.

Table 4-3. CONTROL COST ESTIMATES OF MONITORING AND MAINTENANCE PROGRAM FOR MODEL EXISTING PETROLEUM REFINERY EQUIPMENT LEAKS

Throughput	15,900 m^3/day
Control Technique	Monitoring and Maintenance Program
Instrument Capital Cost ($000)[a]	8.8
Annualized Instrument Capital Charges ($000)[b]	2.4
Annual Instrument Materials, Maintenance, and Calibration Costs ($000)[a,c]	2.5
Annual Monitoring Labor Costs ($000)[d]	25.2
Annual Maintenance Labor Costs ($000)[e]	53.2
Annual Administrative and Support Costs ($000)[f]	31.7
Total Annualized Costs ($000)[g,h]	115.0

[a]References 2, 10 and 11; costs based on the use of two (2) Century Systems Corp. Model OVA-108 Portable Organic Vapor Analyzers.

[b]Capital recovery costs (using capital recovery factor with 10% annual interest rate and 6 year instrument life) plus 4% of capital cost for property taxes and insurance.

[c]EPA estimate.

[d]Estimated monitoring man-hours per Reference 3 and EPA estimate; weighted average labor rate of two person survey team(s) consisting of an Instrument Technician and a Junior Chemical Engineer per References 3, 5, 6, 7, 8, 9 and 12.

[e]Estimated leak repair and maintenance man-hours per Reference 3 and EPA estimate; average maintenance labor rate per References 3, 5, 6, 7, 8, and 9.

[f]Reference 3.

[g]Total Annualized Costs are the sum of Annualized Instrument Capital Charges; Annual Instrument Materials, Maintenance and Calibration Costs; Annual Monitoring Labor Costs; Annual Maintenance Labor Costs; and Annual Administrative and Support Costs.

[h]Credits for recovered (saved) product are <u>not</u> included in these costs.

Engineer are assumed to perform the recommended monitoring. The number and types of personnel actually assigned the monitoring functions will be determined by the respective refineries. The estimated maintenance labor costs include both initial and on-going leak repair and maintenance.

From Table 4-3, it should be noted that the recommended monitoring and maintenance program for the model medium size refinery has an estimated capital cost of $8,800 and a total annualized cost of $115,000, not including recovery credits from reduced emissions. Recovery credits would, of course, reduce the total annualized cost of control. Since these estimates are expected costs of typical medium sized refineries, the control costs of actual refineries may vary from the estimates, depending upon refinery size, configuration, age, condition, and degree of control.

4.2.3 Control Costs of Seal Oil Reservoir Degassing Vent System

Another potential source of VOC emissions are seal oil reservoir degassing vents (refer to Section 6.3.2). In order to bring such a source into compliance with the concentration limits, a refinery may be required to install one or more control systems. Table 4-4 presents the estimated costs of a typical seal oil reservoir degassing vent control system. The technical parameters and cost parameters of the typical degassing vent control system are shown in Tables 4-1 and 4-2, respectively.

From Table 4-4, it can be seen that the typical degassing vent control system has an estimated installed capital cost of $3,700 and a total annualized cost of $1,200. These costs are based on the emissions being piped to an existing heater fire box with no credit allowed for the fuel value of the VOC. Recovered fuel credits would, of course, reduce the total annualized cost of control. Alternately, the VOC emissions may be piped to an existing flare system at slightly lower expected control costs; however, there will be no recovery of the fuel value.

Table 4-4. COST ESTIMATES OF TYPICAL SEAL OIL RESERVOIR DEGASSING VENT CONTROL SYSTEM

Installed Capital Cost ($000)[a]	3.7
Annualized Capital Charges ($000)[b]	0.8
Annual Operating and Maintenance Costs ($000)[c]	0.4
Total Annualized Costs ($000)[d,e]	1.2

[a]References 14, 15, and 16.

[b]Capital recovery costs (using capital recovery factor with 10% annual interest rate and 10 year replacement life) plus 4% of capital cost for property taxes and insurance.

[c]References 15 and 16 and EPA estimates.

[d]Total Annualized Costs are the sum of Annualized Capital Charges and Annual Operating and Maintenance Costs.

[e]Credits for fuel value of recovered VOC are not included in these costs.

4.3 COST-EFFECTIVENESS

Since emission reduction factors are not presently quantifiable, recovered product credits (savings) cannot be calculated and cost effectiveness measures, such as $ per Mg, have not been determined. However, assuming that the recovered (saved) product value is $150/Mg*, it would require an emission reduction of about 767 Mg per year for the total value of recovered product to be equal to the total annualized cost of the monitoring and maintenance program. In this special case, the cost effectiveness would be $0.0 per Mg of reduced emissions. Thus, an emission reduction greater than 767 Mg/year will result in a net credit (savings) while an emission reduction less than 767 Mg/year will be a net cost.

A simple three-step procedure is presented below that may be used to determine recovered product credits and cost effectiveness ratios of the monitoring and maintenance program when new refinery emission factors become available. This procedure is illustrated for a hypothetical emission reduction of 500 Mg/year for the model refinery.

Step 1:

Annual Product Recovery Credits = (Annual Emission Reduction) x (Recovered Product Value) = (500 Mg/yr) ($150/Mg) = $75,000/yr.

