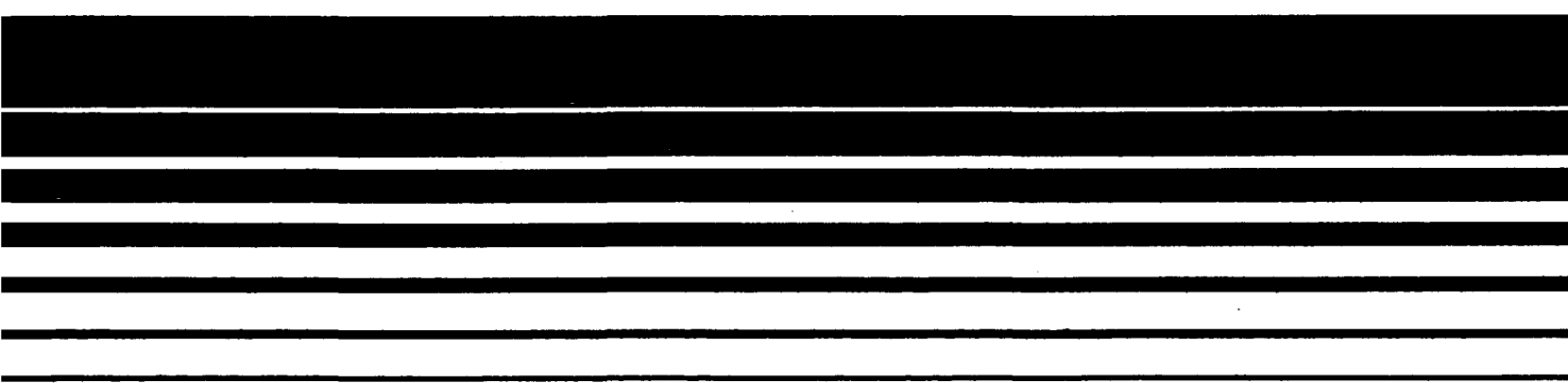

Air



VOC Fugitive Emissions in Synthetic Organic Chemicals Manufacturing Industry — Background Information for Proposed Standards

Draft EIS

Preliminary Draft



NOTICE

This document has not been formally released by EPA and should not now be construed to represent Agency policy. It is being circulated for comment on its technical accuracy and policy implications.

**VOC Fugitive Emissions
in Synthetic Organic Chemicals
Manufacturing Industry —
Background Information
for Proposed Standards**

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

March 1980

This report has been revised 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 Officer (MD-35), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, or from the National Technical Information Services, 5285 Port Royal Road, Springfield, Virginia 22161.

METRIC CONVERSION TABLE

In keeping with U.S. Environmental Protection Agency policy, metric units are used in this report. These units may be converted to common English units by using the following conversion factors:

<u>Metric Unit</u>	<u>Metric Name</u>	<u>Equivalent English Unit</u>
<u>LENGTH</u>		
m	meter	39.3700 in.
m	meter	3.2810 ft.
<u>VOLUME</u>		
l	liters	0.2642 U.S. gal
m ³	cubic meters	264.2 U.S. gal
m ³	cubic meters	6.29 Barrels (bbl)
<u>WEIGHT</u>		
Kg	kilogram (10 ³ grams)	2.2046 lb.
Mg	megagram (10 ⁶ grams)	1.1023 tons
Gg	gigagram (10 ⁹ grams)	1,102.3 tons
<u>ENERGY</u>		
GJ	gigajoule	9.48 X 10 ⁵ Btu
GJ	gigajoule	277.76 KWh
J/g	joule per gram	0.430 Btu/lb.
<u>VOLUMETRIC FLOW</u>		
Nm ³ /sec	normal cubic meters per second	2242 SCFM (ft ³ /min)
<u>SPEED</u>		
m/s	meters per second	196.86 ft/min

Temperature in degrees Celcius (°C) can be converted to temperature in degrees Farenheit (°F) by the following formula:

$$(^{\circ}\text{F}) = 1.8 (^{\circ}\text{C}) + 32$$

TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES	x
LIST OF TABLES	vi
ABBREVIATIONS AND CONVERSION FACTORS	
2. INTRODUCTION	2-1
2.1 Authority for the Standards	2-1
2.2 Selection of Categories of Stationary Sources	2-5
2.3 Procedure for Development of Standards of Performance	2-7
2.4 Consideration of Costs	2-8
2.5 Consideration of Environmental Impacts	2-10
2.6 Impact on Existing Source	2-11
2.7 Revision of Standards through Experience	2-12
3. DESCRIPTION OF FUGITIVE EMISSION SOURCES	3-1
3.1 Introduction and General Industry Information	3-1
3.2 Fugitive Emission Definition and Potential.	3-3
3.3 Baseline Control.	3-17
3.4 References.	3-21
4. EMISSION CONTROL TECHNIQUES.	4-1
4.1 Leak Detection and Repair Methods	4-1
4.2 Equipment Specifications.	4-13
4.3 References.	4-24
5. MODIFICATION AND RECONSTRUCTION	5-1
5.1 General Discussion of Modification and Reconstruction.	5-1
5.2 Applicability of Modification and Reconstruction Provisions to the SOCFI	5-3
6. MODEL PROCESS UNITS AND REGULATORY ALTERNATIVES.	6-1
6.1 Model Units	6-1
6.2 Regulatory Alternatives	6-4
6.3 References	6-7

TABLE OF CONTENTS (cont.)

	<u>Page</u>
7. ENVIRONMENTAL IMPACT	7-1
7.1 Impact on Atmospheric Emissions	7-1
7.2 Impact of Water Quality	7-8
7.3 Impact on Solid Waste	7-11
7.4 Energy Impact	7-12
7.5 Other Environmental Concerns.	7-14
7.6 References.	7-14
8. COST ANALYSIS.	8-1
8.1 Cost Analysis of Regulatory Alternatives.	8-1
8.2 Other Cost Considerations	8-24
8.3 References.	8-25
9. ECONOMIC ANALYSIS.	9-1
9.1 Industry Profile.	9-1
9.2 Economic Impact Analysis.	9-16
9.3 Socio-Economic and Inflationary Impacts	9-40
9.4 References.	9-41
APPENDIX C	C-1
APPENDIX D	D-1
APPENDIX E	E-1
APPENDIX F	F-1

LIST OF TABLES

		<u>Page</u>
3-1	Approximate Level of Uncontrolled Fugitive Emission Factors in the Synthetic Organic Chemical Manufacturing Industry (SOCMI)	3-18
4-1	Fraction of Total Mass Emissions From Various Source Types That Would be Controlled by Different Action Levels.	4-7
4-2	Estimated Occurrence and Recurrence Rate for Various Monitoring Intervals	4-10
4-3	Percent of Mass Emissions Affected by Various Repair Intervals.	4-11
4-4	Average Emission Rates from Sources Above 10,000 ppmv and at 1000 ppmv	4-11
4-5	Example of Control Efficiency Calculation.	4-15
4-6	Impact of Monitoring Interval on Correction Factor Accounting for Leak Occurrence/Recurrence (For Example Calculation)	4-15
4-7	Effectiveness of Equipment Modifications	4-23
6-1	Fugitive Emission Sources for Three Model Units	6-3
6-2	Regulatory Alternatives for NSPS for Fugitive Emission Sources in the SOCMI	6-5
7-1	Emission Factors for Sources Controlled Under Regulatory Alternative II	7-3
7-2	Emission Factors for Sources Controlled Under Regulatory Alternative III	7-4
7-3	Emission Factors for Sources Controlled Under Regulatory Alternative IV	7-5
7-4	Example Calculation of VOC Fugitive Emissions from Model Unit A Under Regulatory Alternative II	7-6
7-5	Estimated Emissions and Emission Reduction on A Model Unit Basis	7-7
7-6	Total VOC Fugitive Emissions from Affected Model Units for Regulatory Alternatives	7-10

LIST OF TABLES (cont.)

	<u>Page</u>
8-1 Capital Cost Data	8-2
8-2 Capital Cost Estimates for New Model Units.	8-3
8-3 Annual Monitoring and Leak Repair Labor Requirements for Regulatory Alternative II	8-5
8-4 Annual Monitoring and Leak Repair Labor Requirements for Regulatory Alternative III	8-6
8-5 Annual Monitoring and Leak Repair Labor Requirements for Regulatory Alternative IV	8-7
8-6 Derivation of Annualized Labor, Administrative, Maintenance, and Capital Charges	8-8
8-7 Labor-Hour Requirements for Initial Leak Repair	8-11
8-8 Recovery Credits.	8-12
8-9 Annualized Control Cost Estimated for Model Unit A	8-13
8-10 Annualized Control Cost Estimated for Model Unit B	8-14
8-11 Annualized Control Cost Estimated for Model Unit C	8-15
8-12 Cost Effectiveness for Model Units	8-16
8-13 Capital Cost Estimates for Modified/Reconstructed Facilities.	8-18
8-14 Annualized Control Cost Estimated for Modified/ Reconstructed Model Units Under Regulatory Alternative IV	8-19
8-15 Nationwide Costs for the Industry Under Regulatory Alternative II.	8-21
8-16 Nationwide Costs for the Industry Under Regulatory Alternative III	8-22
8-17 Nationwide Costs for the Industry Under Regulatory Alternative IV	8-23
8-18 Statutes That May be Applicable to SOCFI	8-25
9-1 Estimated Plant Capacity By State	9-3

LIST OF TABLES (cont.)

	<u>Page</u>
9-2 Distribution of Plants by Capacity and Region	9-4
9-3 Distribution of Industry Capacity By Plant Size and Region	9-6
9-4 Production and Sales of Synthetic Organic Chemicals	9-7
9-5 SOCOMI Resource Use.	9-9
9-6 Industrial Organic Chemicals: U.S. Imports and Exports, 1966-77	9-10
9-7 Industrial Organic Chemicals: U.S. Trade, By Principal Trading Partners, 1976 and 1977	9-13
9-8 Industrial Organic Chemicals: U.S. Imports For Consumption By Principal Source, 1972-77.	9-14
9-9 Industry Concentration	9-18
9-10 Estimated Cost of Capital for Firms in SOCOMI.	9-19
9-11 Average Rate of Return Impacts.	9-28
9-12 Model Units Experiencing Significant Rate of Return Impacts Under Full Cost Absorption.	9-30
9-13 Average Price Impacts of Regulatory Alternatives.	9-32
9-14 Model Units Requiring Significant Price Increases to Maintain Target Rates of Return	9-33
9-15 Investment Impacts of Regulatory Alternatives	9-36
9-16 Employment Impacts of Regulatory Alternatives	9-38
9-17 Model Unit and Industry Annualized Control Costs.	9-39
C-1 Frequency of Leaks from Sources In Synthetic Organic Chemical Plants	C-4
C-2 Sampled Process Units from Nine Refineries During Refinery Study	C-5
C-3 Leak Frequencies and Emission Factors from Fugitive Sources in Petroleum Refineries	C-7

LIST OF TABLES (cont.)

		<u>Page</u>
C-4	Comparison of Leak Frequencies for Fugitive Emission Sources in SOCFI Units and Petroleum Refineries	C-8
C-5	Summary of Maintenance Study Results from Union Oil Company Refinery in Rodeo, California	C-10
C-6	Summary of Maintenance Study Results from the Shell Oil Company Refinery in Martinez, California.	C-12
C-7	Summary of EPA Refinery Maintenance Study Results	C-14
C-8	Unit D-Ethylene Unit Block Valve Repair	C-15
E1-1	SOCFI Chemicals Included in ITC Category Ratios	E-3
E1-2	Ratios Used To Weight ITC Data.	E-5
E2-1	Projections of Replacement Investment	E-8
E3-1	Yields by Rating Class for Cost of Debt Funds, 1979	E-12
E3-2	Financial Data for 100 Firms in SOCFI	E-14

LIST OF FIGURES

	<u>Page</u>
3-1 General schematic of process levels that make up the organic chemical industry.	3-2
3-2 Diagram of a simple packed seal.	3-4
3-3 Diagram of a basic single mechanical seal.	3-5
3-4 Diagram of a double mechanical seal (back-to-back arrangement) .	3-6
3-5 Diagram of a double mechanical seal (tandem arrangement)	3-6
3-6 Chempump canned-motor pump	3-7
3-7 Shriver mechanically actuated diaphragm pump	3-8
3-8 Liquid-film compressor shaft seal.	3-9
3-9 Diagram of a gate valve.	3-10
3-10 Example of bellows seals	3-11
3-11 Diagrams of valves with diaphragm seals.	3-12
3-12 Diagram of a spring-loaded relief valve.	3-13
3-13 Cooling tower (cross-flow)	3-14
3-14 Diagram of hydraulic seal for agitators.	3-15
3-15 Diagram of agitator lip seal	3-16
4-1 Cumulative distribution of total emissions by screening values - valves - gas/vapor streams	4-16
4-2 Cumulative distribution of sources by screening values - valves - gas/vapor streams	4-16

2. INTRODUCTION

Standards of performance are proposed following a detailed investigation of air pollution control methods available to the affected industry and the impact of their costs on the industry. This document summarizes the information obtained from such a study. Its purpose is to explain in detail the background and basis of the proposed standards and to facilitate analysis of the proposed standards by interested persons, including those who may not be familiar with the many technical aspects of the industry. To obtain additional copies of this document or the Federal Register notice of proposed standards, write to EPA Library (MD-35), Research Triangle Park, North Carolina, 27711. When ordering, specify the Background Information Document (BID), Volume 1: Proposed Standards of Performance for the Synthetic Organic Chemical Manufacturing Industry.

2.1 AUTHORITY FOR THE STANDARDS

Standards of performance for new stationary sources are established under Section 111 of the Clean Air Act (42 United States Code 7411), as amended, hereafter 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 health or welfare."

The term new source is defined as "any stationary source, the construction or modification of which is commenced after the publication of regulations (or, if earlier, proposed regulations) prescribing a standard of performance under this section which will be applicable to such source."

The term stationary source is further defined as "any building, structure, facility or installation which emits or may emit any air pollutant."

The term standard of performance as applied to stationary sources (other than fossil-fuel-fired sources) is defined as an "allowable emission limitation for such category of sources." The Act requires that standards of performance for stationary sources reflect, "...the degree of emission limitation achievable through the application of the best technological system of continuous emission reduction. . . the Administrator determines has been adequately demonstrated." In addition, for stationary sources whose emissions result from fossil fuel combustion, the standard must also include a percentage reduction in emissions. The Act also provides that the cost of achieving the necessary emission reduction, the non-air quality health and environmental impacts and the energy requirements all be taken into account in establishing standards of performance.

The term technological system of continuous emission reduction is interpreted as either:

- 1) "a technological process for production or operation by any source which is inherently low polluting or nonpolluting", or
- 2) "a technological system for continuous reduction of the pollution generated by a source before such pollution is emitted into the ambient air, including precombustion cleaning or treatment of fuels."

If a standard of performance as defined above cannot be prescribed or enforced, "the Administrator . . . may distinguish among classes, types, and sizes within categories of new sources for the purposes of establishing such standards." This allows certain types and sizes of facilities to be exempted from compliance with a general standard, or to have a different standard of performance specified. This might be done, for example, to avoid extreme economic hardship on very small facilities.

Section 111 prescribes three steps to follow in establishing standards of performance.

- 1) The Administrator must identify those categories of stationary sources for which standards of performance will ultimately be promulgated by listing them in the Federal Register. For those categories of major stationary sources which have not

already been listed, the following schedule has been specified for the promulgation of standards: 25 percent by August 7, 1980, 75 percent by August 7, 1981, and 100 percent by August 7, 1982.

- 2) The regulations applicable to a category so listed must be proposed by publication in the Federal Register within 120 days of its listing. This proposal provides interested persons an opportunity to comment.
- 3) Within six months after proposal, the standard must be promulgated, incorporating any alterations deemed necessary or desirable.

It is further required that standards of performance be reviewed every four years. If there has been significant change in the industry or control technology, then the standard must be revised to reflect the new condition.

Standards of performance do not guarantee protection of health or welfare because they are not designed to achieve any specific air quality levels. They are designed to reflect the degree of emission limitation achievable through application of the best adequately demonstrated technological system of continuous emission reduction. In this application the cost of achieving such emission reduction, non-air quality health and environmental impacts, and energy requirements should be considered.

Congress had several reasons for including these requirements. First, standards with a degree of uniformity are needed to avoid situations where 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 when pollution ceilings may be reduced in the future. Fourth, 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 (NAAQPS) 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 which falls under the prevention of significant deterioration of air quality provisions of Part C of the Act. These provisions stipulate, among other things, that major emitting facilities to be constructed in such areas are to 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 Section 111 or 112 of this Act."

In addition, Section 111(h) authorizes the Administrator to grant waivers of compliance to permit a source to use innovative continuous emission control technology. In order 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 costs; (2) the proposed system has not been adequately demonstrated; (3) the technology will not cause or contribute to an unreasonable risk to public health, welfare or safety; (4) the governor of the state where the source is located consents; and that (5) the waiver will not prevent the

0

attainment or maintenance of any ambient standard. A waiver may have conditions attached to assure the source will not prevent attainment of any NAAQPS. Any such condition will have the force of a performance standard. Finally, waivers have definite end dates and may be terminated earlier if the system fails to perform as expected. In such a case, the source may be given up to three 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 Administrator to list categories of stationary sources which have not been listed before. The Administrator "...shall include a category of sources in such a 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 while adhering to the schedule referred to earlier.

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 which are emitted by stationary sources. Source categories which emit these pollutants were then 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 by 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 source categories not yet listed by EPA. These are: (1) the quantity of air pollutant emissions which

each such category will emit, or will be designed to emit; (2) the extent to which each pollutant may reasonably be anticipated to endanger public health or welfare; and (3) the mobility and competitive nature of each category of sources and the consequent need for nationally applicable new source standards of performance.

In some cases, it may not be feasible to immediately develop a standard for a source category with a high priority. This might happen when a program of research is needed to develop control techniques or because techniques for sampling and measuring emissions may require refinement. In the development of standards, differences in the time required to complete the necessary investigation of 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. Further, 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 in a systematic fashion 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, determining the types of facilities within the source category to which the standard will apply must be decided. A source category may have several facilities that cause air pollution and emissions from some of these facilities may be insignificant or 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 air pollutants emitted. Thus, although a source category may be selected to be covered by a standard of performance, not all pollutants or facilities within that source category may be covered by the standards.