Step 2:

Total Annualized Cost = $115,000 - (Annual Product Recovery Credits) = $115,000 - $75,000 = $40,000

Step 3:

$$\text{Cost Effectiveness} = \frac{(\text{Total Annualized Cost})}{(\text{Annual Emission Reduction})} = \frac{\$40{,}000}{500\ \text{Mg}} = \$80/\text{Mg}$$

$$*\left(\frac{\$100.60}{m^3}\right)\left(\frac{1m^3}{671\ \text{Kg}}\right)\left(\frac{1000\ \text{Kg}}{1\ \text{Mg}}\right) = \$150/\text{Mg}$$

The cost-effectiveness of each seal oil reservoir degassing vent control system will vary with the particular situation, so quantitative C-E values cannot be presented in this guideline. But, whether or not such a control system is used should be based on an analysis that takes into account the potential emission reduction and the cost and technical feasibility of bringing the source into compliance with the concentration limitation.

4.4 REFERENCES FOR CHAPTER 4.0

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2. K. C. Hustvedt, U.S. EPA. Memo to R. A. Quaney, dated March 6, 1978.

3. J. M. Johnson, Exxon Co., U.S.A. Letter to R. T. Walsh, U.S. EPA, with attached studies of monitoring and maintenance program manpower requirements, dated July 28, 1977.

4. AP-42, Supplement No. 7, pg. 4.3-7.

5. Personal communication with L. Sturrock, Phillips Petroleum Co., Bartlesville, Okla. Memo to be file by R.A. Quaney, U.S. EPA, dated February 24, 1978.

6. Personal communication with F. Roan, Gulf Oil Co., Philadelphia, Penn. Memo to file by R. A. Quaney, U.S. EPA, dated May 24, 1978.

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8. E. D. Blum, Union Oil Co. of California, Los Angeles, Calif. Letter to R. A. Quaney, U.S. EPA, dated June 8, 1978.

9. Personal communication with B. Beyaert, Chevron U.S.A., San Francisco, Calif. Memo to file by R. A. Quaney, U.S. EPA, dated June 9, 1978.

10. Personal communication with W. C. Hood, Century Systems Corp., Arkansas City, Kansas. Memo to file by R. H. Schippers dated July 13, 1977. Personal communication with J. Dickey, Century Systems Corp., Arkansas City, Kansas. Memo to file by R. A. Quaney dated February 14, 1978.

11. Organic Vapor Analyzer Specifications (CS-07907217) and Price List (PL-038-7751), Century Systems Corp., Arkansas City, Kansas, 1977.

12. Personal communication with R. Tew, Director of Career Planning and Placement, North Carolina State University, Raleigh, N.C. Memo to file by R. A. Quaney dated February 27, 1978.

13. "Refined-products prices", Oil and Gas Journal, October 17, 1977 and March 6, 1978.

14. Personal communications with W. Shoemaker, Fluor Corporation, Irvine, Calif. Memo to file by R. A. Quaney, U.S. EPA, dated October 4, 1977. Memo to file by R. H. Schippers, U.S. EPA, dated July 18, 1977.

15. Personal communication with T. Norton, Union Pump Co., Battle Creek, Michigan. Memo to file by R. A. Quaney, U.S. EPA, dated October 3, 1977.

16. Personal communication with J. Columbus, Protecto Seal Co., Bensenville, Illinois. Memo to file by R. A. Quaney, U.S. EPA, dated October 3, 1977.

5.0 EFFECTS OF APPLYING THE TECHNOLOGY

The impacts of the monitoring and maintenance program on air pollution, water pollution, solid waste and energy are discussed in this chapter.

5.1 IMPACT OF A MONITORING AND MAINTENANCE PROGRAM ON VOC EMISSIONS

Estimated volatile organic compound (VOC) emissions from equipment leaks in petroleum refineries are 170,000 metric tons per year. This represents almost one percent of the total nationwide VOC emissions from stationary sources.[1] This estimate is based on existing AP-42 emission factors for leak sources of 174 kilograms per thousand cubic meters of refinery throughput[2] and 1977 industry throughput of 2.69 million cubic meters per day.[3] As discussed in Chapter 2.0, the AP-42 emission factors are based on 20 year old data. Emission factors for petroleum refinery equipment leaks are presently being updated, and preliminary data show the total leak emission rate is greater than AP-42 indicates.[4] In order to avoid confusion that occurs when new emission factors are published based on old or limited data, no attempt has been made to quantify the emission reduction associated with a monitoring and maintenance program. Rather, we will rely on the results of studies presently underway to define total emissions and emission reductions at some future date.

5.2 OTHER ENVIRONMENTAL IMPACTS

EPA has examined the impacts of applying the control technology to petroleum refineries and has determined that there are no significant adverse effects on other air pollution, water pollution, or solid waste. There will be a very small energy requirement for monitoring instruments and equipment repairs. This requirement will be more than offset by energy savings realized through product recovery when leaks are located and repaired.

5.3 REFERENCES

1. "National Air Quality and Emission Trends Report 1975." Environmental Protection Agency, OAQPS, MDAD-MRB, Research Triangle Park, N.C., EPA-450/1-76-002, November, 1976.

2. "Revision of Evaporative Hydrocarbon Emission Factors," EPA Report No. 450/3-76-039, August, 1976.

3. Cantrell, A, Annual Refining Survey. The Oil and Gas Journal, 75(13): 97-123, March 28, 1977.

4. "Assessment of Environmental Emissions From Oil Refining," Radian Corporation, EPA Contract No. 68-02-2665, in progress, March, 1976, to March, 1979.

6.0 ENFORCEMENT ASPECTS

The purpose of this chapter is to define facilities to which regulations will apply, to select appropriate regulatory format and to recommend compliance and monitoring techniques.

6.1 AFFECTED FACILITY

In formulating regulations it is suggested that the affected facility be defined as each individual source within a petroleum refinery complex. A petroleum refinery complex is defined as any facility engaged in producing gasoline, aromatics, kerosene, distillate fuel oils, residual fuel oils, lubricants, asphalt, or other products through distillation of petroleum or through redistillation, cracking, rearrangement or reforming of unfinished petroleum derivatives. The affected facilities are each individual source that could potentially leak volatile organic compounds (VOC) to atmosphere. These sources include, but are not limited to, pump seals, compressor seals, seal oil degassing vents, pipeline valves, flanges and other connections, pressure relief devices, process drains, and open ended pipes.

6.2 FORMAT OF REGULATION

Regulations limiting emissions from refinery equipment leaks should state that when any affected facility (component) within the petroleum refinery complex is found to be leaking, the refinery operator should make every reasonable effort to repair the leak within fifteen (15) days. A leaking component is defined as one which has a VOC concentration exceeding 10,000 parts per million (ppm) when tested in the manner described in Appendix B. Leaks

detected by either the refinery operator or the air pollution control agency would be subject to these guidelines. Recommended monitoring requirements for the refinery operators are presented in Section 6.3. In addition to the concentration limit, regulations should specify that any time a valve is located at the end of a pipe or line containing VOC, the end of the line should be sealed with a second valve, a blind flange, a plug or a cap. This sealing device may be removed only when the line is in use, i.e. when a sample is being taken. This recommendation does not apply to safety pressure relief valves.

6.3 COMPLIANCE AND MONITORING

The following sections outline suggested procedures petroleum refinery operators and air pollution control agencies should follow to control VOC leakage from refinery equipment.

6.3.1 Monitoring Requirements

In order to ensure that all existing leaks are identified and that new leaks are located as soon as possible, the refinery operator should perform component monitoring using the method described in Appendix B as follows:

1. Monitor with a portable VOC detection device one time per year (annually): pump seals
   pipeline valves in liquid service
   process drains

2. Monitor with a portable VOC detection device four times per year (quarterly): compressor seals
   pipeline valves in gas service
   pressure relief valves in gas service

3. Monitor visually fifty-two (52) times per year (weekly):

   pump seals

4. No individual monitoring necessary:

   pipeline flanges

   pressure relief valves in liquid service

For the purposes of this document, gas service for pipeline valves and pressure relief valves is defined as the VOC being gaseous at conditions that prevail in the component during normal operations. These components should be marked or noted in some way so that their location is readily obvious to both the refinery operator performing the monitoring and the air pollution control officer. Whenever liquids are observed dripping from a pump seal, the seal should be checked immediately with a portable VOC detector to determine if a leak is present, i.e., a concentration over 10,000 ppm. If so, the leak should be repaired within 15 days. In addition, whenever a relief valve vents to atmosphere, the operator again has fifteen (15) days to monitor and repair any leak that occurs. Finally, pressure relief devices which are tied in to either a flare header or vapor recovery should be exempted from the monitoring requirements.

6.3.2 Recording Requirements

When a leak is located, a weatherproof and readily visible tag bearing an I. D. number and the date the leak is located should be affixed to the leaking component. The presence of the leak should also be noted on a survey log similar to the one shown in Figure 6-1. When the leak is repaired, the remaining portions of the survey log (Figure 6-1) should be completed and the tag discarded. The operator should retain the survey log for two years after the inspection is completed.

6.3.3 Reporting Requirements

After each quarterly monitoring has been performed (and the annual), the refinery operator should submit a report to the air pollution control officer listing all leaks that were located but not repaired within the fifteen (15) day limit. A sample report is shown in Figure 6-2. In addition to submitting the report, the refinery operator should submit a signed statement attesting to the fact that all monitoring has been performed as stipulated in their control plan.

6.3.4 Other Considerations

Presently, there is little information available on the amount of monitoring necessary to ensure that leaks are kept to a reasonable limit. Considering this shortcoming, regulations that are written should allow for modifications in the monitoring schedule where it is proven to be either inadequate or excessive. If, after over one year of monitoring, i.e., at least two complete annual checks, the refinery operator feels that modifications of the requirements are in order, he may request in writing to the air pollution control officer that a revision be made. The submittal should include data that have been developed to justify any modifications in the monitoring schedule. On the other hand, if the air pollution control officer finds an excessive number of leaks during an inspection, or if the refinery operator found an excessive number of leaks in any given area during scheduled monitoring, the air pollution control officer should increase the frequency of inspections for that part of the facility.