2.3 PROCEDURE FOR DEVELOPMENT OF STANDARDS OF PERFORMANCE

Standards of performance must: (1) realistically reflect the best demonstrated control practice; (2) adequately consider the cost, and the non-air quality health and environmental impacts and energy requirements of such control; (3) be applicable to existing sources that are modified or reconstructed as well as 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 development of standards is to identify the best technological system of continuous emission reduction which has been adequately demonstrated. The legislative history of Section 111 on what has been adequately demonstrated is not limited to systems that are in actual routine use. The search may include a technical assessment of control systems which have been adequately demonstrated but for which there is limited operational experience. In most cases, determination of the "...degree of emission reduction achievable..." is based on results of tests of emissions from well controlled existing sources. At times, this has required the investigation and measurement of emissions from control systems found in other industrialized countries that have developed more effective systems of control than those available in the United States.

Since the best demonstrated systems of emission reduction may not be in widespread use, the data base upon which standards are developed may be somewhat limited. Test data on existing well-controlled sources are obvious starting points in developing emission limits for new sources. However, since the control of existing sources generally represents retrofit technology or was originally designed to meet an existing state or local regulation, new sources may be able to meet more stringent emission standards. Accordingly, other information must be considered before a judgment can be made as to the level at which the emission standard should be set.

A process for the development of a standard has evolved which considers the following:

1. Emissions from existing well-controlled sources as measured.
2. Data on emissions from such sources are assessed with consideration of such factors as: (a) how representative is the tested source with regard to feedstock, operation, size, age, etc.; (b) age and maintenance of the control equipment tested; (c) design uncertainties of control equipment being considered; and (d) the degree of uncertainty that new sources will be able to achieve similar levels of control.
3. Information from pilot and prototype installations, guarantees by vendors of control equipment, unconstructed but contracted projects, foreign technology, and published literature are also considered during the standard development process. This is especially important for sources where "emerging" technology appears to be a significant alternative.
4. Where possible, standards are developed which permit the use of more than one control technique or licensed process.
5. Where possible, standards are developed to encourage or permit the use of process modifications or new processes as a method of control rather than "add-on" systems of air pollution control.
6. In appropriate cases, standards are developed to permit the use of systems capable of controlling more than one pollutant.
7. Where appropriate, standards for visible emissions are developed in conjunction with concentration/mass emission standards. The opacity standard is established at a level that will require proper operation and maintenance of the emission control system installed to meet the concentration/mass standard on a day-to-day basis. In some cases, however, it is not possible to develop concentration/mass standards, such as with fugitive sources of emissions. In these cases, only opacity standards may be developed to limit emissions.

2.4 CONSIDERATION OF COSTS

Section 317 of the Act requires, among other things, 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 and standard including the extent to which the cost of compliance varies depending on the effective date of the standard or regulation and the development of less expensive or more efficient methods of compliance;
2. The potential inflationary or recessionary effects of the standard or regulation;
3. The effects of the standard or regulation on competition among small businesses;
4. The effects of the standard or regulation on consumer cost, and
5. The effects of the standard or regulation on energy use.

Section 317 requires that the economic impact assessment be as extensive as practical, taking into account the time and resources available to EPA.

The economic impact of a proposed standard upon an industry is usually addressed both in absolute terms and by comparison of the costs of typical existing state control regulations with the control costs that would be incurred as a result of complying with the standard. An incremental approach is taken since 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 impact upon industry resulting from the cost differential that exists between a standard of performance and the typical state standard.

The costs of controlling air pollutants are not the only costs considered in analyzing the economic impacts of the proposed standard. The costs associated with the control of water pollutants and solid wastes are also analyzed wherever possible.

A thorough study of the profitability and price-setting mechanism of the industry is essential to the analysis so that an accurate estimate of potential adverse economic impacts can be made. It is also essential to know the capital requirements placed on plants in the absence of federal standards of performance so that the additional capital requirements

necessitated by these standards can be placed in the proper perspective. Finally, it is necessary to recognize any constraints on capital availability with an industry, as this factor also influences the ability of new plants to generate the capital required for installation of 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 required 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 decision-making 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 Federal Court of Appeals have 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 Federal Court of Appeals have determined that "...the best system of emission reduction,...require(s) the Administrator to taken into account counter-productive environmental effects of a proposed standard, as well as economic costs to the industry..." On this basis, therefore, the Courts "...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."

The Agency has concluded, however, that the preparation of environmental impact statements could have beneficial effects on certain regulatory actions. Consequently, while not legally required to do so by Section 102(2)(C) of NEPA, environmental impact statements will 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 is included in this document which 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 identified and 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. An existing source becomes a new source if the source is modified or reconstructed. Both modification and reconstruction are 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 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 THROUGH EXPERIENCE

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 four years, review and, if appropriate, revise..." the standards. Revisions are made to assure 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. DESCRIPTION OF FUGITIVE EMISSION SOURCES

3.1 INTRODUCTION AND GENERAL INDUSTRY INFORMATION

3.1.1 Introduction

The primary purposes of this chapter are to define the synthetic organic chemical manufacturing industry (SOCMI) and describe the potential fugitive emission sources that are typically found in this industry. Where possible, the leak rates of uncontrolled emissions from the various potential fugitive emission sources are quantified. Industrial practices and state or local regulations that currently reduce fugitive emissions from the SOCMI are also briefly discussed in this chapter.

3.1.2 General Information

Organic chemicals are manufactured in a multi-leveled system of chemical processes that is based on about ten feedstock chemicals which are principally produced in petroleum refineries. These feedstocks then proceed through one or more of the process levels and result in literally thousands of intermediate or finished chemicals (see Figure 3-1).

Generally, each process level contains more chemicals than the preceding level; the plants manufacturing the products are smaller than the plants supplying the feedstock; and the volatilities of the products are lower than the volatilities of the feedstocks. Because of the number and diverse nature of the organic chemicals included in the multi-leveled system, the synthetic organic chemical manufacturing industry (SOCMI) is defined, for this study, to consist of 378 of the higher volume, higher volatility intermediate and finished products. A list of the 378 chemicals is presented in Appendix F.

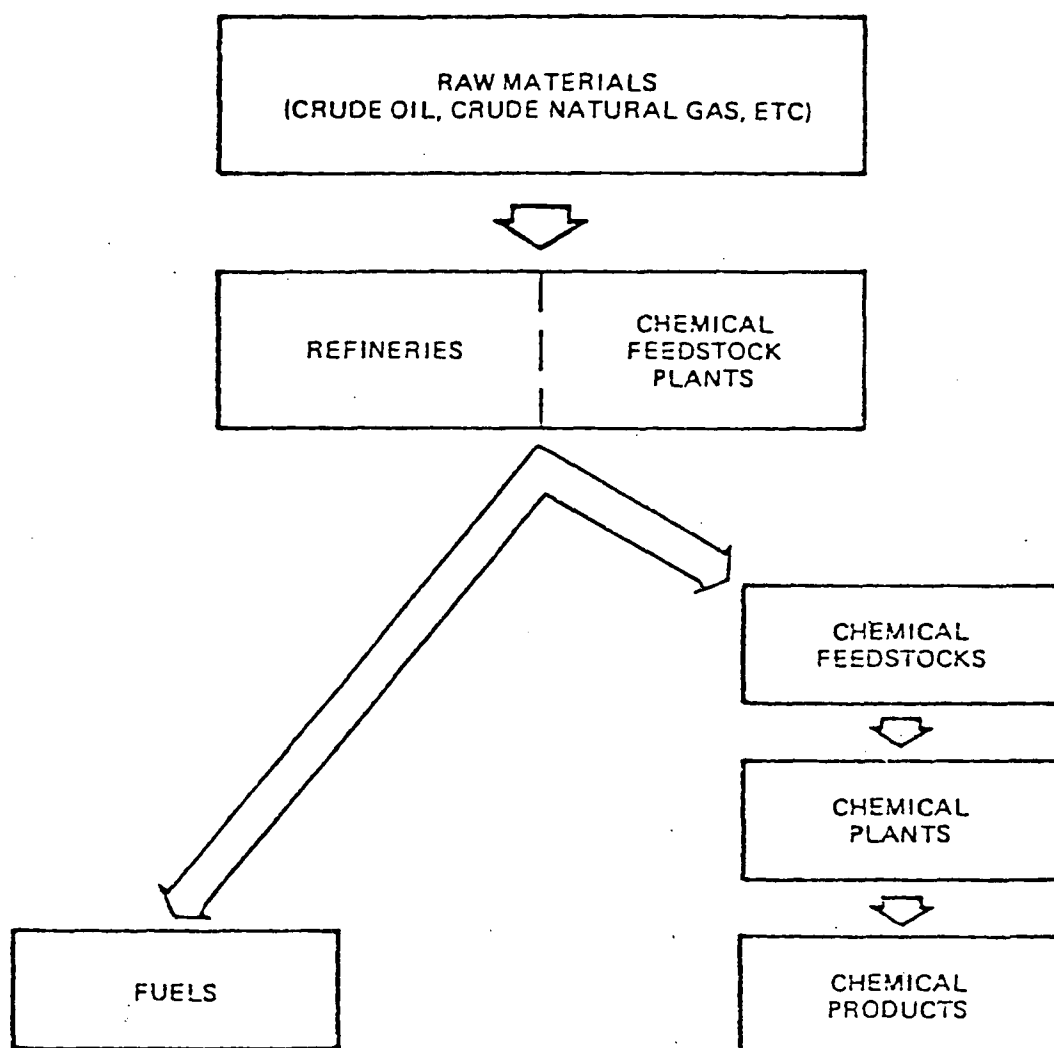


Figure 3-1. General schematic of process levels that make up the organic chemical industry.

Although there are organic chemical manufacturing plants in most industrialized areas of the country, about 60 percent of the SOCFI volume is produced in Texas and Louisiana. Each plant site may manufacture from one to several organic chemicals using one or more processes. Although most processes result in one basic product, some produce a family of chemicals. Conversely, many chemicals are produced by more than one process. Yearly, production quantities at each plant can range from a few million to several billion kilograms.

3.2 FUGITIVE EMISSION DEFINITION AND POTENTIAL SOURCE DESCRIPTION

3.2.1 Definition

In this study, fugitive emissions in the SOCFI are considered to be those volatile organic compound (VOC) emissions that result when process fluid (either liquid or gaseous) leaks from plant equipment. Those VOC emissions resulting from the transfer, storage, treatment, and/or disposal of process wastes will be covered by other standards.

3.2.2 Potential Source Characterization and Description

There are many potential sources of fugitive emissions in a typical synthetic organic chemical plant. The following sources will be considered in this chapter: pumps, compressors, in-line process valves, pressure relief devices, open-ended valves, sampling connections, flanges, agitators, and cooling towers. These potential sources are described below.

3.2.2.1 Pumps. Pumps are used extensively in the SOCFI for the movement of organic liquids.¹ The centrifugal pump is the most widely used pump in the SOCFI; however, other types, such as the positive-displacement, reciprocating and rotary action, and special canned and diaphragm pumps, are also used in this industry. Chemicals transferred by pumps can leak at the point of contact between the moving shaft and stationary casing. Consequently, all pumps except the shaftless type (canned-motor and diaphragm) require a seal at the point where the shaft penetrates the housing in order to isolate the pump's interior from the atmosphere.

Two generic types of seals, packed and mechanical, are currently in use on pumps in the SOCFI. Packed seals can be used on both reciprocating

and rotary action types of pumps. As Figure 3-2 shows, a packed seal consists of a cavity ("stuffing box") in the pump casing filled with special packing material that is compressed with a packing gland to form a seal around the shaft. Lubrication is required to prevent the buildup of frictional heat between the seal and shaft. The necessary lubrication is provided by a lubricant that flows between the packing and the shaft.² Deterioration of the packing will result in process liquid leaks.

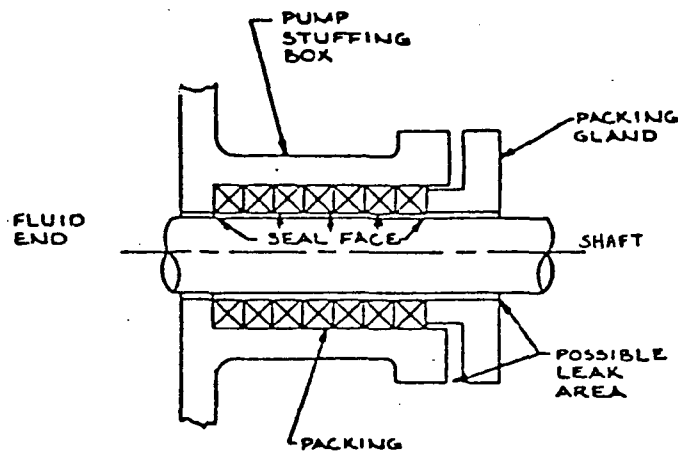


Figure 3-2. Diagram of a simple packed seal.³

Mechanical seals are limited in application to pumps with rotating shafts and can be further categorized as single and double mechanical seals. There are many variations to the basic design of mechanical seals, but all have a lapped seal face between a stationary element and a rotating seal ring. In a single mechanical seal application (Figure 3-3), the rotating-seal ring and stationary element faces are lapped to a very high degree of flatness to maintain contact throughout their entire mutual surface area. As with a packed seal, the seal faces must be lubricated to remove frictional heat; however, because of its construction, much less lubricant is needed.

A mechanical seal is not a leak-proof device. Depending on the condition and flatness of the seal faces, the leakage rate can be quite low (as small as a drop per minute) and the flow is often not visually

detectable. In order to minimize fugitive emissions due to seal leakage, an auxiliary sealing device such as packing can be employed.⁴

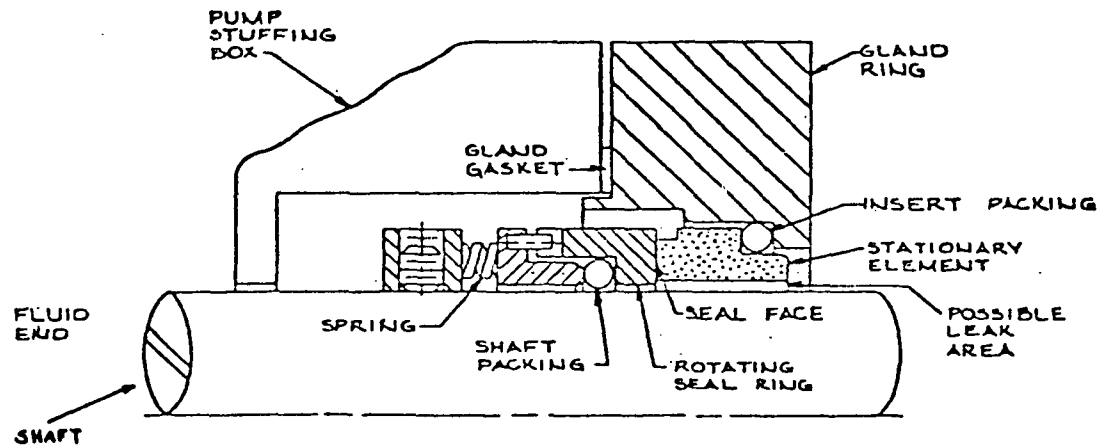


Figure 3-3. Diagram of a basic single mechanical seal.⁵

In a double mechanical seal application, two seals can be arranged back-to-back or in tandem. In the back-to-back arrangement (Figure 3-4), the two seals provide a closed cavity between them. A seal liquid, such as water or seal oil, is circulated through the cavity. Because the seal liquid surrounds the double seal and lubricates both sets of seal faces in this arrangement, the heat transfer and seal life characteristics are much better than those of the single seal. In order for the seal to function, the seal liquid must be at a pressure greater than the operating pressure of the stuffing box. As a result some seal liquid will leak across the seal faces. Liquid leaking across the inboard face will enter the stuffing box and mix with the process liquid. Seal liquid going across the outboard face will exit to the atmosphere. Therefore, the seal liquid must be compatible with the process liquid as well as with the environment.⁶

In a tandem double mechanical seal arrangement (Figure 3-5), the seals face the same direction. The secondary seal provides a backup for the primary seal. A seal flush is used in the stuffing box to remove the heat generated by friction. The cavity between the two seals is filled

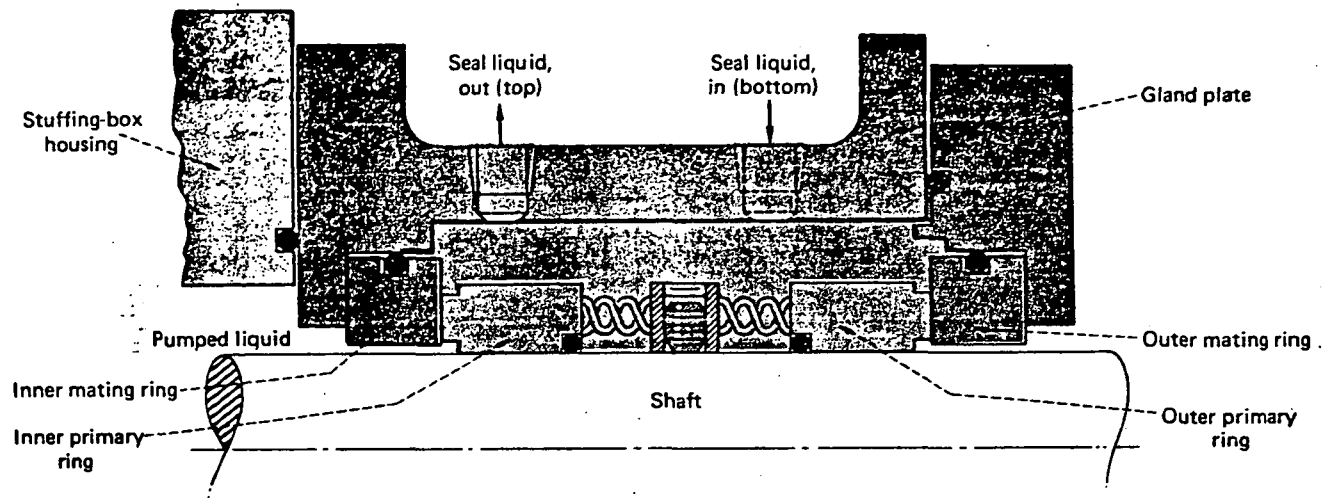


Figure 3-4. Diagram of a double mechanical seal (back-to-back arrangement).⁷

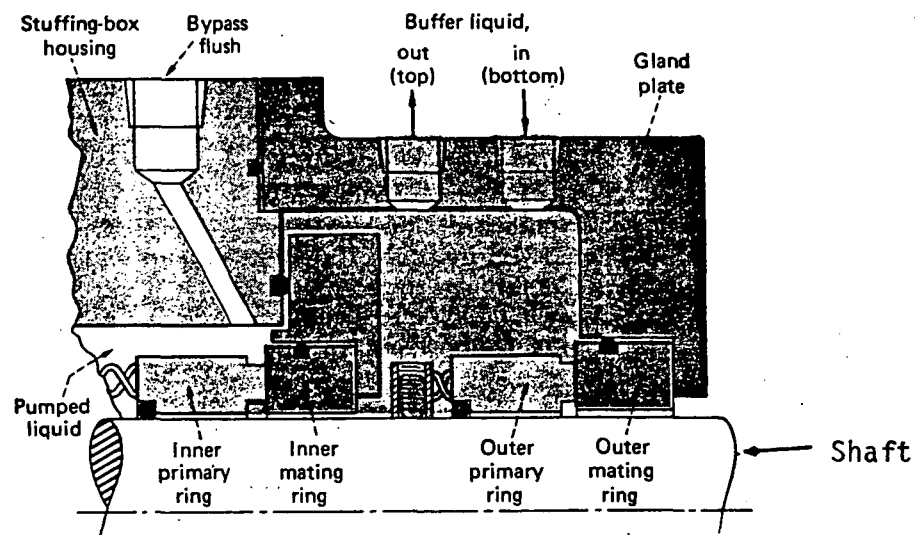


Figure 3-5. Diagram of a double mechanical seal (tandem arrangement).⁸

with a buffer or barrier liquid. However, the barrier liquid is at a pressure lower than that in the stuffing box. Therefore, any leakage will be from the stuffing box into the seal cavity containing the barrier liquid. Since this liquid is routed to a closed reservoir, process liquid that has leaked into the seal cavity will also be transferred to the reservoir. At the reservoir, the process liquid could vaporize and be emitted to the atmosphere. To ensure that VOC's do not leak from the reservoir, the reservoir can be vented to a control device.⁹