The refinery operator should not be restrained from adopting alternative monitoring methods if these methods are shown to be equivalent to those presented here. An example would be substituting walkthrough

monitoring (as described in Appendix B) for the quarterly individual gas service valve monitoring. In order to apply for such a modification, the refinery operator should establish a VOC concentration "action level" and document its effectiveness at locating leaks. Other alternative monitoring methods such as using soap solution to detect leaks from "cool" components may be used if the refinery operator can develop a data base to prove equivalence with the recommended procedure, i.e. a concentration limit of 10,000 ppm.

It is anticipated that in most cases, a leaking component will be able to be brought into compliance with the 10,000 ppm concentration limit (repaired) with a minimum of effort. There are sources, however, that may need to be isolated from the process in order to be repaired. This procedure may be difficult for some equipment, especially compressors that do not have spares and valves that cannot be isolated. For these and possibly other sources, it may be necessary to have a partial or complete unit shutdown to repair the leak. Since a unit shutdown may create more emissions than the repair eliminates, these sources need not be repaired until the necessary shutdown occurs, such as a scheduled unit turnaround.

In certain instances, more than simple or unit shutdown repairs will be necessary to bring a leaking component into compliance. This can be true for some pump or compressor seals or for drain systems. It may be necessary to modify or replace the whole pump or compressor seal system or to modify the underground drain pipes. One example of this is when a dual sealing system is used for pumps or compressors. A seal oil is flushed between the two seals creating a potential for VOC emissions if the seal oil reservoir is degassed to atmosphere. If such a system is used, instead

of monitoring the VOC concentration of the double seal, the refinery operator should monitor the seal oil reservoir degassing vent to determine if it is over the 10,000 ppm concentration limit. This source can be controlled by venting to a firebox or to the flare header. Sources such as this, where the leak cannot be repaired by maintenance or equipment changeout, should be addressed individually by the air pollution control agency, taking into account both the potential emission reduction and the cost and technical feasibility of bringing such a source into compliance with the concentration limit.

LEAK DETECTION AND REPAIR SURVEY LOG

INSTRUMENT OPERATOR: _____

RECORDER: _____

UNIT	COMPONENT	STREAM COMPOSITION	TAG NUMBER	DATE LEAK LOCATED	DATE MAINTENANCE PERFORMED	COMPONENT RECHECK AFTER MAINTENANCE	
						DATE	INSTRUMENT READING (ppm)

FIGURE 6-1. Example Monitoring Survey Log Sheet

UNIT	COMPONENT	STREAM COMPOSITION	DATE LEAK LOCATED	DATE MAINTENANCE ATTEMPTED	DATE LEAK WILL BE REPAIRED	REASON REPAIRS FAILED OR POSTPONED

FIGURE 6-2. Example Refinery Leak Report

APPENDIX A - EMISSION SOURCE TEST DATA

The purpose of Appendix A is to summarize and discuss source tests that were conducted by EPA to define the present leak status of petroleum refineries in the United States. EPA performed source tests at two Los Angeles, California, area refineries during February 1977; a Houston, Texas, area refinery in October, 1977; and a New Orleans, Louisiana, area refinery in November, 1977. Refineries A, C and D are integrated refineries that produce a wide variety of products. Refinery B is a crude topping and asphalt producing refinery. The following sections give a brief description of the units tested in the refineries and conditions that existed during the tests. Overall results are summarized in Table A-1 and the individual results are shown in Tables A-2 through A-5. The hydrocarbon concentrations that are reported are the maximum concentrations that were found at a distance of 5 centimeters from each individual leak source. All tests were performed with a Century Systems OVA-108 instrument.

A.1 REFINERY A

Refinery A is a medium sized integrated refinery owned by a major oil company. Units surveyed in Refinery A included a cooling tower, a delayed coker, three wastewater separators, the tank farm, a superfractionation unit, an atmospheric distillation unit, a vacuum distillation unit, a fluid catalytic cracking (FCC) unit and the FCC gas plant. All units were operating normally throughout the testing except for the desalter in the atmospheric

distillation unit. Improper oil-water separation caused elevated hydrocarbon concentrations in the process drains. In a few units there was a large hydrocarbon cloud downwind from pumps that had mechanical seal failures. This made it impossible to survey the pumps and associated equipment in such an area. A summary of results of component testing at Refinery A is shown in Table A-2.

A.2 REFINERY B

Refinery B is a small, independently owned crude topping refinery. All of the operating equipment in the refinery was surveyed, including the equipment associated with their atmospheric and vacuum distillation units. Most of the pumps in the refinery have dual mechanical seals with a barrier fluid so very few had detectable leaks. Results of Refinery B testing are shown in Table A-3.

A.3 REFINERY C

Refinery C is a large, major integrated petroleum refinery. Many units in Refinery C were surveyed, including two wastewater separators, a distillate desulfurizer, an aromatics recovery unit, a crude atmospheric and vacuum distillation unit, a fluid catalytic cracking unit, a hydrocracker, two reformers and the tank farm. All of the units were operating normally when the surveys were performed. The test results are summarized in Table A-4.