Another type of pump that has been used in the chemical industry is the shaftless pump which includes canned-motor and diaphragm pumps. In canned-motor pumps (Figure 3-6) the cavity housing the motor rotor and the pump casing are interconnected. As a result, the motor bearings run in the process liquid and all seals are eliminated. Because the process liquid is the bearing lubricant, abrasive solids cannot be tolerated. Canned-motor pumps are being widely used for handling organic solvents, organic heat transfer liquids, light oils, as well as many toxic or hazardous liquids, or where leakage is an economic problem.¹⁰

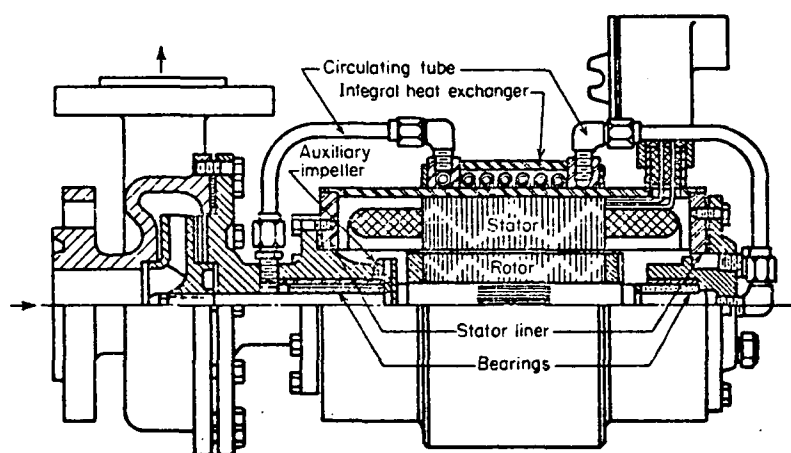


Figure 3-6. Chempump canned-motor pump.¹¹

Diaphragm pumps (see Figure 3-7) perform similarly to piston and plunger pumps. However, the driving member is a flexible diaphragm fabricated of metal, rubber, or plastic. The primary advantage of this arrangement is the elimination of all packing and seals exposed to the process liquid. This is an important asset when hazardous or toxic liquids are handled.¹²

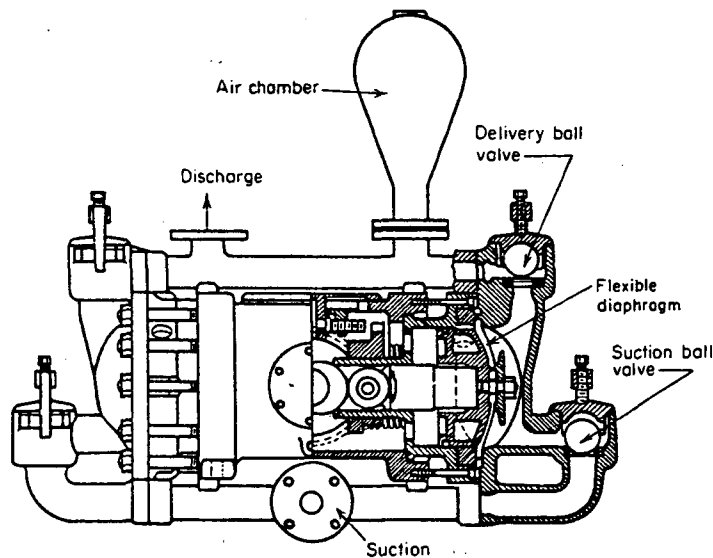


Figure 3-7. Shriver mechanically actuated diaphragm pump.¹³

3.2.2.2 Compressors. Gas compressors used in the SOCM I are similar to pumps in that they can be driven by rotary or reciprocating shafts. Correspondingly, the same types of seals that are used on pumps are used on compressors to isolate the process gas from the atmosphere. As with pumps, these seals are likely to be the source of fugitive emissions from compressors.

In addition to the mechanical seals that can be used on compressors, centrifugal compressors can be equipped with liquid film seals (Figure 3-8). This seal is formed by a film of oil between the rotating shaft and stationary gland. The seal oil exits the compressor from chambers on both sides of the gland. The oil leaving the chamber on the process

side is under pressure and contaminated with process gas. When the contaminated oil is returned to the oil reservoir, process gas can be released and emitted to the atmosphere.¹⁴ To eliminate the release of VOC emissions from the oil reservoir, the reservoir can be vented to a control device.

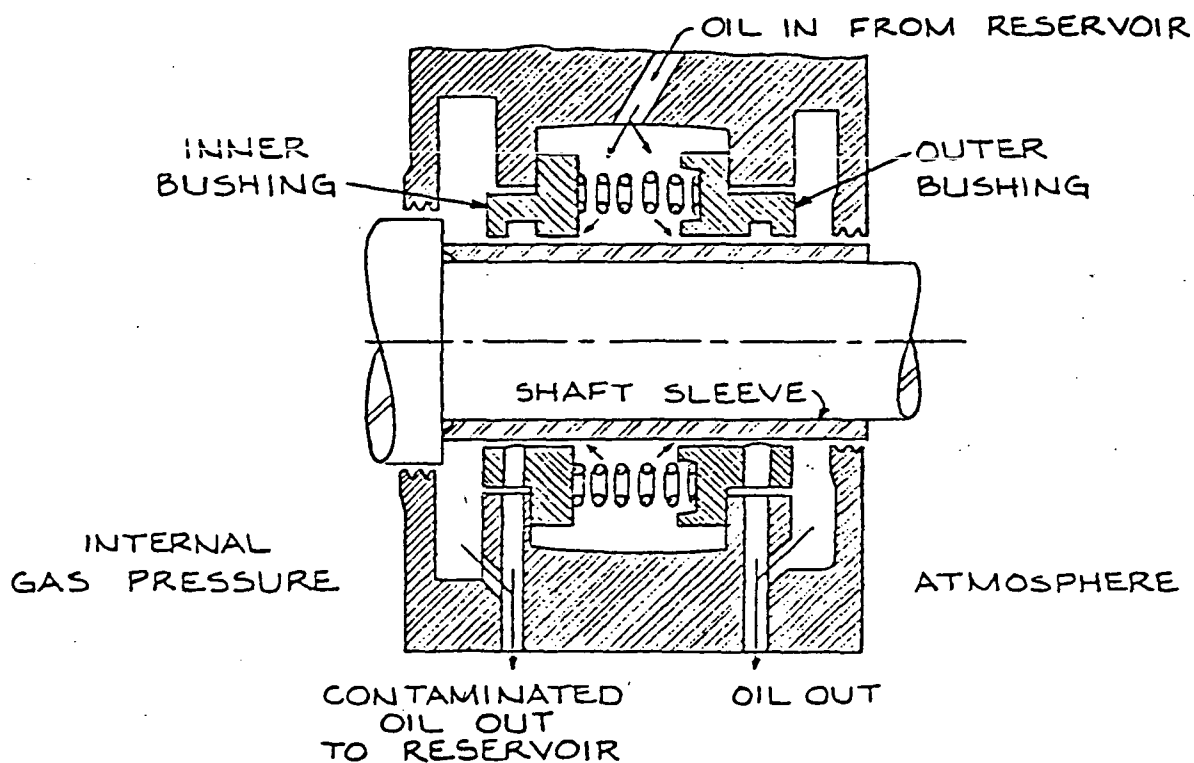


Figure 3-8. Liquid-film compressor shaft seal.¹⁵

3.2.2.3 Process Valves. One of the most common pieces of equipment in organic chemical plants is the valve. The types of valves commonly used are control, globe, gate, plug, ball, relief, and check valves. All except the relief valve (to be discussed further below) and check valve are activated by a valve stem, which may have either a rotational or linear motion, depending on the specific design. This stem requires a seal to isolate the process fluid inside the valve from the atmosphere as illustrated by the diagram of a gate valve in Figure 3-9. The possibility of a leak through this seal makes it a potential source of fugitive

emissions. Since a check valve has no stem or subsequent packing gland, it is not considered to be a potential source of fugitive emissions.

Sealing of the stem to prevent leakage can be achieved by packing inside a packing gland or O-ring seals. Valves that require the stem to move in and out with or without rotation must utilize a packing gland. Conventional packing glands are suited for a wide variety of packing material; the most common are various types of braided asbestos that contain lubricants. Other packing materials include graphite, graphite-impregnated fibers, and tetrafluorethylene; the packing material used depends on the valve application and configuration.¹⁶ These conventional packing glands can be used over a wide range of operating temperatures. At high pressures these glands must be quite tight to attain a good seal.¹⁷

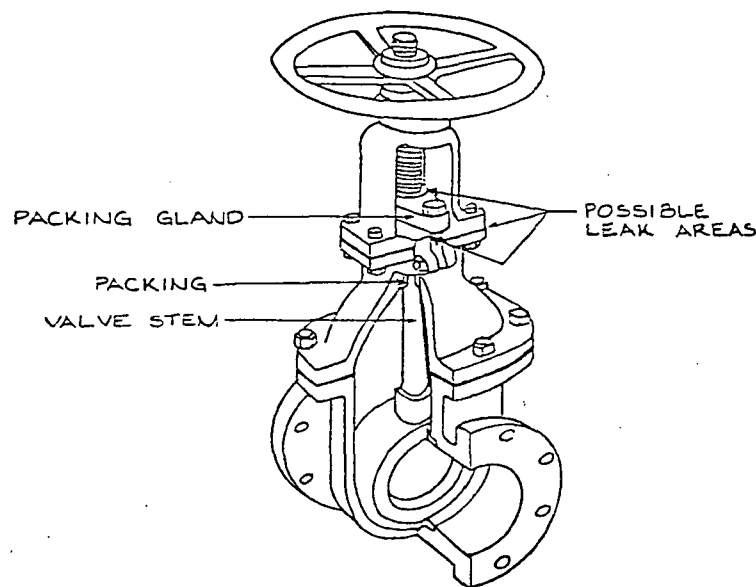


Figure 3-9. Diagram of a gate valve.¹⁸

Elastomeric O-rings are also used for sealing process valves. These O-rings provide good sealing but are not suitable where there is sliding motion through the packing gland. Those seals are rarely used in high pressure service and operating temperatures are limited by the seal material.¹⁹

Bellows seals are more effective for preventing process fluid leaks than the conventional packing gland or any other gland-seal arrangement.²⁰ This type of seal incorporates a formed metal bellows that makes a barrier between the disc and body bonnet joint. An example of this seal is presented in Figure 3-10. The bellows is the weak point of the system and service life can be quite variable. Consequently, this type of seal is normally backed up with a conventional packing gland and is often fitted with a leak detector in case of failure.²¹

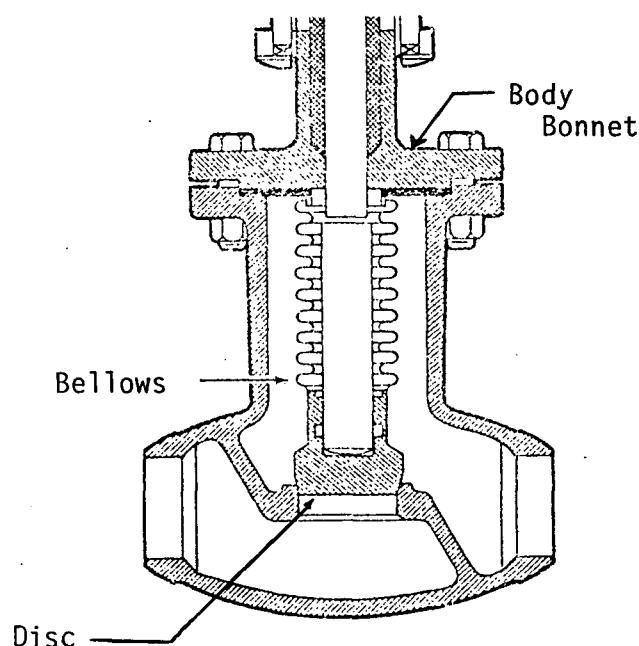


Figure 3-10. Example of bellows seals.²²

A diaphragm may be used to isolate the working parts of the valve and the environment from the process liquid. Two types of valves which utilize diaphragms are illustrated in Figures 3-11(a) and (b). As Figure 3-11(b) shows, the diaphragm may also be used to control the flow of the process fluid. In this design, a compressor component pushes the diaphragm toward the valve bottom, throttling the flow. The diaphragm and compressor are connected in a manner so that it is impossible for them to be separated under normal working conditions. When the diaphragm reaches the valve

bottom, it seats firmly against the bottom, forming a leak-proof seal. This configuration is recommended for fluids containing solid particles and for medium-pressure service. Depending on the diaphragm material, this type of valve can be used at temperatures up to 205°C and in severe acid solutions. If failure of the seal occurs, a valve employing a diaphragm seal can become a source of fugitive emissions.²³

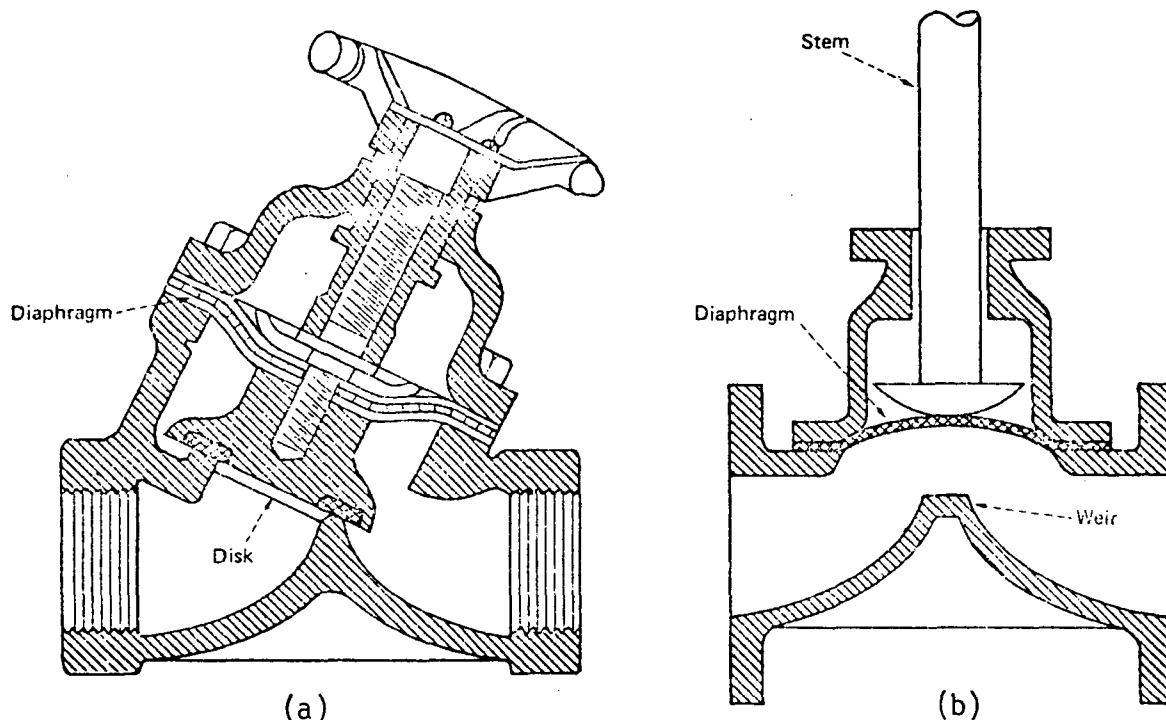


Figure 3-11. Diagrams of valves with diaphragm seals.²⁴

3.2.2.4 Pressure Relief Devices. Engineering codes require that pressure-relieving devices or systems be used in applications where the process pressure may exceed the maximum allowable working pressure of the vessel. The most common type of pressure-relieving device used in the SOCM I is the pressure relief valve (Figure 3-12). Typically, relief valves are spring-loaded and designed to open when the process pressure exceeds a set pressure, allowing the release of vapors or liquids until the system pressure is reduced to its normal operating level. When the normal

pressure is re-attained, the valve reseats, and a seal is again formed.²⁵ The seal is a disk on a seat, and the possibility of a leak through this seal makes the pressure relief valve a potential source of VOC fugitive emissions. Two potential causes of leakage from relief valves are: "simmering or popping", a condition due to the system pressure being close to the set pressure of the valve, and improper reseating of the valve after a relieving operation.²⁶

Rupture disks are also common in the SOCM. These disks are made of a material that ruptures when a set pressure is exceeded, thus allowing the system to depressurize. The advantage of a rupture disk is that the disk seals tightly and does not allow any VOC's to escape from the system under normal operation. However, when the disk does rupture, the system depressurizes until atmospheric conditions are obtained; this could result in an excessive loss of product or correspondingly an excessive release of fugitive emissions.

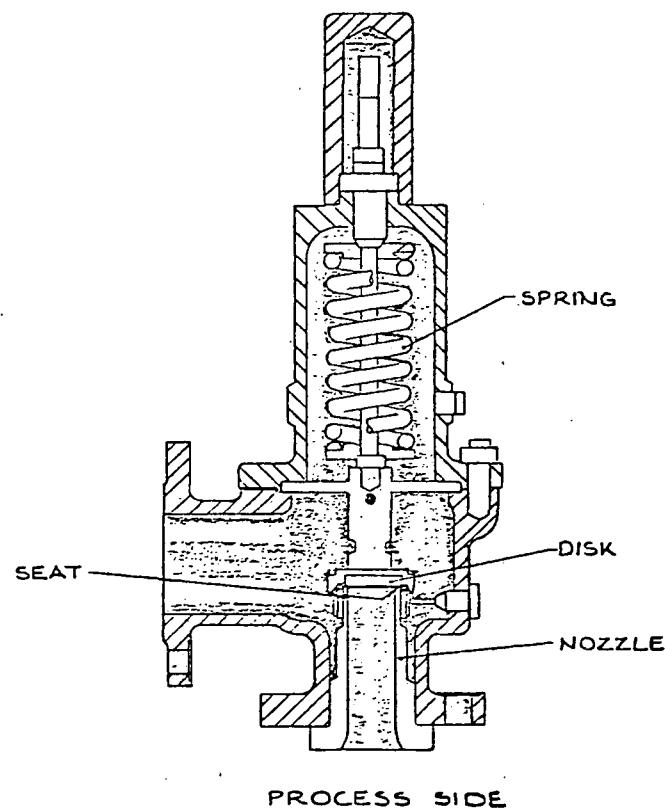


Figure 3-12. Diagram of a spring-loaded relief valve.²⁷

3.2.2.5 Cooling Towers. Cooling towers (Figure 3-13) are found in most SOCMIs plants. The purpose of these towers is to cool the plant's process cooling waters which have been heated while removing heat from various process equipment (reactors, condensers, heat exchangers). This cooling process is achieved by evaporation when the process cooling water and air are contacted. Under normal operating conditions, a cooling tower would not be considered a fugitive emission source. However, if a leak occurs in the process equipment and if this equipment is operating at a pressure greater than that of the cooling water, organic chemicals can leak into the water. When the process water is recirculated to the cooling tower, these chemicals can be released to the atmosphere.

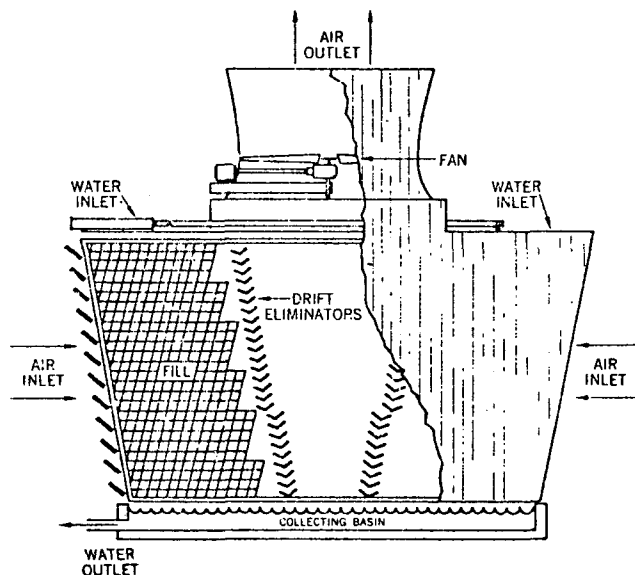


Figure 3-13. Cooling tower (cross-flow).²⁸

3.2.2.6 Agitators. Agitators are commonly used in the SOCMIs to stir or blend chemicals. Like pumps and compressors, agitators may leak organic chemicals at the point where the shaft penetrates the casing. Consequently, seals are required to minimize fugitive emissions from agitators. Four seal arrangements are commonly used with agitators; they include: compression packing (packed seal), mechanical seals, hydraulic

seals, and lip seals.²⁹ Packed seals for agitators are very similar in design and application to the packed seals for pumps (Section 3.2.2.1).

Although mechanical seals are more costly than the other three seal arrangements, they offer a greatly reduced leakage rate to offset their higher cost. The maintenance frequency of mechanical seals is, also, one-half to one-fourth that of packed seals.³⁰ In fact, at pressures greater than 1135.8 kPa (150 psig), the leakage rate and maintenance frequency are so superior that the use of packed seals on agitators is rare.³¹ As with packed seals, the mechanical seals for agitators are similar to the design and application of mechanical seals for pumps (Section 3.2.2.1).

The hydraulic seal (Figure 3-14) is the simplest and least used agitator shaft-seal. In this type of seal, an annular cup attached to the process vessel contains a liquid that is in contact with an inverted cup attached to the rotating agitator shaft. The primary advantage of this seal is that it is a non-contact seal. However, this seal is limited to low temperatures and pressures and can only handle very small pressure fluctuations. Organic chemicals may contaminate the seal liquid and then be released into the atmosphere as fugitive emissions.³²

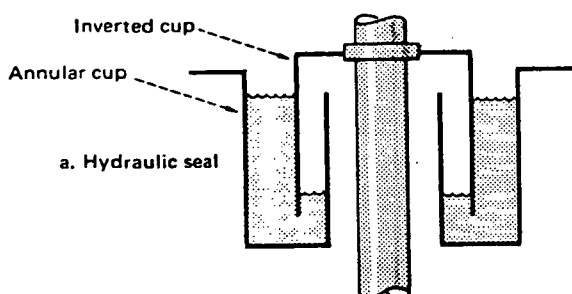


Figure 3-14. Diagram of hydraulic seal for agitators.³³

A lip seal (Figure 3-15) can be used on a top-entering agitator as a dust or vapor seal. The sealing element is a spring-loaded elastomer; subsequently, lip seals are relatively inexpensive and easy to install. Once the seal has been installed the agitator shaft rotates in continuous

contact with the lip seal. Pressure limits of the seal are 2 to 3 psi because it operates without lubrication. Operating temperatures are limited by the characteristics of the elastomer. Fugitive VOC emissions could be released through this seal when this seal wears excessively or the operating pressure surpasses the pressure limits of the seal.³⁴

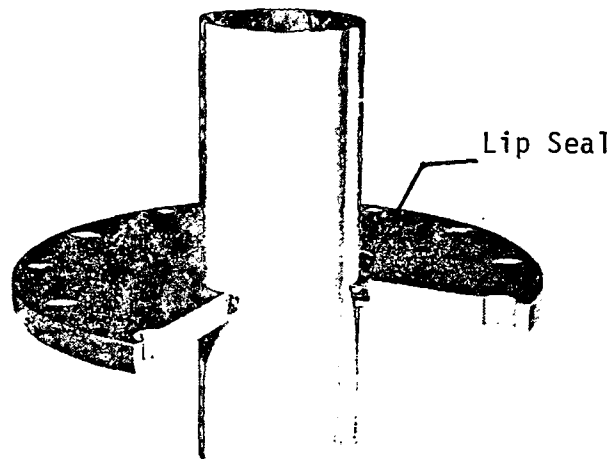


Figure 3-15. Diagram of agitator lip seal.³⁵

3.2.2.7 Open-Ended Valves or Lines. Some valves are installed in a system so that they function with the downstream line open to the atmosphere. Examples are purge valves, drain valves, and vent valves. A faulty valve seat, or incompletely closed valve would result in leakage through the valve and fugitive VOC emissions to the atmosphere.

3.2.2.8 Sampling Connections. The operation of a process unit is checked periodically by routine analyses of feedstocks and products. To obtain representative samples for these analyses, sampling lines must first be purged prior to sampling. The purged liquid or vapor is sometimes drained onto the ground or into a sewer drain, where it can evaporate and release VOC emissions to the atmosphere.

3.2.2.9 Flanges. Flanges are bolted, gasket-sealed junctions used wherever pipe or other equipment such as vessels, pumps, valves, and heat exchangers may require isolation or removal. Normally, flanges are employed for pipe diameters of 50 mm or greater and are classified by pressure and face type.

Flanges may become fugitive emission sources when leakage occurs due to improperly chosen gaskets or a poorly assembled flange. The primary cause of flange leakage is due to thermal stress that piping or flanges in some services undergo; this results in the deformation of the seal between the flange faces.³⁶

3.3 BASELINE CONTROL

There are presently no federal regulations that specifically reduce emissions from synthetic organic chemical manufacturing plants. However, some fugitive emission reduction is achieved by operating practices currently followed by industry and applicable state or local regulations. Because these practices and regulations only "incidentally" control fugitive emissions, they are considered, in this study, to be the baseline control level. The procedures, specific control techniques, and regulations that make up the baseline control level are discussed below.

Fugitive emissions occurring under the baseline control level are subsequently considered in this report to be uncontrolled emissions. Data characterizing the uncontrolled levels of fugitive emissions in the SOCM I are presently unavailable. However, data of this type have been obtained for the refining industry. These data are presented in Table 3-1. Because the operation of the various process equipment in the SOCM I is not expected to differ greatly from the operation of the same equipment in the refining industry, it is felt that the refinery fugitive emission data can be used to approximate the levels of fugitive emissions in SOCM I.

3.3.1 Industrial Practices

The organic chemical industry has been primarily interested in leaks that are large enough to be physically evident (leaks that can be seen, heard, or smelled); such leaks are normally repaired to minimize the loss of product and are, consequently, termed "easily detectable leaks". Fugitive emissions, as they are considered in this report, are also the results of leaks from process equipment but have considerably smaller emission rates than "easily detectable leaks". In the past, SOCM I has generally not monitored equipment for fugitive emissions nor repaired equipment on the basis of reducing the level of fugitive emissions. Processes which have emitted toxic or hazardous compounds have been exceptions to this rule.

TABLE 3-1. UNCONTROLLED FUGITIVE EMISSION FACTORS IN THE SYNTHETIC ORGANIC CHEMICAL MANUFACTURING INDUSTRY (SOCMI)³⁾

Fugitive emission source	Uncontrolled emission factor, ^a kg/hr
Pumps	
Light liquids ^b	
With packed seals	0.12
With single mechanical seals	0.12
With double mechanical seals	0.12 ^c
With no seals	0.0
Heavy Liquids ^d	
With packed seals	0.020
With single mechanical seals	0.020
With double mechanical seals	0.020 ^c
With no seals	0.0
Valves (in-line)	
Gas	0.021
Light liquid ^b	0.010
Heavy liquid ^d	0.0003
Safety/relief valves	
Gas	0.16
Light liquid ^b	0.006
Heavy liquid ^d	0.009
Open-ended valves	
Gas	0.025
Light liquid ^b	0.014
Heavy liquid ^d	0.003
Flanges	0.0003
Sampling connections	0.015
Compressors	0.44
Cooling towers	13.6-1107 ^e
Agitators	NA ^f

^aThese uncontrolled emission levels are based upon the refinery data presented in reference 37.

^bLight liquid is defined as a fluid with vapor pressure greater than 0.3 kPa at 20°C. This vapor pressure represents the split between kerosene and naphtha and is based on data presented in reference 37. The average vapor pressure between these components is approximately 0.04 psi at 68 °F.

^cAssumes the inner seal leaks at the same rate as single seal and that the VOC is emitted from the seal oil degassing vent.

^dHeavy liquid is defined as a fluid with vapor pressure less than 0.3 kPa at 20°C. This vapor pressure represents the split between kerosene and naphtha and is based on data presented in reference 37. The average vapor pressure between these components is approximately 0.04 psi at 68 °F.

^eThese levels are based on cooling tower circulation rates that range from 0.05-3.66 m³/sec (714-58,000 GPM). Ref. 38.

^fNA = no data available.

While SOCFI has been primarily concerned with easily detectable leaks, certain equipment and procedures used in many organic chemical plants may help to reduce fugitive VOC emissions. For instance, some plants cap-off or use double block valves on the end of process lines; either of these procedures will reduce fugitive emissions. In some plants, relief valves are checked to see if the valve has reseated properly after relieving.³⁹ As previously mentioned, an improperly seated relief valve may allow fugitive VOC emissions to occur. Rupture discs, which are commonly used in the SOCFI, also prevent fugitive VOC emissions. Some organic chemical plants employ closed-loop sampling which may help to reduce fugitive emissions.

The flaring of vapors vented from various vessels or equipment is another technique which is used by some plants (particularly those producing toxic or hazardous chemicals) that will reduce fugitive emissions.

3.3.2 Existing Regulations

There are, presently, two types of regulations that impact fugitive VOC emissions from organic chemical plants. The first type is to regulate industrial operating practices on the basis of worker health and safety. Because some aspects of these regulations deal with worker exposure to process emissions, they may have some impact on fugitive VOC emissions. The second type of regulations is regulations that were specifically developed to limit fugitive emissions.

3.3.2.1 Health and Safety Regulations. Several regulations have been established under the direction of the Occupational Safety and Health Administration and National Institute for Occupational Safety and Health to: 1) limit the level of process emissions and 2) limit worker exposure to process emissions. These regulations may result in a reduction in the levels of fugitive VOC emissions.

In the vinyl chloride monomer and benzene industries, the safety and health regulations are designed to limit the ambient VOC levels to which workers may be exposed. Since these standards do not stipulate how the allowable ambient levels should be achieved, workers can be protected from high ambient VOC levels by: 1) a reduction in the fugitive

VOC emissions or 2) the use of special equipment (such as personal respirators) to isolate the worker from the emissions. This example illustrates that the present health and safety regulations do not mandate a reduction in fugitive VOC emissions, and any reduction in fugitive emissions resulting from these regulations can be considered to be "incidental". By contrast, fugitive emission regulations do require the fugitive emissions to be reduced.

3.3.2.2 Fugitive Emissions Regulations. Currently, there are no federal fugitive emission regulations for the SOCMI. However, California has established such regulations, and organic chemical plants in this state must comply with the appropriate regulations.

California presently requires open-ended process lines to be capped-off in order to minimize fugitive VOC emissions. This state also requires relief valves to be vented to a flare system, monitored and maintained, or a rupture disk to be used. In addition to these regulations, the South Coast Air Quality Management District requires organic chemical plants to vent fugitive emissions from compressor seals to a fired-heater or flare system. The South Coast and Bay Area AQMD also require periodic inspection of valves in the chemical and refining industries.

3.4 REFERENCES

1. Erikson, D. G., and V. Kalcevic. Emissions Control Options for the Synthetic Organic Chemicals Manufacturing Industry, Fugitive Emissions Report, Draft Final. Hydrosience, Inc., 1979. p. II-2.
2. Ref. 1.
3. Ref. 1, p. II-3.
4. Ramsden, J. H. How to Choose and Install Mechanical Seals. Chem. E., 85(22):97-102. 1978.
5. Ref. 1, p. II-3.
6. Ref. 4, p. 99.
7. Ref. 4, p. 100.
8. Ref. 4, p. 101.
9. Ref. 4, p. 99.
10. Perry, R. H., and C. H. Chilton. Chemical Engineers' Handbook, 5th Ed. New York, McGraw-Hill Book Company, 1973. p. 6-8.
11. Ref. 10, p. 6-12.
12. Ref. 10, p. 6-13.
13. Ref. 10, p. 6-13.
14. Ref. 1, p. II-7.
15. Ref. 1, p. II-8.
16. Lyons, J. L., and C. L. Ashland, Jr. Lyons' Encyclopedia of Valves. New York, Van Nostrand Reinhold Co., 1975. 290 p.
17. Templeton, H. C. Valve Installation, Operation and Maintenance. Chem. E., 78(23)141-149, 1971.
18. Ref. 1, p. II-5.
19. Ref. 17, p. 147-148.
20. Ref. 17, p. 148.
21. Ref. 17, p. 148.
22. Ref. 17, p. 148.

23. Pikulik, A. Manually Operated Valves. Chem. E., April 3, 1979. p. 121.
24. Ref. 23, p. 121.
25. Steigerwald, B. J. Emissions of Hydrocarbons to the Atmosphere from Seals on Pumps and Compressors. Report No. 6, PB 216 582, Joint District, Federal and State Project for the Evaluation of Refinery Emissions. Air Pollution Control District, County of Los Angeles, California. April 1958. 37 p.
26. Ref. 1, p. II-7.
27. Ref. 1, p. II-6.
28. Cooling Tower Fundamentals and Application Principles. Kansas City, Missouri, The Marley Company, 1969. p. 4.
29. Ramsey, W. D., and G. C. Zoller. How the Design of Shafts, Seals and Impellers Affects Agitator Performance. Chem. E., 83(18): 101-108. 1976.
30. Ref. 29, p. 105.
31. Ref. 29, p. 105.
32. Ref. 29, p. 105.
33. Ref. 29, p. 106.
34. Ref. 29, p. 106.
35. Ref. 29, p. 106.
36. McFarland, I. Preventing Flange Fires. Chem. E. Prog., 65(8): 59-61. 1969.
37. Wetherold, R. G., et al. Emission Factors and Frequency of Leak Occurrence for Fittings in Refinery Process Units, interim report. EPA Contract No. 68-02-2665. Austin, Texas, Radian Corporation, February 1979. p. 22.
38. Radian Corporation. The Assessment of Environmental Emissions From Oil Refining. Draft Report, Appendix B. EPA Contract No. 68-02-2147, Exhibit B. Austin, Texas. August, 1979.
39. Letter with Attachments from J. M. Johnson, Exxon Company, U.S.A., to Robert T. Walsh, U.S. EPA. July 28, 1977.

4. EMISSION CONTROL TECHNIQUES

Sources of fugitive VOC emissions from SOCFI plants were identified in Chapter 3 of this document. The potential emission control techniques that can be applied to SOCFI fugitive emission sources are discussed in this chapter. The applicability and estimated control effectiveness of each technique are also presented. The quantitative control effectiveness for many of the control techniques is not known. Qualitative discussions of effectiveness and references to technology transfer from similar industries are presented wherever applicable.

4.1 LEAK DETECTION AND REPAIR METHODS

Leak detection and repair methods can be applied in order to reduce fugitive emissions from any source. Leak detection methods are used to identify equipment components that are emitting significant amounts of VOC. Emissions from leaking sources may be reduced by three general methods: repair, modification, or replacement of the source.

4.1.1 Leak Detection Methods

Leak detection methods include individual component surveys, area (walk-through) surveys, and fixed point monitors. They are described in this order since the first method is also included as part of the other methods.

4.1.1.1 Individual Component Survey. Each fugitive emission source (pump, valve, compressor, etc.) is checked for VOC leakage in an individual component survey. The source may be checked for leakage by visual, audible, olfactory, soap bubble, or instrument techniques. Visual methods are good for locating liquid leaks, especially pump seal failures. Observation of a visible leak does not necessarily indicate VOC emissions, since the leak may be composed of non-VOC compounds. High pressure leaks

may be detected by hearing the escaping vapors, and leaks of odorous materials may be detected by smelling the odor. Current industry practices include leak detection by visual, audible, and olfactory methods. However, in many instances, even very large VOC leaks are not detected by these methods.