A.4 REFINERY D

Refinery D is a fairly large integrated refinery. It is a recently built grassroots refinery and is owned by one of the major oil companies. Only two units were surveyed in Refinery D; the aromatics recovery unit and

the saturated gas plant. Both units were operating normally during testing. Refinery D test results are shown in Table A-5.

TABLE A - 1 SUMMARY OF RESULTS OF FOUR EPA TESTS

Emission Source	Number of Sources Tested	Percent Leaking [b]
Pump Seals	482	13
Compressor Seals	15	7
Block Valves	940	6
Control Valves	287	7
Open-Ended Valves [c]	43[a]	12
Drains	367	6
Pressure Relief Devices	15 [a]	0

a Not a representative sample of refinery units

b VOC concentration over 1000 ppm measured at 5 centimeters from the source. (Equivalent to 10,000 ppm at the source - see Chapter 2.)

c Including bleed valves and sample connections

TABLE A - 2 SUMMARY OF REFINERY A TESTING

Emission Source	Number of Sources Tested	Percent Leaking [b]
Pump Seals	87	7
Compressor Seals	2	50
Block Valves	172	7
Control Valves	26	11
Open-Ended Valves [c]	3 [a]	100
Drains	59	3
Pressure Relief Devices	15 [a]	0

a Not a representative sample of refinery units

b VOC concentration over 1000 ppm measured at 5 centimeters from the source. (Equivalent to 10,000 ppm at the source - see Chapter 2.)

c Including bleed valves and sample connections

TABLE A - 3 SUMMARY OF REFINERY B TESTING

Emission Source	Number of Sources Tested	Percent Leaking [a]
Pump Seals	25	4
Compressor Seals	-	-
Block Valves	25	20
Control Valves	2	0
Open-Ended Valves [b]	1	0
Drains	5	0
Pressure Relief Devices	-	-

a VOC concentration over 1000 ppm measured at 5 centimeters from the source. (Equivalent to 10,000 ppm at the source - see Chapter 2.)

b Including bleed valves and sample connections.

TABLE A - 4 SUMMARY OF REFINERY C TESTING

Emission Source	Number of Sources Tested	Percent Leaking [a]
Pump Seals	327	16
Compressor Seals	12	0
Block Valves	601	3
Control Valves	198	8
Open-Ended Valves [b]	36	0
Drains	279	5
Pressure Relief Devices	-	-

a VOC concentration over 1000 ppm measured at 5 centimeters from the source. (Equivalent to 10,000 ppm at the source - see Chapter 2.)

b Including bleed valves and sample connections

TABLE A - 5 SUMMARY OF REFINERY D TESTING

Emission Source	Number of Sources Tested	Percent [a] Leaking
Pump Seals	43	16
Compressor Seals	1	0
Block Valves	142	13
Control Valves	61	3
Open-Ended Valves [c]	3 [b]	67
Drains	24	15
Pressure Relief Devices	-	-

a VOC concentration over 1000 ppm measured at 5 centimeters from the source. (Equivalent to 10,000 ppm at the source - see Chapter 2.)

b Not a representative sample

c Including bleed valves and sample connections.

APPENDIX B

DETECTION OF VOC LEAKS FROM PETROLEUM REFINERY EQUIPMENT

B.1 INTRODUCTION

This test method describes the procedures used to detect volatile organic compound (VOC) leaks from petroleum refinery equipment. A portable test instrument is used to survey individual equipment leak sources. The specifications and performance criteria for the test instrument are included. Also included is a description of an alternative walkthrough procedure that may be used if the refinery owner or operator demonstrates that the procedure is effective for locating individual equipment leaks.

B.2 APPARATUS

B.2.1 Monitoring Instrument

The VOC detection instrument used in this procedure may be of any type that is designed to respond to total hydrocarbons or combustible gases. The instrument must incorporate an appropriate range option so that source levels (10,000 ppm) can be measured. The instrument shall be equipped with a pump so that a continuous sample is provided to the detector. The instrument meter readout shall be such that the scale can be read to $\pm$ 5 percent at 10,000 ppmv. The instrument must be capable of achieving the performance criteria given in Table B.1. The definitions and evaluation procedures for each parameter are given in Section B.4.

Table B.1. Monitoring Instrument Performance Criteria

Parameter	Specification
1. Zero drift (2-hour)	$\leq$ 5 ppmv
2. Calibration drift (2-hour)	$\leq$ 5% of the calibration gas value
3. Calibration error	$\leq$ 5% of the calibration gas value
4. Response time	$\leq$ 5 seconds

The instrument must be subjected to the performance evaluation test prior to being placed in service and every 6 months thereafter. The performance evaluation test is also required after any modification or replacement of the instrument detector.

B.2.2 Calibration Gases

The VOC detection instrument is calibrated so that the meter readout is in terms of parts per million by volume (ppmv) hexane. The calibration gases required for monitoring and instrument performance evaluation are a zero gas (air, < 3 ppmv hexane) and a hexane in air mixture of about 10,000 ppmv. If cylinder calibration gas mixtures are used, they must be analyzed and certified by the manufacturer to be within $\pm$ 2 percent accuracy. Calibration gases may be prepared by the user according to any accepted gaseous standards preparation procedure that will yield a mixture accurate to within $\pm$ 2 percent. Alternative calibration gas species may be used in place of hexane if a relative response factor for each instrument is determined so that calibrations with the alternative species may be expressed as hexane equivalents on the meter readout.