Spraying soap bubbles on equipment components is another individual survey method. If the soap bubbles expand or are blown away, it is an indication that something is leaking from the component. A disadvantage of this method is that it does not distinguish leaks of non-VOC compounds from VOC leaks. Consequently, air or steam leaks would produce the same observed effect as VOC leaks. This method is only semiquantitative since it requires that the observer subjectively determine the rate of leakage based on behavior of the soap bubbles. This method is limited to "cool" sources, since temperatures above 100°C would cause the water in the soap solution to boil away. This method is also not suited for moving shafts on pumps or compressors, since the motion of the shaft may interfere with the motion of the bubbles caused by a leak.

Portable hydrocarbon detection instruments are the best method for identifying leaks of VOC from equipment components. The instrument is used to sample and analyze the air in close proximity to the potential leak surface by traversing the sampling probe tip over the entire area where leaks may occur. This sampling traverse is called "monitoring" in subsequent descriptions. The hydrocarbon concentration of the sampled air is displayed on the instrument meter. The performance criteria for monitoring instruments and a description of instrument survey methods are included in Appendix D. The hydrocarbon concentration observed during monitoring of a component is proportional to the VOC emission rate from the component. Data from petroleum refineries have been used to develop relationships between monitoring concentration and mass emission rates. The hydrocarbon concentration which defines a component needing maintenance must be chosen. Components which have indicated concentrations higher than this "action level" are marked for repair. Data from petroleum refineries indicate that large variations in mass emission rate

may occur over short time periods for an individual equipment component. More frequent monitoring intervals tend to reduce the chance of missing "large leaks" because of their variable leak rates.

4.1.1.2 Area Survey. An area survey (also known as a walk-through survey) requires the use of a portable hydrocarbon detector and a strip chart recorder. The procedure involves carrying the instrument within one meter of the upwind and downwind sides of process equipment and associated fugitive emission sources. An increase in observed concentration indicates leaking fugitive emission sources. The instrument is then used for an individual component survey in the suspected leak area. The efficiency of this method for locating leaks is not well established. It has been estimated that the walk-through survey combined with selected individual surveys will detect about 50 percent of the number of leaks identified in a complete individual survey.¹ The time and labor requirements for the walk-through are much lower. This method will not detect leaks from sources such as elevated valves or relief valves. Leaks from adjacent units and adverse meteorological conditions can also interfere with the walk-through survey. Consequently, the walk-through survey is best for locating only large leaks with a small resource expenditure.

4.1.1.3 Fixed Point Monitors. This method consists of placing several automatic hydrocarbon sampling and analysis instruments at various locations in the process unit. The instruments may sample the ambient air intermittently or continuously. Elevated hydrocarbon concentrations indicate a leaking component. As in the walk-through method, an individual component survey is required to identify the specific leaking component in the area. For this method, the portable hydrocarbon detector is also required. Leaks from adjacent units and adverse meteorological conditions may interfere with the method. The efficiency of this method is not well established, but it has been estimated that 33 percent of the number of leaks identified by a complete individual component survey could be located by fixed-point monitors.² Fixed-point monitors are more expensive, multiple units may be required, and the portable instrument is also required to locate the specific leaking component.

Calibration and maintenance costs may be higher. Fixed-point monitors have been used to detect emissions of hazardous or toxic substances (such as vinyl chloride) as well as potentially explosive conditions. Fixed-point monitors have an advantage for these cases, since a particular compound can be selected as the sampling criterion.

4.1.2 Repair Methods

The following descriptions of repair methods include only those features of each fugitive emission source (pump, valve, etc.) which need to be considered in assessing the applicability and effectiveness of each method. They are not intended to be complete repair procedures. The effectiveness of repairs in reducing fugitive emissions has not been well documented; however, data for valve repairs have been collected in various petroleum refineries. In many cases, perfect repair will not be achieved, but whenever repairs are performed, the portable hydrocarbon detector should be used to identify the lowest achievable emission rate.

4.1.2.1 Pumps. Many pumps have spares which can be operated while the leaking pump is being repaired. Leaks from packed seals may be reduced by tightening the packing gland. At some point, the packing may deteriorate to the point where further tightening would have no effect or possibly even increase fugitive emissions from the seal. The packing can be replaced with the pump out of service. When mechanical seals are utilized, the pump must be dismantled so the leaking seal can be repaired or replaced. Dismantling pumps will result in spillage of some process fluid and evaporate emissions of VOC. These temporary emissions may be greater than the continued leak from the seal, if the seal leak is small.

4.1.2.2 Compressors. Leaks from packed seals may be reduced by the same repair procedure that was described for pumps. Other types of seals require that the compressor be out of service for repair. Since most compressors do not have spares, repair or replacement of the seal would require a shutdown of the process. Temporary emissions resulting from a shutdown may be greater than the emissions from the seal if it was allowed to leak until the next scheduled shutdown.

4.1.2.3 Relief Valves. In general, relief valves which leak must be removed in order to repair the leak. In some cases of improper reseating, manual release of the valve may improve the seat seal. In order to remove the relief valve without shutting down the process, a block valve is required upstream of the relief valve. A spare relief valve should be attached while the faulty valve is repaired and tested. After a relief valve has been repaired and replaced, there is no guarantee that the next over-pressure relief will not result in another leak.

4.1.2.4 Valves. Most valves have a packing gland which can be tightened while in service. Although this procedure should decrease the emissions from the valve, in some cases it may actually increase the emission rate if the packing is old and brittle or has been overtightened. Plug type valves can be lubricated with grease to reduce emissions around the plug. Some types of valves have no means of in-service repair and must be isolated from the process and removed for repair or replacement. Other valves, such as control valves, may be excluded from in-service repair by operating or safety procedures. In many cases, valves cannot be isolated from the process for removal. Most control valves have a manual bypass loop which allows them to be isolated and removed. Most block valves cannot be isolated easily although temporary changes in process operation may allow isolation in some cases. If a process unit must be shut down in order to isolate a leaking valve, the emissions resulting from the shutdown will probably be greater than the emissions from the valve if allowed to leak until the next process change which permits isolation for repair.

Depending on site specific factors, it may be possible to repair process valves by injection of a sealing fluid into the source. This type of repair may affect the operability of the valve such that replacement of the source might be necessary within a short time after its repair, and the emissions that could result due to the replacement of the source should be evaluated when considering this type of repair. It should be noted that injection of sealing fluid has been successfully used to repair leaks from valves in petroleum refineries in California.

4.1.2.5 Flanges. In some cases, leaks from flanges can be reduced by replacing the flange gaskets. Most flanges cannot be isolated to permit replacement of the gasket. Data from petroleum refineries show that flanges emit very small amounts of VOC.³

4.1.3 Control Effectiveness of Leak Detection and Repair Methods

The instrument survey of individual components is the only type of leak detection method for which control effectiveness has been quantified. Therefore, the following estimations of control effectiveness do not pertain to the soap bubble leak detection method, area surveys, or fixed-point monitoring methods.

There are several factors which determine the control effectiveness of individual component surveys; these include

- Action level or leak definition,
- Inspection interval or monitoring frequency,
- Achievable emission reduction of maintenance, and
- Interval between detection and repair of the leak.

Some of these factors can be estimated by using data collected from petroleum refineries.⁴

4.1.3.1 Action Level. The action level is the minimum hydrocarbon concentration observed during monitoring which defines a leaking component which requires repair. The choice of the action level for defining a leak is influenced by a number of important considerations. First, the percent of total mass emissions which can potentially be controlled by the monitoring and repair program can be affected by varying the leak definition, or action level. Table 4-1 gives the percent of total mass emissions affected by various action levels for a number of equipment types. The data in this table, indicate that, in general, a low action level results in larger potential emission reductions. However, the choice of an appropriate leak definition is most importantly limited by the ability to repair leaking components. Test data indicate that about 50 percent of valve leaks with initial screening values equal to or greater than 10,000 ppmv can be successfully repaired. Similar data indicate that attempted repair of valve leaks with initial screening values

TABLE 4-1. FRACTION OF TOTAL MASS EMISSIONS FROM VARIOUS SOURCE TYPES THAT WOULD BE CONTROLLED BY DIFFERENT ACTION LEVELS

Action level ^a (ppmv)	Fraction of mass emissions (as %) ^b			
	100,000	50,000	10,000	1,000
<u>Source type</u>				
Pump seals				
Light liquid service	56	68	87	97
Heavy liquid service	0	0	21	66
In-line valves				
Vapor service	85	92	98	99
Light liquid service	49	62	84	96
Heavy liquid service	0	0	0	23
Safety/relief valves	20	33	69	92
Compressor seals	28	48	84	98
Flanges	0	0	0	48

^aLevel of emission at which repair of the source is required.

^bThese data show the fraction of the total emissions from a given source type that is attributable to sources with leaks above the various action levels.

of less than 10,000 ppmv can increase instead of decrease emissions from these values. From these data it is concluded that repairing leaks with screening values in the 1,000-10,000 ppmv range may not result in a net reduction in mass emissions.⁶ The nature of repair techniques for pipeline valves, for instance, are such that to repair leaks below a certain level by tightening valve packing may actually result in an increase in emissions. In practice, valve packing material becomes hard and brittle after extended use. As the packing loses its resiliency, the valve packing gland must be tightened to prevent loss of product to the atmosphere. Excessive tightening, however, may cause cracks in the packing, thus increasing the leak rate. Unbalanced tightening of the packing gland may also cause the packing material to be positioned improperly in the valve and allow leakage. Valves which are not often used can build up a "static" seal of paint or hardened lubricant which could be broken by tightening the packing gland. Therefore, it may be important not to cause small leaks to become large leaks by requiring tightening of valves to meet a very low leak repair action level.

4.1.3.2 Inspection Interval. A monitoring plan may include annual, quarterly, monthly, or even weekly inspections. The length of time between inspections should depend on the expected occurrence and recurrence of leaks after a piece of equipment has been checked and/or repaired. This interval can be related to the type of equipment and service conditions, and different intervals can be specified for different pieces of equipment after appropriate equipment histories have been developed. In the refinery VOC leak Control Techniques Guideline (CTG) document,⁷ 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. The choice of the interval affects the emission reduction achievable since more frequent inspection will result in leaking sources being found and fixed sooner. In order to evaluate the effectiveness of different inspection intervals, it is

necessary to estimate the rate at which new leaks will occur and repaired leaks will recur. The estimates which have been used to evaluate yearly, quarterly, and monthly inspections are shown in Table 4-2.

4.1.3.3 Allowable Interval Before Repair. If a leak is detected, the equipment should be repaired within a certain time period. The allowable repair time should reflect an interest in eliminating a source of VOC emissions but should also allow the plant operator sufficient time to obtain necessary repair parts and maintain some degree of flexibility in overall plant maintenance scheduling. The determination of this allowable repair time will affect emission reductions by influencing the length of time that leaking sources are allowed to continue to emit pollutants. Some of the components with concentrations in excess of the leak definition action level may not be able to be repaired until the next scheduled unit shutdown, e.g., a unit turnaround.

The effects of different allowable repair intervals are shown in Table 4-3. The percentages shown in the table are the percent of emissions from the component which will be affected by the repair. The emissions which occur between the time the leak is detected and repair is attempted are increased with increasing allowable repair intervals.

4.1.3.4 Achievable Emission Reduction. Repair of leaking components will not always result in complete emission reduction. The repair of components which have initial monitoring levels below 1,000 ppm has not been adequately demonstrated. Repair of those components with low initial leak rates may actually result in an emission rate increase. In order to estimate repair effectiveness, it was assumed that emission would be reduced to a level equal to components with screening values of 1,000 ppm. The average emission rates of components above 10,000 ppm and at 1,000 ppm are shown in Table 4-4.

4.1.3.5 Development of Controlled Emission Factors. The uncontrolled emission levels for the emission sources that are typically found in the model plants were previously presented in Chapter 3 (Table 3-1). Controlled VOC emission levels can be calculated by a "controlled emission" factor. This factor can be developed for each type of emission source by using the general expression:

TABLE 4-2. ESTIMATED OCCURRENCE AND RECURRENCE RATE FOR VARIOUS MONITORING INTERVALS

Source type	Estimated percent of sources leaking at above 10,000 ppm initially ^a	Estimated percent of initial leaks which are found leaking at subsequent inspections ^b			Estimated percent of sources which are found leaking at subsequent inspections ^c		
		Annual	Quarterly	Monthly	Annual	Quarterly	Monthly
Pump seals							
Light liquid service	23	20	10	5	4.6	2.3	1.2
Heavy liquid service	2	20	10	5	0.4	0.2	0.1
In-line valves							
Vapor service	10	20	10	5	2.0	1.0	0.5
Light liquid service	12	20	10	5	2.4	1.2	0.6
Heavy liquid service	0	20	10	5	0.0	0.0	0.0
Safety/relief valves	8	20	10	5	1.6	0.8	0.4
Compressor seals	33	20	10	5	6.3	3.3	1.7
Flanges	0	20	10	5	0.0	0.0	0.0

^aApproximate fraction of sources having leaks equal to or greater than 10,000 ppm prior to repair.

^bApproximate fraction of leaking sources that were repaired but found to leak during subsequent inspections. These approximations are based on engineering judgment.

^cApproximate fraction of sources that were repaired but found to leak during a subsequent inspection. These approximations are the product of the information presented in footnotes a and b.

TABLE 4-3. PERCENT OF MASS EMISSIONS AFFECTED BY VARIOUS REPAIR INTERVALS

Allowable repair interval (days)	30	15	5	1
Percent of emissions affected	95.9	97.9	99.3	99.9

TABLE 4-4. AVERAGE EMISSION RATES FROM SOURCES ABOVE 10,000 PPMV AND AT 1000 PPMV⁹

Source type	(Y) Emission rate from sources above 10,000 ppmv ^a (kg/hr)	(X) Emission rate from sources at 1000 ppmv ^b (kg/hr)	$\left(\frac{X}{Y}\right)(100)$ Percentage reduction
Pump seals			
Light liquid service	0.45	0.035	92.0
Heavy liquid service	0.21	0.035	83.0
In-line valves			
Vapor service	0.21	0.001	99.5
Light liquid service	0.07	0.004	94.0
Heavy liquid service	0.005	0.004	20.0
Safety/relief valves	1.4	0.035	97.5
Compressor seals	1.1	0.035	97.0
Flanges	0.003	0.002	33.0

^a Average emission rate of all sources, within a source type, having screening values above 10,000 ppmv.

^b Emission rate of all sources, within a source type, having screening values of 1000 ppmv.

Controlled emission factor = Uncontrolled factor - uncontrolled
factor x emission reduction efficiency

The reduction efficiency can be developed by the following expression and correction factors:

$$\text{Reduction efficiency} = A \times B \times C \times D$$

Where:

A = Theoretical Maximum Control Efficiency = fraction of total mass emissions for each source type with VOC concentrations greater than the action level (Table 4-1, Figure 4-1).

B = Leak Occurrence and Recurrence Correction Factor = correction factor to account for sources which start to leak between inspections (occurrence) and for sources which are found to be leaking, are repaired and start to leak again before the next inspection (recurrence) (Table 4-2, 4-6).

C = Non-Instantaneous Repair Correction Factor = correction factor to account for emissions which occur between detection of a leak and subsequent repair; that is, repair is not instantaneous (Table 4-3).

D = Imperfect Repair Correction Factor = correction factor to account for the fact that some sources which are repaired are not reduced to zero emission levels. For computational purposes, all sources which are repaired are assumed to be reduced to a 1000 ppm emission level (Table 4-4).

These correction factors can, in turn, be determined from the following expressions:

$$(1) \quad B = 1 - \frac{\bar{n}_m}{N}$$

$$(2) \quad C = \frac{365 - t}{365}$$

$$(3) \quad D = 1 - \frac{f}{F}$$

Where:

\bar{n}_m = Average number of leaks occurring and recurring over the monitoring interval.

N = Total number of sources at or above the action level (Figure 4-2).

t = Average time before repairs are made (with a 15-day repair limit, 7.5 is the average used).

f = Average emission factor for sources at the average screening value achieved by repair.

F = Average emission factor for all sources at or above the action level.

An example of a control effectiveness calculation is presented in Table 4-5. Support data for this calculation are presented in Tables 4-1, 4-2, 4-3, 4-4, and 4-6, as well as in Figures 4-1 and 4-2.

4.2 EQUIPMENT SPECIFICATIONS

Equipment specifications for each emission source are described below. Some of the specifications may be applicable to more than one type of source. In these cases, references are made to the preceding description with any differences in applicability or effectiveness notes.

4.2.1 Pumps

Fugitive emissions from pumps occur at the junction of a moving shaft and a stationary casing. Equipment specifications that may be implemented for pumps include elimination of this junction, improvement of the seal at the junction, or collection and control of the emissions from the junction.

4.2.1.1 Sealless Pumps. Pumps such as diaphragm type pumps or "canned" pumps do not have a shaft/casing junction and therefore do not leak the pumped fluid as a normal course of operation. Failure of the diaphragm may result in temporary emissions of VOC. Sealless pumps are used primarily in SOCM processes where the pumped fluid is hazardous or toxic, and every effort must be made to prevent leaks of the fluid.

TABLE 4-5. EXAMPLE OF CONTROL EFFICIENCY CALCULATION

Assume:

- 1) A leak detection and repair program to reduce emissions from valves in gas/vapor source.
- 2) Action level = 10,000 ppm.
- 3) Average screening value after directed repair = 1,000 ppm.
- 4) Leak detection monitoring interval = 3 months.
- 5) Allowable repair interval = 15 days.
- 6) Number of valves having new or recurring leaks between repair intervals, $n_m = 0.2N$ (see Table 4-6).

Calculations:

A = 0.98 (from Figure 4-1 for a screening value of 10,000 ppmv)

B = 0.9 (from Table 4-6)

C = 0.979 (from Table 4-3 for 15-day interval)

where:

$$F = \frac{A(\text{Avg. uncontrolled emission factor})^a}{\text{Fraction of sources screening} \geq 10,000 \text{ ppm}^b}$$

$$= (0.98)(0.021 \text{ kg/hr})/0.10 = 0.206 \text{ kg/hr}$$

$$f = \text{Emission factor at } 1000 \text{ ppm}^c$$

$$= 0.001 \text{ kg/hr}$$

$$\text{and } D = (1 - \frac{0.001}{0.206}) = 0.995$$

$$\text{Overall percentage reduction} = A \times B \times C \times D$$

$$= (0.98) \times (0.9) \times (0.979) \times (0.995)$$

$$= 86 \text{ Percent}$$

Therefore:

$$\text{Control effectiveness factor} = 0.021 \text{ kg/hr} - (0.86)(0.021 \text{ kg/hr})$$

$$= 0.003 \text{ kg/hr}$$

^a Reference 10.
^b From Figure 4-2.
^c Reference 11.

TABLE 4-6. IMPACT OF MONITORING INTERVAL ON CORRECTION FACTOR ACCOUNTING FOR LEAK OCCURRENCE/RECURRENCE (FOR EXAMPLE CALCULATION)

Monitoring interval	a n_m	b \bar{n}_m	c B
1 month	0.1N	0.05N	0.95
3 months	0.2N	0.1N	0.90
1 year	0.4N	0.2N	0.80

a n_m = Total number of leaks which occur, recur, and remain between monitoring intervals.

b \bar{n}_m = Average number of leaks over the monitoring interval.

c B = Correction factor accounting for leak occurrence/recurrence.

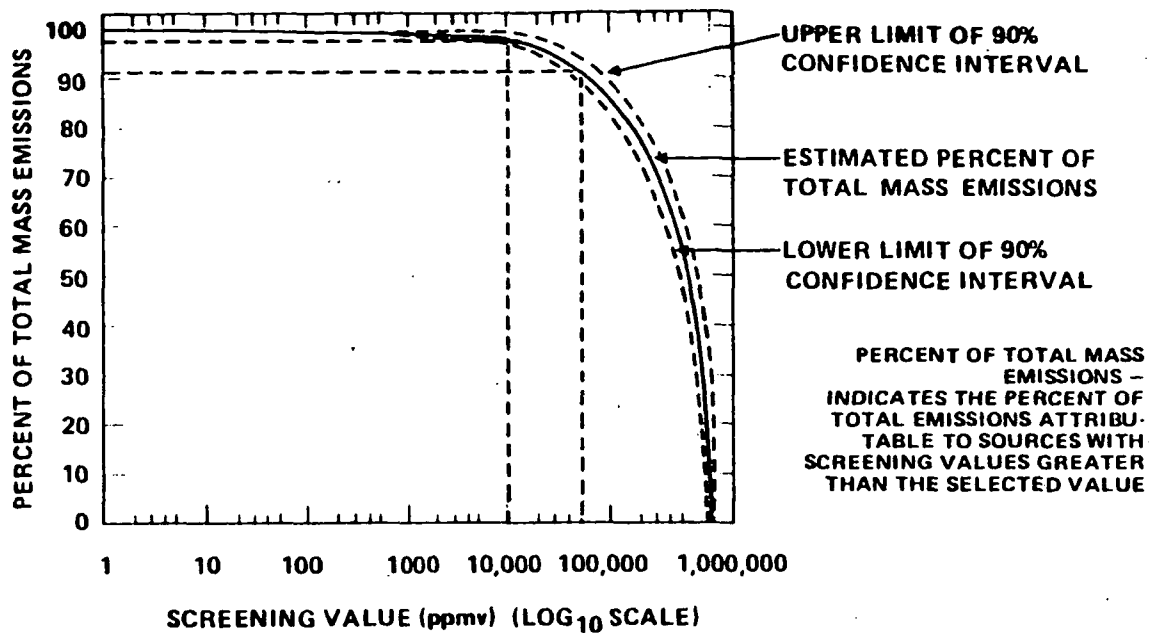


Figure 4-1. Cumulative distribution of total emissions by screening values - valves - gas/vapor streams.¹²

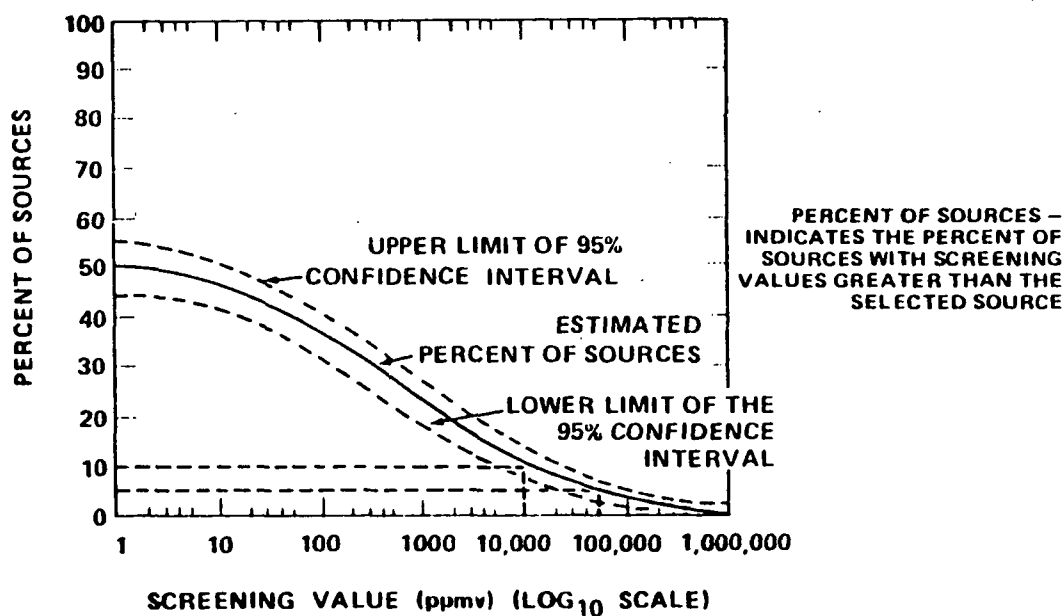


Figure 4-2. Cumulative distribution of sources by screening values - valves - gas/vapor streams.¹³

4.2.1.2 Double Mechanical Seals. Double mechanical seals consist of two mechanical sealing elements with a barrier fluid in the chamber between the seals. This chamber is either flushed with circulating barrier fluid or is flooded with static barrier fluid. The pressure of the static barrier fluid can be monitored to detect failure of the inner seal.¹⁴ Any leaks through the inner seal may be dissolved or suspended in the barrier fluid, and subsequent degassing of the sealing fluid may result in emission of VOC. Therefore, barrier fluid degassing vents must be controlled in order to provide maximum control effectiveness of double mechanical seals. After extended periods of use, double seals may also develop leaks at the outer seal/shaft junction.

Emissions of VOC from degassing vents can be controlled by a closed vent system which consists of piping and, if necessary, flow inducing devices to transport the degassing emissions to a control device such as a process heater, or vapor recovery system. Control effectiveness of a double mechanical seal and closed vent system is dependent on the effectiveness of the heater, or vapor recovery system, and the frequency of seal failure. Failure of both the inner and outer seals can result in relatively large VOC emissions at the seal area of the pump. As noted, the pressure monitoring of the static barrier fluid may be used in order to detect failure of the seals. In addition, visual inspection of the seal area also can be effective for detecting failure of the outer seals. Upon seal failure, the leaking pump would have to be shut down for repair.

Double mechanical seals are used in many SOCFI process applications; however, there are some conditions that preclude use of double mechanical seals. Their maximum service temperature is usually limited to less than 260°C, and mechanical seals cannot be used on pumps with reciprocating shaft motion. Process fluids containing catalyst fines or other abrasive materials may not be suitable for use with mechanical seals.

4.2.1.3 Closed Vent Systems. The system described above for controlling degassing vent emissions could also be applied to control emissions from the seal area of pumps. This application would require the use of some type of flow inducing device to transport the emissions from the seal area to the control device. The seal area would be enclosed

in order to collect the emissions and a vacuum eductor or a compressor could be used to remove vapors from the seal area. However, normal pump operating practices may require frequent visual inspection or mechanical adjustments in the seal area. This would not be possible with a closed vent system at the seal area. A potential problem with this approach is that explosive mixtures may be created by enclosing the pump seal area, and therefore safety and operating practices may limit the use of closed vent systems for pump seal areas.

4.2.2 Compressors

Fugitive emissions from compressors occur at the junction of a moving shaft and a stationary casing. Emission reductions from this source type may be achieved by improving the seal at the junction, or collecting and controlling the emissions from the junction.

4.2.2.1 Double Mechanical Seals. Double mechanical seals for compressors are similar to those described above for pump applications, and reciprocating shafts cannot be fitted with mechanical seals. Labyrinth type seals may also have barrier fluid systems. Existing compressors may have double mechanical seals and seal oil flush systems, but seal oil reservoir degassing vents must be controlled with closed vent systems as described above. Control efficiency is dependent on the control device efficiency and the frequency of seal failures.

4.2.2.2 Closed Vent Systems. The seal area of a compressor may be enclosed, and the VOC emissions routed to a control device through a closed vent system. However, flow inducing devices may be required to transport vapors to the control device. Although the formation of explosive mixtures in the enclosed seal area may prohibit application of this equipment modification, closed vent systems have been applied to compressor seal areas in petroleum refineries.

4.2.3 Pressure Relief Devices

Pressure relief devices include rupture disks and safety/relief valves. Fugitive emissions from these devices occur because of improper seating or partial failure of the device. These fugitive emissions do not include emissions which result from normal operation of the devices

caused by overpressure of the process or vessel which the device protects. Fugitive emissions from rupture disks may be caused by pinhole leaks in the disk itself caused by corrosion or fatigue. Fugitive emission from relief valves may be caused by failure of the valve seating surfaces, improper reseating after overpressure relieving, or process operation near the relief valve set pressure which may cause "simmering".

4.2.3.1 Rupture Disks. Although they are also pressure relief devices, rupture disks can be installed upstream of a safety/relief valve in order to prevent fugitive emissions through the relief valve seat. This procedure may require use of a larger size relief valve because of operating codes. The disk/valve combination may also require appropriate piping changes to prevent disk fragments from lodging in and damaging the relief valve when relieving overpressure. A block valve upstream of the rupture disk is also required in order to permit in-service replacement of the disk after overpressuring. If the disk could not be replaced, the first overpressure would result in the relief valve being the same as an uncontrolled relief valve, and it may actually be worse since disk fragments may prevent proper reseating of the relief valve. In some chemical plants, installation of a block valve upstream of a pressure relief device may be a common practice. In others, it may be forbidden by operating or safety procedures. Tandem pressure relief devices with a three-way valve can be used to avoid operation without overpressure protection. Rupture disk/relief valve combinations must have some provision for testing the integrity of the disk. The area between the rupture disk and relief valve must be connected to a pressure indicator, recorder, or alarm. If the process fluid is not hazardous or toxic, a simple bubbler apparatus could be used to test disk integrity by connecting the bubbler to the disk/valve area. The control efficiency of the disk valve combination is assumed to be 100 percent for fugitive emissions. If the disk integrity is not maintained or if the disk is not replaced after overpressure relief, the control efficiency would be lowered. The disk/valve combination has no effect on emissions which result from overpressure relieving.

4.2.3.2 Resilient Seat Relief Valves. Manufacturers of relief valves state that resilient seat or "O-ring" relief valves provide better reseal qualities compared to standard relief valves. No test data are available to verify these statements. These improvements would have no effect on overpressure emissions or fugitive emissions due to seal failure or "simmering"..

4.2.3.3 Closed Vent Systems. A closed vent system can be used to transport the discharge or leakage of pressure relief devices to a control device such as a flare. Since overpressure discharges as well as fugitive emissions are routed to the control device, it must be sized appropriately. A larger pressure relief device may be required for use with a closed vent system. The control efficiency of a closed vent system is dependent on the effectiveness of the control device. Typical flare systems may be only 60 percent effective for fugitive emission destruction.¹⁵ This efficiency reflects the fact that many flare systems are not of optimum design. As a result flares that are designed to handle large volumes of vapors associated with overpressure releases are used to handle low volumes of fugitive emissions. With such designs, optimum mixing is not achieved because the vent gas exit velocity is low and large flares generally cannot properly inject steam into low volume streams.¹⁶ A properly designed flare system typically exhibits a 99 percent hydrocarbon destruction efficiency.¹⁷ Closed vent systems for pressure relief devices are used in existing SOGMI processes especially where the emissions may be hazardous or toxic.

4.2.4 Open-Ended Valves

Fugitive emissions from open-ended valves are caused by leakage through the seat of the valve. Emissions may also occur through the stem and gland of the valve, and these emissions may be controlled by methods described for valves in Section 4.1.2. Approximately 28 percent of SOGMI valves (excluding safety/relief and check valves) in VOC service are open-ended.¹⁸ They include drain, purge, sample, and vent valves. Fugitive emissions from open-ended valves can be controlled by installing a cap, plug, flange, or second valve to the open end of the valve. In the case of a second valve, the

upstream valve should always be closed first after use of the valves. Each time the cap, plug, flange, or second valve is opened, any VOC which has leaked through the first valve seat will be released. These emissions have not been quantified. The control efficiency of these devices is assumed to be 100 percent. The actual efficiency will be dependent on the frequency of removal of the cap or plug. Caps, plugs, etc. for open-ended valves do not affect emissions which may occur during use of the valve. These emissions may be caused by line purging for sampling, draining, or venting through the open-ended valve. Caps, plugs, flanges, or second valves for open-ended valves are required by California regulations.¹⁹

4.2.5 Sampling Connections

Fugitive emissions from sampling connections occur as a result of purging the sampling line in order to obtain a representative sample of the process fluid. Approximately 25 percent of open-ended valves are used for sampling connections.²⁰ Fugitive emissions from sampling connections can be reduced by using a closed loop sampling system. The closed loop system is designed so that the purged fluid is returned to the process at a point of lower pressure. A throttle valve or other device is required to induce the pressure drop across the sample loop. The purged fluid could also be directed to a control device such as a flare. In this case the control efficiency would be dependent on the flare efficiency for hydrocarbon destruction. Closed loop sampling is assumed to be 100 percent effective for controlling fugitive emissions. Since some pressure drop is required to purge sample through the loop, low pressure processes or tankage may not be amenable to closed loop sampling. Safety requirements may prohibit closed loop sampling in some instances.

4.2.6 In-Line Valves

Fugitive emissions from valves occur at the stem or gland area of the valve body. Diaphragm and bellows seal valves do not have a stem or gland and therefore are not prone to fugitive emissions. Diaphragm valves are generally used where hazardous or toxic process fluids are present and fugitive emissions must be eliminated. Their control effectiveness is approximately 100 percent, although failure of the diaphragm may cause

large temporary emissions. The applicability of diaphragm valves is limited by the strength of the diaphragm. Diaphragm valves may not be suitable for many applications because of process conditions or cost considerations.

4.2.7 Effectiveness of Equipment Specifications

In order to quantify the environmental and economic impacts of applying controls, the control efficiency must be determined. In some cases, there are many complicating factors which make it difficult to accurately estimate control efficiency. For example, the efficiency of caps or plugs for open-ended valves is dependent on 1) the frequency of removal of the cap or plug, since this removal will result in emission of fluids trapped by the cap or plug, and 2) the emission rate through the valve seat. The estimated control efficiencies for various equipment modifications are shown in Table 4-7. These estimates represent the maximum emission reduction possible for the equipment modifications. In some instances, the actual emission reduction will depend on other factors such as the efficiency of control devices attached to closed vent systems. Carbon absorption or vapor recovery systems would approach the 100 percent efficiency, but flares may be only 60 percent effective for hydrocarbon destruction. These estimates of effectiveness are used to calculate environmental and economic impacts of regulatory alternatives in Chapters 7 and 8 of this document.

TABLE 4-7. EFFECTIVENESS OF EQUIPMENT MODIFICATIONS

Source type/ equipment modification	Control efficiency (%)
Pumps	
Sealless pumps	100
Double mechanical seals/closed vent system	~100 ^a
Closed vent system on seal area	~100 ^a
Compressors	
Double mechanical seals/closed vent system	~100 ^a
Closed vent system on seal area	~100 ^a
Safety/relief valves	
Closed vent system	60 ^b
Rupture disks	100
Open-ended lines	
Caps, plugs, blinds, second valves	100 ^c
Sampling connections	
Closed loop sampling	100
In-line valves	
Diaphragm valves	100

^a Although a control efficiency is not attained in all cases, it is achievable in some cases.

^b This control effectiveness reflects the fact that a closed vent system is normally sized for emergency relief.²¹

^c This is the control efficiency reflects the use of these devices downstream of an initial valve with VOC on one side and atmosphere on the other.

4.3 REFERENCES

1. Hustvedt, K. C., and R. C. Weber. Detection of Volatile Organic Compound Emissions from Equipment Leaks. Presented at 71st Annual Air Pollution Control Association Meeting, Houston, Texas, June 25-30, 1978.
2. Ref. 1.
3. Wetherold, R. G., and L. P. Provost. Emission Factors and Frequency of Leak Occurrence for Fittings in Refinery Process Units. Interim Report. EPA/600/2-79-044. Radian Corporation. February 1979. p. 2.
4. Ref. 3.
5. Ref. 3.
6. Valve Repair Summary and Memo from F. R. Bottomley, Union Oil Company. Rodeo, California. To Milton Feldstein, Bay Area Quality Management District. April 10, 1979.
7. Environmental Protection Agency. Control of Volatile Organic Compound Leaks from Petroleum Refinery Equipment. EPA-450/2-78-036. OAQPS No. 1.2-111. Research Triangle Park, North Carolina. June 1978.
8. Ref. 3.
9. Ref. 3.
10. Ref. 3.
11. Ref. 3.
12. Ref. 3.
13. Ref. 3.
14. Erikson, D. G., and V. Kalcevic. Emission Control Options for the Synthetic Organic Chemicals Manufacturing Industry, Fugitive Emissions Report, Draft Final. Hydrosience, Inc. 1979. p. III-1.
15. Draft-of Background Information Document (BID), Chapter 4, for a National Emission Standard for Hazardous Air Pollutants from the Ethylbenzene/Styrene Industry. U.S. Environmental Protection Agency, RTP, North Carolina, October 1979.

16. Ref. 15.
17. Environmental Protection Agency. Control of Volatile Organic Emissions from Existing Stationary Sources. Volume 1: Control Methods for Surface Coating Operations. EPA-450/2-76-028. Research Triangle Park, North Carolina. November 1976, p. 42.
18. Ref. 14, p. III-5.
19. Ref. 14, p. III-5.
20. Ref. 14.
21. Ref. 15.

5. MODIFICATION AND RECONSTRUCTION

In accordance with the provisions of 40 Code of Federal Regulation (CFR), Sections 60.14 and 60.15, an "existing facility" can become an affected facility and, subsequently, subject to the standards of performance if it is modified or reconstructed. An existing facility, as defined in 40 CFR 60.2 (aa), is a facility of the type for which standards of performance have been promulgated and the construction or modification of which was begun prior to the proposal date of the applicable standards.