B. 3 PROCEDURES

B.3.1 Calibration

Assemble and start up the VOC analyzer and recorder according to the manufacturer's instructions. After the appropriate warmup period and zero or

internal calibration procedure, introduce the 10,000 ppmv hexane or hexane equivalent calibration gas into the instrument sample probe. Adjust the instrument meter readout and chart recorder to correspond to the calibration gas value.

B.3.2 Individual Source Surveys

Place the instrument sample probe inlet at the surface of the component interface where leakage could occur. During sample collection, the probe should be moved along the interface surface with special emphasis placed on positioning the probe inlet at the local upwind and downwind side of the component interface. If a concentration reading in excess of 10,000 ppmv is observed, record the date, time, and equipment identification. This general technique is applied to specific types of equipment leak sources as follows:

B.3.2.1 Valves - The most common source of leaks from block (glove, plug, gate, ball, etc.) and control valves is at the seal between the stem and housing. The probe should be placed at the interface where the stem exits the seal and sampling should be conducted on all sides of the stem. For valves where the housing is a multipart assembly, or where leaks can occur from points other than the stem seal, these sources should also be surveyed with the probe inlet moved along the surface of the interface.

B.2.2.2 Flanges and other connections - For welded flanges, the probe should be placed at the outer edge of the flange-gasket interface and samples collected around the circumference of the flange. For other types of non-permanent joints such as threaded connections, a similar traverse is conducted at the component interface.

B.3.2.3 Pumps and compressors - A circumferential traverse is conducted at the outer surface of the pump or compressor shaft and housing seal interface. In cases where the instrument probe cannot be placed in contact with a

rotating shaft, the probe inlet must be placed within one centimeter of the shaft-seal interface. In those cases where the housing configuration of the pump or compressor prevents the complete traversing of the seal periphery, all accessible portions of the shaft seal should be probed. All other joints where leakage could occur shall also be sampled with the probe inlet placed at the surface of the interface. For pumps or compressors using sealing oil, the vent from the seal oil reservoir shall be sampled by placing the probe inlet at approximately the centroid of the vent area to atmosphere.

B.3.2.4 Pressure relief devices - The physical configuration of most pressure relief devices prevents sampling at the sealing surface interface. However, most devices are equipped with an enclosed extension, or horn. For this type device, the probe inlet is placed at approximately the centroid of the exhaust area to atmosphere.

B.3.2.5 Process drains - For open process drains, the sample probe inlet shall be placed at approximately the centroid of the area open to the atmosphere. For covered drains, the probe should be placed at the surface of the cover interface and a circumferential traverse shall be conducted.

B.3.2.6 Open-ended valves - Leakage from open-ended valves such as sample taps or drain lines shall be detected by placing the probe inlet at approximately the centroid of the uncapped opening to atmosphere.

B.4 INSTRUMENT PERFORMANCE EVALUATION PROCEDURES

B.4.1 Definitions

Zero drift - The change in the instrument meter readout over a stated period of time of normal continuous operation when the VOC concentration at the time of measurement is zero.

Calibration Drift - The change in the instrument meter readout over a stated period of time of normal continuous operation when the VOC concentration at the time of measurement is the same known upscale value.

Calibration Error - The difference between the VOC concentration indicated by the meter readout and the known concentration of a test gas mixture.

Response Time - The time interval from a step change in VOC concentration at the input of the sampling system to the time at which 95 percent of the corresponding final value is reached as displayed on the instrument readout meter.

B.4.2 Evaluation Procedures

At the beginning of the instrument performance evaluation test, assemble and start up the instrument according to the manufacturer's instructions for recommended warmup period and preliminary adjustments.

B.4.2.1 Zero and calibration drift test - Calibrate the instrument per the manufacturer's instructions using zero gas and a calibration gas representing about 10,000 ppmv. Record the time, zero, and calibration gas readings (example data sheet shown in Figure B.1). After 2 hours of continuous operation, introduce zero and calibration gases to the instrument. Record the zero and calibration gas meter readings. Repeat for three additional 2-hour periods.

B.4.2.2 Calibration error test - Make a total of nine measurements by alternately using zero gas and a calibration gas mixture corresponding to about 10,000 ppmv. Record the meter readings (example data sheet shown in Figure B.2).

B.4.2.3 Response time test procedure - Introduce zero gas into the instrument sample probe. When the meter reading has stabilized, switch quickly to the 10,000 ppmv calibration gas. Measure the time from concentration switching

to 95 percent of final stable reading. Perform this test sequence three (3) times and record the results (example data sheet given in Figure B.3).

B.4.2.4 The calibration error test and the response time test may be performed during the zero and calibration drift test.

B.4.3 Calculations

All results are expressed as mean values, calculated by:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_1$$

where:

x_i = value of the measurements

Σ = sum of the individual values

$\bar{x}$ = mean value

n = number of data points

The specific calculations for each performance parameter are indicated on the respective example data sheet given in Figures B.1, B.2, and B.3.