The applicability of provisions 40 CFR 60.14 and 60.15 to the SO2MI, and the conditions, as outlined in these provisions, under which existing facilities could become subject to standards of performance are discussed below.

5.1 GENERAL DISCUSSION OF MODIFICATION AND RECONSTRUCTION PROVISIONS

5.1.1 Modification

"Modification" is defined in 40 CFR 60.14 (a) as any physical or operational change of an existing facility which increases the emission rate of any pollutant to which a standard applies. Exceptions to this definition are presented in paragraphs (d), (e), and (f) of Section 60.14. These exceptions are as follows:

Paragraph (d) - In accordance with the paragraph, an existing facility may undergo a physical or operational change, which increases the emission rate of any pollutant to which standards of performance apply, but not judged to be a modification, if the owner or operator can demonstrate to the Administrator's satisfaction (by any of the procedures prescribed in paragraph (b) of this section) that

the total emission rate of that pollutant has not increased from the facility.

Paragraph (e) - Physical or operational changes to an existing facility which will not be considered modifications are specified in this portion of Section 60.14.

These changes include:

- a. Routine maintenance, repair, and replacement.
- b. An increase in the production rate not requiring a capital expenditure as defined in Section 60.2(bb).
- c. An increase in the hours of operation.
- d. Use of an alternative fuel or raw material if prior to the standard, the existing facility was designed to accommodate that alternate fuel or raw material.
- e. The addition or use of any system or device whose primary function is the reduction of air pollutants, except when an emission control system is removed or replaced by a system considered to be less efficient.

Paragraph (f) - This paragraph provides for superceding any conflicting provisions of this section.

Upon modification, an existing facility becomes an affected facility for each pollutant to which a standard applies and for which there is an increase in the emission rate to the atmosphere. Paragraph (c) also declares that the addition of an affected facility to a stationary source through any mechanism--new construction, modification, or reconstruction--does not make any other facility within the stationary source subject to the applicable standards.

5.1.2 Reconstruction

Under the provisions of Section 60.15, an existing facility becomes an affected facility upon reconstruction, irrespective of any change in emission rate. Generally, reconstruction is considered to occur upon the replacement of components if the fixed capital cost of the new components exceeds 50 percent of the fixed capital cost that would be required to

construct a comparable entirely new facility, and it is economically and technically feasible for the facility to comply with the applicable standards of performance. The final judgments on what replacement constitutes reconstruction and when it is technologically and economically feasible to comply with the applicable standards of performance is made by the Administrator. The Administrator's final determinations are made on the following bases:

- (1) comparison of the fixed capital costs of the replacement components and a newly constructed comparable facility,
- (2) the estimated life of the facility after the replacements compared to the life of a comparable entirely new facility,
- (3) the extent to which the components being replaced cause or contribute to the emissions from the facility, and
- (4) any economic or technical limitations on compliance with applicable standards of performance which are inherent in the proposed replacements.

The purpose of this provision is to ensure that an owner or operator does not perpetuate an existing facility by replacing all but vestigial components, support structures, frames, housing, etc., rather than totally replacing it in order to avoid subjugation to applicable standards of performance. In accordance with Section 60.5, EPA will, upon request, determine if the action taken constitutes construction (including reconstruction).

5.2 APPLICABILITY OF MODIFICATION AND RECONSTRUCTION PROVISIONS TO THE SOCFI

5.2.1 Modification

Several operating conditions that could be encountered in an organic chemical plant are presented below. These conditions may or may not result in an increase in emissions.

The replacement of a potential fugitive emission source such as a pump or valve commonly occurs in an organic chemical plant. If such a source is replaced with an equivalent source (such as is done during routine repair and replacement), the fugitive emissions from the facility should not increase because the number of potential sources in the same vapor pressure service (handling the same organic chemical) remains unchanged.

Process equipment pieces such as heat exchangers, reactors, distillation columns, reboilers, filters and separators, or new control loops are commonly added to existing facilities in the organic chemical industry to increase the capacity of or to optimize a process. The addition of this equipment would normally increase fugitive emissions from a facility due to the increased number of potential emission sources (pumps, valves, sampling connections, etc.) that are associated with the process equipment. However, in those cases where some sources are physically removed from service, the addition of new fugitive emission sources would not necessarily increase the level of fugitive emissions from the stationary source.

In some cases a facility in the organic chemical industry can be converted from the production of one chemical to the production of a second chemical. This normally occurs when production of the second chemical results in greater profits. In such a case, whenever either the number of fugitive emission sources or the vapor pressure of the second chemical increases during this conversion, the level of VOC emissions from the facility could be expected to increase.

Changes may be made to a process, although the chemical being produced remains the same. One such case would be a change in catalyst for producing a given chemical. In such a case the level of fugitive emissions would not be expected to change because the number of sources nor the vapor pressure of the chemical would change.

In many cases, there may be a desire to increase the capacity of an existing facility. This may be achieved by replacing certain process equipment (pumps, heat exchangers, reactors, etc.) with similar equipment but of larger capacity or addition of process equipment. If this replacement or addition does not increase the number of fugitive emission sources handling the given organic chemical, the level of fugitive emissions would not be expected to increase. However, if the number of sources were to increase due to this replacement or addition, then VOC emissions could be expected to increase.

5.2.2 Reconstruction

When an owner or operator replaces several components of an existing facility, that facility may or may not become subject to applicable standards of performance under the provisions of Section 60.15. For example, if an owner or operator replaces several reactors in an existing facility, reconstruction is considered to have occurred if the fixed capital costs for these reactors exceeds 50 percent of the costs that would be required to construct an entirely new facility. Replacement of other major equipment components such as heat exchangers, and distillation columns may also be considered as reconstruction if the fixed capital costs for the replaced equipment exceeds 50 percent of the costs of constructing an entirely new facility.

6. MODEL PROCESS UNITS AND REGULATORY ALTERNATIVES

This chapter presents model process unit parameters and alternative emission controls considered for reduction of fugitive emissions from SOCM I sources. The model units were selected to represent the range of processing complexity in the industry to provide a basis for comparing environmental and economic impacts of the regulatory alternatives. The selected regulatory alternatives provide varying levels of emission control.

6.1 MODEL UNITS

Available data show that fugitive emissions are proportional to the number of potential sources, but are not related to capacity, throughput, age, temperature, or pressure.¹ SOCM I model units therefore represent different levels of process complexity (number of sources) rather than unit size.

6.1.1 Sources of Fugitive Emissions

The various potential fugitive emission sources in a SOCM I process unit were described in Chapter 3. Data from petroleum refineries indicate that cooling towers are very small sources of VOC emissions.² Differences in SOCM I operating procedures, such as recirculation of process water, might result in cooling tower VOC emissions, but no data are available to verify this. The number of agitator seals in SOCM I is not known. Furthermore, the emission rate from SOCM I agitator seals has not been measured. Since there are no data from similar sources in other industries, no estimates of emission rate can be made. Because of these uncertainties, cooling towers and agitator seals are not included in the Model Units.

6.1.2 Model Unit Parameters

SOCMI process units vary considerably in size, complexity, age, and types of products manufactured. In order to estimate emissions, control costs, and environmental impacts on a unit specific basis, three model units were developed. The technical parameters for the model units are shown in Table 6-1. These three model units represent the range of emission source populations that may exist in SOCMI process units. The technical parameters were developed from a data base compiled by Hydro-science, Inc.³ The data base included equipment source counts from 62 SOCMI plants which produce 35 different chemicals. These plant sites represent approximately 5 percent of the total existing SOCMI plants and include large and small capacities, batch and continuous production methods, and varying levels of process complexity. Hydrosience estimates that 52 percent of existing SOCMI plants are similar to Model Unit A, 33 percent are similar to B, and 15 percent are similar to C. The source counts for the 35 chemicals include pumps, valves, and compressors. These counts were used in combination with the number of sites which produce each chemical in order to determine the average number of sources per site.⁴

Data from petroleum refineries indicate that emission rates of sources decrease as the vapor pressure (volatility) of the process fluid decreases. Three classes of volatility have been established based on the petroleum refinery data. These include gas/vapor service, light liquid service, and heavy liquid service.⁵ The split between light and heavy liquids for the refinery data is between streams called naphtha and kerosene. Since similar stream names may have different vapor pressures, depending on site specific factors, it is difficult to quantify the light-heavy split. The break point is approximately at a vapor pressure of 0.3 kPa at 20°C.

The data collected by Hydrosience were used to estimate the split between gas/vapor and liquid service for each source type.⁶ In order to apply emission factors for light and heavy liquid service, it is assumed that one half of SOCMI liquid service sources are in light liquid service. There are no data available on the actual distribution of sources in volatility ranges. It is assumed that all SOCMI packed seal pumps are in heavy liquid service. This assumption is reasonable, since more volatile liquids are

TABLE 6-1. FUGITIVE EMISSION SOURCES FOR THREE MODEL UNITS

Equipment component ^a	Number of components in model unit ^c		
	Model unit A	Model unit B	Model unit C
Pump seals			
Light liquid service			
Single mechanical	5	19	60
Double mechanical	3	10	31
Sealless	0	1	1
Heavy liquid service			
Single mechanical	5	24	73
Packed	2	6	20
In-line valves			
Vapor service	90	365	1117
Light liquid service	84	335	1037
Heavy liquid service	84	335	1037
Safety/relief valves			
Vapor service	11	42	130
Light liquid service	1	4	13
Heavy liquid service	1	4	14
Open-ended valves and lines ^b			
Vapor service	9	37	115
Light liquid service	47	189	581
Heavy liquid service	48	189	581
Compressor seals	1	2	8
Sampling connections ^c	26	104	320
Flanges	600	2400	7400
Cooling towers	-- ^c	-- ^c	-- ^e
Agitator seals	600 ^e	2400 ^e	7400 ^e

^aEquipment components in VOC service only.

^bSample, drain, purge valves.

^cBased on 25% of open-ended valves. From Ref. 3, pg. IV-3.

^d52% of existing units are similar to Model Unit A.

33% of existing units are similar to Model Unit B.

15% of existing units are similar to Model Unit C.

Ref. 3, pg. IV-1.

^eData not available.

more suitable for mechanical seal applications, and newer process units tend to use fewer packed seals. Sampling connections are a subset of the open-ended valve category. Approximately 25 percent of open-ended valves are used for sampling connections.⁷ Emissions which occur through the valve stem, gland, and open-end are included in the open-ended valve category. The emission factor for sampling connections applies only to emissions which result from sample purging.

6.2 REGULATORY ALTERNATIVES

Regulatory alternatives represent comprehensive programs for reduction of emissions by combining the individual control techniques described in Chapter 4. The regulatory alternatives described in this section contain feasible control techniques for reducing fugitive emissions of VOC from SOCFI sources.

The purpose of developing different regulatory alternatives is to provide a basis, along with model unit parameters, for determining the air-quality and non air-quality environmental impacts, energy requirements, and the costs associated with varying degrees of VOC fugitive emissions reduction. The regulatory alternatives selected for analysis include a "status quo of fugitive emission control" case and three increasingly restrictive levels of emission control requirements. The "status quo" case allows for the analysis of not implementing standards of performance. The three increasingly restrictive control requirements allow for analysis of the impacts of different systems with varying degrees of emission reduction. The requirements for each of these regulatory alternatives are summarized in Table 6-2 and are described below.

6.2.1 Regulatory Alternative I

Alternative I represents the general level of control that would exist in the absence of establishing any VOC fugitive emission control requirement. For this case, SOCFI facilities located in oxidant National Ambient Air Quality Standard (NAAQS) attainment areas, in general, would not be subject to any requirements. However, some states may require leak detection and repair programs to control fugitive emissions of VOC through prevention of significant deterioration (PSD) statutes. SOCFI facilities located in

TABLE 6-2. REGULATORY ALTERNATIVES FOR FUGITIVE EMISSION SOURCES IN SOCM1

Source type ^a	Regulatory alternative							
	I	II	III	IV				
	Monitoring interval	Equipment specification	Monitoring interval	Equipment specification	Monitoring interval	Equipment specification	Monitoring interval	Equipment specification
Pumps								
Light liquids with single mechanical seals	None	None	Annually ^b	None	Monthly ^b	None	None ^b	Double seals; degassing vents connected to control device ^e
with double mechanical seals	None	None	Annually ^b	None	Monthly ^b	None	None ^b	Degassing vents connected to control device ^e
with no seals	None	None	None	None	None	None	None	None
Heavy liquids with packed seals	None	None	None	None	None	None	None	None
with single mechanical seals	None	None	None	None	None	None	None	None
Valves (in-line)								
Gas	None	None	Quarterly	None	Monthly	None	Monthly	None
Light liquid	None	None	Annually	None	Monthly	None	Monthly	None
Heavy liquid	None	None	None	None	None	None	None	None
Safety/relief valves								
Gas	None	None	Quarterly ^c	None	Monthly ^c	None	None ^c	Upstream rupture disks
Light liquid	None	None	None	None	None	None	None	None
Heavy liquid	None	None	None	None	None	None	None	None
Open-ended valves and lines								
Gas	None	None	Quarterly	Caps ^f	Monthly	Caps ^f	Monthly	Caps ^f
Light liquid	None	None	Annually	Caps ^f	Monthly	Caps ^f	Monthly	Caps ^f
Heavy liquid	None	None	None	Caps ^f	None	Caps ^f	None	Caps ^f
Flanges	None	None	None	None	None	None	None	None
Sampling connections	None	None	None ^d	None	None ^d	None	None ^d	Closed loop sampling
Compressor seals	None	None	Quarterly	None	Monthly	None	None	Seal area or degassing vents connected to control device

^aSources in VOC service.^bPlus weekly visual inspection. If liquid leak is observed, instrument monitoring is required to determine if action level is being exceeded.^cMonitoring is required after each over pressure release. If it is found to be leaking, the valve will be repaired.^dIncluded in open-ended valves.^eSealless pumps may also be used.^fOr blinds, plugs, second valves.

non-attainment areas would be subject to the applicable SIP regulations and other permitting requirements. In some areas control of fugitive VOC emissions may be used to achieve hydrocarbon emission offsets. However, no present or anticipated SIP regulations would be generally applicable to SOCFI. This baseline control alternative merely presents a generalized fugitive emission control level that can be used to compare the impacts of the more stringent alternatives. As such, this alternative does not consider the levels of control for specific facilities.

6.2.2 Regulatory Alternative II

This alternative would require leak detection and repair methods as in the petroleum refinery control techniques guideline (CTG), EPA-450/2-78-036. Leak detection would be accomplished by checking equipment components for emissions of VOC using a portable VOC detection instrument to sample and analyze the air in close proximity to the potential leak area. A measured VOC concentration greater than some predetermined level, known as an "action level", would be defined as a leak that would require equipment repair. A measured VOC concentration less than the action level would not require equipment repair. The action level is defined as 10,000 ppmv VOC concentration for all cases.

Quarterly monitoring of compressors, gas service relief valves, inline valves, and open-ended valves would be required. Annual monitoring of light liquid service pumps and valves would be required. Weekly visual inspections of light liquid pump seals would also be required. Leaks detected visually would require instrument monitoring to determine if the action level is exceeded. Relief valve monitoring after over pressure relieving would be required. Open-ended valves would be required to be sealed with a cap, blind, plug, or another valve.

6.2.3 Regulatory Alternative III

Regulatory Alternative III would provide for more restrictive control than Alternative II by increasing the inspections for all applicable equipment to monthly. Increasing the inspections would result in a reduction of emissions from residual leaking sources; i.e., those sources which are found

leaking and are repaired and recur before the next inspection and those sources that begin leaking between inspection. Thus, although this alternative is similar in approach to Alternative II, it provides for more emissions reduction. The requirements for weekly visual pump seal inspections, relief valve monitoring after over pressure, and caps for open-ended valves are the same as Alternative II.

6.2.4 Regulatory Alternative IV

Alternative IV would require equipment specifications instead of more frequent equipment inspections. This alternative would provide a more restrictive level of control than the other alternatives. Several equipment specifications would be required, including caps for open-ended valves as in Alternatives II and III. Closed loop sampling techniques would be required and rupture disks would be required on gas service relief valves venting to atmosphere. The integrity of the disk would be required and replacement of the disk would be required whenever a failure is detected. No monitoring would be required for relief valves which have rupture disks upstream or which vent to a control device header. Compressor seal areas and degassing vents from seal oil reservoirs, or both, would be required to be connected to a control device with a closed vent system. Pumps in light liquid service would be required to have double mechanical seals with a seal oil flushing system. The degassing vent from the seal oil reservoir would be required to be connected to a control device with a closed vent system.

6.3 REFERENCES

1. Wetherold, R.G., L.P. Provost, D.D. Rosebrook, and C.D. Smith. Emissions Factors and Frequency of Leak Occurrence for Fittings in Refinery Process Units. Interim Report. Radian Corporation. Austin, Texas. EPA Contract Number 68-02-2665. p. 11-49.
2. The Assessment of Environmental Emissions from Oil Refining. Draft Report, Appendix B. Radian Corporation. Austin, Texas. August 1979. pp. 3-5 through 3-16.
3. Erikson, D.G., and V. Kalcevic. Emissions Control Options for the Synthetic Organic Chemicals Manufacturing Industry. Draft Report. Hydrosience, Inc. Knoxville, Tennessee, EPA Contract Number 68-02-2577. p. IV-1,2.

4. Ref. 3, p. II-9-13.
5. Ref. 1, p. 11-23.
6. Ref. 3, p. II-10.
7. Ref. 3, p. IV-8.

7. ENVIRONMENTAL IMPACT

The environmental impacts that would result from implementing the regulatory alternatives being considered in this study are examined in this chapter. Included in this chapter are estimations of the controlled VOC fugitive emissions and the incremental reductions in uncontrolled VOC emissions that could be achieved under each of the alternatives. Also, the impacts of these regulatory alternatives on water quality, waste water generation and treatment, solid waste generation and treatment or disposal, and energy consumption or savings are discussed.

7.1 IMPACT ON ATMOSPHERIC EMISSIONS

Implementation of Regulatory Alternatives II, III, or IV, would reduce VOC fugitive emissions from the SOCM I. To quantify these reductions, the controlled VOC emission levels from emission sources in the model units (described in Chapter 6) were estimated for each alternative. These emission levels are developed below for individual emission sources, for model units in SOCM I, and then for SOCM I as a whole.

7.1.1 Emission Source Characterization

As indicated in Chapter 6, a SOCM I model unit typically consists of several types of process equipment that contribute to fugitive VOC emissions. Under Regulatory Alternative I (baseline case), all these sources are "uncontrolled" emission sources. However, if Regulatory Alternative II, III, or IV were implemented, the emissions from some uncontrolled sources would be reduced; these sources would subsequently become "controlled" sources. Both the controlled and uncontrolled sources are important because the total fugitive VOC emissions from the model units and ultimately the SOCM I are the sum of emissions from both types of sources.