(NOTE: The example data sheets are constructed so that performance criteria tests can be conducted on 10,000 ppmv levels and a low level (<100 ppmv) gas. For the purposes of the individual source surveys, use only the portions identified as "high calibration.")

Instrument ID:_____ Calibration Gas Data: Low _____ ppmv High _____ ppmv

Date and Time	Zero Reading	Zero Drift	Low Calibration Gas Reading	Low Calibration Drift	High Calibration Gas Reading	High Calibration Drift
Start						
1.						
2.						
3.						
4.						

Mean Value: (1) Zero Drift = _____ ppmv

Calibration Drift = $\frac{\text{mean calibration drift}}{\text{calibration gas value}} \times 100$ = Low _____% High _____%

(1) Absolute Value

Figure B.1. Zero and Calibration Drift Determination

Instrument ID_____

Calibration Gas Mixture Data

Low _____ ppm High _____ ppm

Run No.	Calibration Gas Concentration, ppm	Instrument Meter Reading, ppm	Difference,[1] ppm
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			

	Low	High
Mean Difference	_____	_____
Calibration Error = $\frac{\text{Mean Difference}^{(2)}}{\text{Calibration Gas Concentration}} \times 100$	_____	_____

(1) Calibration Gas Concentration - Instrument Reading

(2) Absolute Value

Figure B.2. Calibration Error Determination

Instrument ID _____

Calibration Gas Concentration _____

95% Response Time:

1. _____ Seconds

2. _____ Seconds

3. _____ Seconds

Mean Response Time _____ Seconds

Figure B.3. Response Time Determination

B.5 ALTERNATIVE UNIT AREA SURVEYS

B.5.1 Introduction

In this procedure, a process unit area is surveyed with a portable VOC detector to determine if there is an increased local ambient VOC concentration in the equipment area. The unit area walkthrough should be planned so that the unit perimeter and all ground level equipment is surveyed. The walkthrough must include ambient VOC measurements at a distance of about one meter upwind and downwind of all pump rows and control valves. In order to simplify data recording and subsequent data review, a planned walkthrough path with codes for location identification is recommended.

B.5.2 Apparatus

B.5.2.1 Monitoring instrument - The VOC detection instrument used must conform to the specifications and performance specifications given in B.2.1 except that a measurement range must be available for accurately measuring ambient VOC levels (usually less than 100 ppmv). The minimum detectable VOC concentration must be 2 ppmv hexane or less. Also, the instrument must be equipped with a portable strip chart recorder so that a permanent record of the walkthrough survey can be retained.

B.5.2.2 Calibration gases - The specifications for the calibration gases required are given in B.2.2, except that the calibration mixture must be approximately the same concentration as the chosen action level that indicates a leak in the area.

B.5.2.3 Procedures - Prior to the start of the walkthrough, record the date, time, origination point, and approximate wind speed and direction in the unit area. Begin the walkthrough and record location identifications during the course of the survey. Make two complete traverses along the walkthrough path to complete the survey. If an elevated VOC concentration is observed,

specifically identify the location on the chart record. After completion of the walkthrough survey, record the time and local wind conditions.

B.5.2.4 Data evaluation - Compare the results obtained during each of the two traverses through the unit area by observing the strip chart records. Using the ambient VOC concentration upwind of the unit area as a basis, identify the locations where elevated VOC concentrations were observed on both traverses Use the prevailing local wind condition information to locate the possible sources of VOC leakage and use the procedures given in B.3.2 to determine if a leak is present. For those cases where an increased VOC concentration is observed in a specific location on one traverse, but not on the other, repeat the ambient measurements in that general location. If increased VOC levels are again observed, use the procedures in B.3.2 to locate the leak source. If a repetition of an increased VOC level cannot be obtained, or if shifts in the location of elevated VOC concentrations during traverse repetitions cannot be explained by varying wind direction or speed, treat these as transient conditions and exclude these areas from individual leak source surveys required above.

B.5.2.5 Instrument performance evaluation procedures - The VOC instrument evaluation procedures are the same as those given in B.4 for source level VOC detection instruments except that the calibration test concentrations must be in the range expected during ambient surveys. The example data sheets in Figures B.1, B.2, and B.3 include provisions for evaluation of ambient level VOC detectors. For those cases where a single detector is used for both source and ambient (walkthrough) surveys, the performance evaluations can be performed at the same time.

APPENDIX C

C.1 MONITORING AND MAINTENANCE MANPOWER REQUIREMENTS

Table C-1 shows estimated annual manpower requirements for monitoring in the model 15,900 cubic meter per day refinery. These estimates are based on data supplied by industry,[1] EPA estimates, and the monitoring guidelines presented in Section 6-3. For the purposes of these estimates only, it is assumed that these surveys will generally be performed by two people--one operating the VOC detection instrument and the other recording the results.[2] The visual inspections are assumed to be performed by one person. It is shown that the total direct labor requirement for performing monitoring inspections in the model refinery is 1800 manhours per year, of which almost 1000 manhours were spent on the complete annual inspection. Actual complete component testing by a contractor in a more complex but similarly sized refinery took 936 manhours to perform.[3]

When a leak is detected during the required monitoring, the leaking component must then be repaired to reduce VOC emissions to atmosphere. Table C-2 was developed to estimate manpower requirements for maintenance using the percent of sources that leak from Table 3-1 and the number of sources from industry estimates.[4] In this analysis it is assumed that an additional ten percent of the initial leaks will be found each quarter during ongoing gas service component monitoring. Manpower requirements

for maintenance of each source were approximated by a refining company[5] and the State of California Air Resources Board.[6] As shown in Table C-2, the total annual direct labor requirement for repairing leaks is 3,800 manhours.

It should be noted that this estimate is for the maximum maintenance requirements and will probably be realized only during the first year that the monitoring and maintenance program is in effect. Assuming that refinery equipment was properly specified and installed, leaks (especially in valves) are usually the result of insufficient leak detection and maintenance. Once these leaks are identified and repaired, fewer leaks will be detected during subsequent inspections. This should result in much lower maintenance manpower requirements for following years.

TABLE C-1. ANNUAL MONITORING MANPOWER REQUIREMENTS FOR MODEL 15,900 CUBIC METER PER DAY REFINERY

SOURCE	Number of Sources [a]	Type of Monitoring	Estimated Time Required to to Monitor [a] (minutes)	Number of Times Monitored [d] per Year	Annual Total Manpower Requirement [f] (hours)
Pump Seals	250	Instrument	5	1	42
		Visual	0.5	52	108[g]
Compressor Seals	14	Instrument	10	4	18
Pipeline Valves	25,500				
Liquid Service	19,500 [b]	Instrument	1	1	650
Gas Service	6,000 [b]	Instrument	1	4	800
Process Drains	1,400	Instrument	1	1	46
Pressure Relief Devices	130 [c]	Instrument	8	4 [e]	138
Pipeline Flanges	64,000	None	-	-	0
				TOTAL	1800

a Based on industry (Reference 1) and EPA estimates

b Based on Joint Study (Reference 7) estimate of 23.6 percent of refinery valves being in gas service

c Pressure relief devices in gas service venting to atmosphere

d Monitoring requirements from Section 6-3

e In addition, pressure relief devices will need to be monitored whenever they vent to atmosphere

f Except as noted, total manpower requirements for these estimates are assumed to be based on two person teams performing the monitoring

g One person performs visual inspections

TABLE C-2. ANNUAL MAINTENANCE MANPOWER REQUIREMENTS FOR MODEL 15,900 CUBIC METER PER DAY REFINERY

Source	Number of Sources[a]	Estimated Number of Leaks Detected Per Year[b]	Average Repair Time (hours)[a,d]	Total Annual Manpower Requirement (hours)
Pump Seals	250	30	80	2400
Compressor Seals	14	2	40	80
Pipeline Valves	25,500	1640	0.6[e]	984
Process Drains	1,400	84	4	336
Pressure Relief Valves	130	34	0[f]	0
Pipeline Flanges	64,000	-	-	-
			TOTAL	3800

a Based on industry (Reference 1) and EPA estimates

b Based on Table 3-1 and ten percent of initial leak recurrence rate for quarterly inspections

c No monitoring performed

d This estimate includes time for rechecking the component after maintenance is performed

e Weighted average repair time with ten percent of leaks isolated and repaired (Reference 1) at a cost of 4 manhours, and the remaining 90 percent tightened or greased on-line at a cost of 0.17 manhours (Reference 6)

f These leaks repaired by routine maintenance at no incremental increase in manpower requirements (Reference 1)

C.2 REFERENCES

1. Letter with attachments from J.M. Johnson, Exxon Company, U.S.A., to Robert T. Walsh, U.S. EPA, July 28, 1977.

2. Personal communication between Lynn Sturrock, Phillips Petroleum Company, and R.A. Quaney, U.S. EPA, memo to files, February 24, 1978.

3. Letter with attachments from B.F. Ballard, Phillips Petroleum Company, to William Stewart, Texas Air Control Board, September 8, 1977.

4. Johnson, J.M. Op Cit.

5. Ibid.

6. "Emissions From Leaking Valves, Flanges, Pump and Compressor Seals, and Other Equipment at Oil Refineries," State of California Air Resources Board, Report No. LE-78-001, April 24, 1978.

7. "Hydrocarbon Losses From Valves and Flanges," Robert K. Palmer, Joint District, Federal and State Project for the Evaluation of Refinery Emissions. Report No. 2, March, 1957.

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16. ABSTRACT

This report provides the necessary guidance for development of regulations to limit emissions of volatile organic compounds (VOC) from petroleum refinery equipment leaks. Equipment considered includes pump seals, compressor seals, seal oil degassing vents, pipeline valves, flanges and other connections, pressure relief devices, process drains, and open ended pipes. Reasonably available control technology (RACT) for these sources consists of a routine monitoring schedule to locate leaks so that maintenance can be performed as possible and emissions of VOC to atmosphere reduced. An example cost analysis for implementing these controls in a model refinery is presented along with a methodology for evaluating the cost effectiveness of these controls when updated emission factors become available.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Air Pollution Control	13B
Hydrocarbons	Stationary Sources	14B
Petroleum Refining	Hydrocarbon Emission Control	13H

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