7.1.2 Development of VOC Emission Levels

The uncontrolled emission levels were previously presented in Chapter 3 (Table 3-1). Controlled emission levels were developed for those sources that would be controlled by the implementation of a regulatory alternative. These controlled fugitive emission levels were calculated by multiplying the uncontrolled emissions from this equipment by a "control efficiency" presented in Chapter 4, Tables 4-2 through 4-4. The resulting controlled VOC emission factors for each source are presented in Tables 7-1, 7-2, and 7-3 for Regulatory Alternatives II, III, and IV, respectively.

The total VOC fugitive emissions from Model A, Model B, and Model C units in the SOCFI were determined under each regulatory alternative. Initially, emissions from each source type within a model unit were estimated by using the model unit equipment inventories presented in Table 6-1 and the source emission factors presented in Tables 7-1, 7-2, and 7-3. These emissions were then used to estimate the VOC fugitive emissions from each of the three model units. An example calculation is presented in Table 7-4 to illustrate the procedure used to estimate the total VOC fugitive emissions from a model unit under Regulatory Alternative II. The total VOC fugitive emissions calculated for the respective model units under each regulatory alternative are presented in Table 7-5. Also, presented in this table are the average percent reductions in the baseline emission levels that result from implementing Regulatory Alternative II, III, or IV. The incremental reductions in fugitive emission levels achieved by implementing the alternatives are also presented in Table 7-5.

7.1.3 Future Impact on VOC Fugitive Emissions

In order to assess the future impacts of the various regulatory alternatives on VOC fugitive emissions from the SOCFI, the levels of these emissions were estimated for a period of five years after adoption of a regulatory alternative. These emissions were estimated by using:

- 1) the emission factors presented in Tables 7-1, 7-2, and 7-3;
- 2) the industry population for the assumed base year of 1980;

TABLE 7-1. EMISSION FACTORS FOR SOURCES CONTROLLED UNDER REGULATORY ALTERNATIVE II

Uncontrolled emission source	Inspection ^a interval	Uncontrolled emission factor, kg/hr ^b	Correction factors				Control efficiency (AxBxCxD)	Controlled emission factor, kg/hr ^g
			A ^c	B ^d	C ^e	D ^f		
Pumps								
Light liquid service	Yearly	0.120	0.87	0.80	0.98	0.92	0.63	0.044
Valves								
Gas service	Quarterly	0.021	0.98	0.90	0.98	0.99	0.86	0.003
Light liquid service	Yearly	0.010	0.84	0.80	0.98	0.94	0.62	0.004
Safety/relief valves								
Gas service	Quarterly	0.160	0.69	0.90	0.98	0.97	0.59	0.067
Compressors	Quarterly	0.440	0.84	0.90	0.98	0.97	0.72	0.126

^aFrom Table 6-2.

^bFrom Table 3-1.

^cTheoretical maximum control efficiency.¹

^dLeak occurrence and reoccurrence correction factor - assumed to be 0.80 for yearly inspection, 0.90 for quarterly inspection, and 0.95 for monthly inspection.²

^eNon-instantaneous repair correction factor - for a 15-day maximum allowable repair time, the 7.5-day average repair time yields a 0.98 yearly correction factor $[365 - (15/2)] \div 365$.³

^fImperfect repair correction factor - calculated as $1 - (f \div F)$. Where f = average emission rate for sources at 1000 ppm and F = average rate for emission sources greater than 10,000 ppm.^{4,5}

^gControlled emission factor = uncontrolled emission factor $\times [1 - (A \times B \times C \times D)]$.

TABLE 7-2. EMISSION FACTORS FOR SOURCES CONTROLLED UNDER REGULATORY ALTERNATIVE III

Uncontrolled emission source	Inspection ^a interval	Uncontrolled ^b emission factor, kg/hr	Correction factors				Control efficiency (AxBxCxD)	Controlled ^g emission factor, kg/hr
			A ^c	B ^d	C ^e	D ^f		
Pumps								
Light liquid service	Monthly	0.120	0.87	0.95	0.98	0.92	0.75	0.030
Valves								
Gas service	Monthly	0.021	0.98	0.95	0.98	0.99	0.90	0.002
Light liquid service	Monthly	0.010	0.84	0.95	0.98	0.94	0.74	0.003
Safety/relief valves								
Gas service	Monthly	0.160	0.69	0.95	0.98	0.97	0.62	0.061
Compressors	Monthly	0.440	0.84	0.95	0.98	0.97	0.76	0.108

^aFrom Table 6-2.

^bFrom Table 3-1.

^cTheoretical maximum control efficiency.⁶

^dLeak occurrence and reoccurrence correction factor - assumed to be 0.80 for yearly inspection, 0.90 for quarterly inspection, and 0.95 for monthly inspection.

^eNon-instantaneous repair correction factor - for a 15-day maximum allowable repair time, the 7.5-day average repair time yields a 0.98 yearly correction factor $[365 - (15/2)] \div 365$.⁸

^fImperfect repair correction factor - calculated as $1 - (f \div F)$. Where f = average emission rate for sources at 1000 ppm and F = average rate for emission sources greater than 10,000 ppm.^{9,10}

^gControlled emission factor = uncontrolled emission factor $\times [1 - (A \times B \times C \times D)]$.

TABLE 7-3. EMISSION FACTORS FOR SOURCES CONTROLLED UNDER REGULATORY ALTERNATIVE IV

Uncontrolled emission source	Inspection ^a interval	Uncontrolled ^b emission factor, kg/hr	Correction factors				Control efficiency (AxBxCxD)	Controlled ^g emission factor, kg/hr
			A ^c	B ^d	C ^e	D ^f		
Pumps								
Light liquid service	None	0.120	NA ^h	NA	NA	NA	-	0.0
Valves								
Gas service	Monthly	0.021	0.98	0.95	0.98	0.99	0.90	0.002
Light liquid service	Monthly	0.010	0.84	0.95	0.98	0.94	0.74	0.003
Safety/relief valves								
Gas service	None	0.160	NA	NA	NA	NA	-	0.0
Compressors	None	0.440	NA	NA	NA	NA	-	0.0
Sampling connections	None	0.015	NA	NA	NA	NA	-	0.0

^aFrom Table 6-2.^bFrom Table 3-1.^cTheoretical maximum control efficiency.¹¹^dLeak occurrence and recurrence correction factor - assumed to be 0.80 for yearly inspection, 0.90 for quarterly inspection, and 0.95 for monthly inspection.¹²^eNon-instantaneous repair correction factor - for a 15-day maximum allowable repair time, the 7.5-day average repair time yields a 0.98 yearly correction factor $[365 - (15/2)] \div 365$.¹³^fImperfect repair correction factor - calculated as $1 - (f \div F)$. Where f = average emission rate for sources at 1000 ppm and F = average rate for emission sources greater than 10,000 ppm.^{14,15}^gControlled emission factor = uncontrolled emission factor $\times [1 - (A \times B \times C \times D)]$.^hSince the equipment associated with this regulatory alternative essentially eliminates fugitive emissions, these correction factors are not applicable.

TABLE 7-4. EXAMPLE CALCULATION OF VOC FUGITIVE EMISSIONS FROM MODEL UNIT A UNDER REGULATORY ALTERNATIVE II

	Number of sources in model unit ^a (N)	Emission factor, ^b kg/hr-source (E)	Emissions from sources, kg/hr (N x E)
Emission Source:^c			
Pumps			
Light liquid ^d single mechanical seal	5	0.044	0.220
Light liquid ^d double mechanical seal	3	0.044	0.132
Heavy liquid ^e single mechanical seal	5	0.020	0.100
Heavy liquid ^e packed seal	2	0.020	0.040
In-line valves			
Vapor service	90	0.003	0.270
Light liquid ^d service	84	0.004	0.336
Heavy liquid ^e service	84	0.0003	0.025
Safety/relief valves			
Vapor service	11	0.067	0.737
Light liquid ^d service	1	0.006	0.006
Heavy liquid ^e service	1	0.009	0.009
Open-ended valves ^f			
Vapor service	9	0.003	0.027
Light liquid ^d service	47	0.004	0.188
Heavy liquid ^e service	48	0.003	0.014
Compressors	1	0.126	0.126
Sampling connections	26	0.015	0.390
Flanges	600	0.0003	0.180
Total emissions			2.800

^aModel units are characterized in Table 6-1.

^bEmission factors from Tables 3-1 and 7-1.

^cSources in VOC service.

^dLight liquid service means that the fugitive emission source contains a liquid which has a vapor pressure equal to or greater than 0.3 kPa at 20°C.

^eHeavy liquid service means that the fugitive emission source contains a liquid which has a vapor pressure less than 0.3 kPa at 20°C.

^fOpen-ended valve factor is equivalent to the in-line valve factor because capping the open end is assumed to eliminate emissions from this source.

TABLE 7-5. ESTIMATED EMISSIONS AND EMISSION REDUCTIONS ON A MODEL UNIT BASIS^a

Regulatory Alternative	Estimated emissions, ^{b,c} (Mg/yr)			Average percent reduction from emissions estimated under Regulatory Alternative I	Average incremental percent reduction in emissions
	Model unit				
	A	B	C		
I	67	260	800	--	--
II	24	94	290	63	63
III	21	80	250	69	6
IV	8	34	106	87	18

^aThe emissions and percentage reductions presented in this table were calculated using the following:

- controlled and uncontrolled emission factors (see Tables 7-1, 7-2, and 7-3), and
- emission sources given in Table 6-1.

^bA year is assumed to be equivalent to 8,760 hours.

^c1.0 Mg/yr = 2200 pounds/yr

3) annual replacement of the industry population based on a twenty-year equipment life¹⁶; and

4) annual growth rate of 5.9 percent for the industry.¹⁷

Using these bases and the techniques presented in Appendix E, the total number of affected facilities (model units) in operation in 1981 were estimated to be 148. In 1985 the total number of affected facilities were estimated to be 831.¹⁸

Under Regulatory Alternative I, the total VOC fugitive emissions from affected facilities were estimated to increase from 35 to 199 gigagrams per year (Gg/yr) during the same five-year (1981-1985) period (see Table 7-6). In the same time period, implementation of Regulatory Alternative II could be expected to reduce the baseline case (Regulatory Alternative I) fugitive emissions 65 percent. Implementation of Regulatory Alternative III would reduce the baseline emissions by 69 percent. As Table 7-5 indicates, Regulatory Alternative IV, the most stringent of all the proposed alternatives, would reduce the baseline emissions by about 87 percent.

7.2 IMPACT ON WATER QUALITY

In the absence of standards to reduce fugitive emissions of VOC from SOCFI and under normal equipment operation, liquid leaks from various equipment components could increase the quantity of wastewater generated by a "typical" SOCFI facility. Under Regulatory Alternative I, liquid leaks could originate from pumps and process valves in light or heavy liquid service as well as valves on open-ended lines in light or heavy liquid service and enter the wastewater system as runoff. Although the uncontrolled emission rates for these sources are given in Chapter 3, the gas-liquid split of these emissions is not defined. Consequently, the increase in wastewater from SOCFI due to liquid leaks from potential fugitive emission sources cannot be quantified.

Implementation of Regulatory Alternative II could reduce the wastewater from a "typical" SOCFI facility by reducing the fugitive liquid emissions resulting under Alternative I. The reduced emissions would be due to the use of caps, plugs or second valves on open-ended lines in gas and light or heavy liquid service. For example, caps, plugs, or second valves required

under Alternative II would reduce the VOC fugitive emission rate from open-ended lines in light or heavy liquid service from 0.01 kg/hr under Alternative I to 0.004 kg/hr. This reduction would reflect a reduction in gaseous emissions and liquid leaks. Since the gas-liquid split of the emission from a given source is site specific, the impact of Alternative II on wastewater from SOCMIs cannot be quantified. However, it is likely that this impact would be minor.

Implementation of Alternative III would result in impacts on wastewater from SOCMIs similar to those resulting from Alternative II. However, the impacts under Alternative III would be more pronounced due to the more frequent inspection intervals required by this alternative. The more frequent intervals would reduce the VOC fugitive emission rate from values in light or heavy liquid service from 0.004 kg/hr under Alternative II to 0.003 kg/yr under Alternative III. Similarly, the fugitive emission rate from pumps in light liquid service would be 0.044 kg/hr under Alternative II and 0.03 kg/hr under Alternative III. Consequently, the potential for wastewater production by possible fugitive emission sources in SOCMIs would be less under Alternative III than under Alternative II.

Of the alternatives being considered, Regulatory Alternative IV could have the greatest impact on the quality of water that is discharged from a "typical" SOCM facility. Implementation of this alternative could have positive (and possibly some negative) impacts on wastewater depending on the specific control device requirements at each unit. Implementation of Regulatory Alternative IV could reduce the amount of wastewater from a SOCM facility by reducing the fugitive liquid emissions resulting under Alternative I. The reduction of these emission levels is primarily due to the reduction of leaks from equipment in light liquid service, e.g., from the use of double mechanical seals for pumps and closed loop sampling. Under Regulatory Alternative IV, a double mechanical seal-degassing vent arrangement reduces the emission rate of a pump seal in light liquid service under Regulatory Alternative I from 0.12 to 0.0 kg/hr. A portion of this emission reduction would be a reduction in liquids leaked to the ground or ditch. However, the amount of liquids leaked to the ground or ditch that could enter a plant wastewater system is not known.

TABLE 7-6. TOTAL VOC FUGITIVE EMISSIONS FROM AFFECTED MODEL UNITS
FOR REGULATORY ALTERNATIVES

Year	Number of affected model units ^a			Total fugitive emissions estimated under Regulatory Alternative ^{b,c}			
	A	B	C	I (Gg/yr)	II (Gg/yr)	III (Gg/yr)	IV (Gg/yr)
1981	77	49	22	35.4	12.9	11.0	4.6
1982	158	100	46	73.1	26.7	22.8	9.5
1983	244	155	71	113.0	41.2	35.2	14.8
1984	335	213	97	155	56.5	48.3	20.2
1985	432	274	125	199	72.8	62.1	26.0

^aThe bases for estimating the number of model units, as detailed in Appendix E, are:

- an industry growth rate of 5.9 percent per year,
- unit replacement based on a 20-year equipment life, and
- a base year (1980) total of 872 Model A, 554 Model B, and 252 Model C Units.

^bEstimated total VOC fugitive emissions from Model Units A, B, and C.

^cDoes not include emissions from units in existence prior to 1981.

Implementation of Regulatory Alternative IV could also result in a negative impact on water quality due to the operation of an ultimate control device which "captures" the fugitive VOC's. If a carbon adsorption device were used to capture any VOC released at the degassing vent, a wastewater containing suspended solids and some dissolved organics could be produced during the carbon regeneration process if the carbon is regenerated at the unit. The use of a refrigeration process as the ultimate control device could possibly result in a condensate containing dissolved organics. The wastewater flow rates would be quite small and would generally be suitable for treatment in the existing unit wastewater treatment process. Overall the impacts, both positive and negative, of Alternative IV on wastewaters from SOCM I would be minor.

7.3 IMPACT ON SOLID WASTE

In the absence of standards to reduce fugitive emissions of VOC from SOCM I and under normal operation, solid wastes that could result from SOCM I include replaced seals, packing, rupture disks, equipment components such as pumps and valves, spent catalysts, and polymerization products. Metal solid wastes such as mechanical seals, rupture disks and disposed valves can be sold as scrap metal to companies which can recycle the metal. This would help to minimize the impact on solid waste. The quantity of used valve packings and used batteries for monitoring instruments would not significantly contribute to solid waste.

Implementation of Alternatives II and III would require the use of caps, plugs, or second valves on open-ended lines in light or heavy liquid service, and more frequent monitoring intervals. Implementing either of these alternatives would have no greater impact on solid waste than Alternative I. This is due to the relatively long life of caps, plugs, and second valves on open-ended lines as well as the ability to sell discarded components such as valves, mechanical seals, and rupture disks as scrap metal.

Implementation of Regulatory Alternative IV could result in the generation of solid waste if carbon adsorption were used as a control device and the carbon disposed of instead of being regenerated. However, the carbon could be sent back to the manufacturer for regeneration, and thereby reducing the solid waste problem at the facility. It is anticipated that the manufacturer could incinerate or commercially dispose of

any carbon that could not be regenerated (such as carbon fines) without any serious environmental problems. Consequently, the negative impact of implementing Alternative IV would be minor.

7.4 ENERGY IMPACT

Regulatory Alternatives II, III and IV call for passive controls on equipment handling VOC streams (i.e., pump seals, process vent enclosures, degassing vents, etc.); so implementing any of these alternatives will not significantly increase the energy usage of a typical SOCFI plant. If a control device such as carbon adsorption were used, steam (or another hot regenerating medium) would be needed to regenerate the carbon at the unit; however, the energy requirements would be quite small. The energy requirements of vapor recovery systems and of closed loop sampling would also be small. Because fugitive emissions of VOC have an energy value, implementation of any of the alternatives being considered will result in a positive energy impact.

The average energy value of the fugitive VOC emissions from SOCFI is estimated to be approximately 31×10^6 joule/kg.¹⁹ The energy savings resulting from the fugitive VOC emission reductions associated with Alternatives II, III, and IV are presented in Table 7-7. Because Alternative IV is the most stringent, it will result in the greatest emission reduction. As Table 7-7 indicates, implementation of this regulatory alternative would reduce the uncontrolled fugitive emissions by 173 Gg in the fifth year and by a total of 520 Gg over a five-year period after implementation. These "recovered" VOC emissions have a total energy value of 1.55×10^{13} joules based on an average heating value of 31×10^6 joule/kg. Assuming an energy value of 5.8×10^6 Btu per barrel of crude oil,²⁰ the energy value of the total fugitive emissions recovered over the five-year period is approximately equal to 2.5 million barrels of crude oil under Regulatory Alternative IV. This corresponds to an average daily savings of 1390 bbl/day of crude oil over the five-year period.

TABLE 7-7. ENERGY IMPACT OF EMISSION REDUCTIONS FOR REGULATORY ALTERNATIVES

Year	Reduction from baseline emissions under Regulatory Alternatives, Gg ^a			Energy value of emission reductions under Regulatory Alternatives, terajoule ^b			Crude oil equivalent of emission reductions, thousand barrels		
	II	III	IV	II	III	IV	II ^c	III ^c	IV ^c
1981	22.4	24.4	30.8	694	756	955	113	124	156
1982	46.4	50.3	63.6	1,440	1,560	1,970	235	255	322
1983	71.8	77.8	98.2	2,230	2,410	3,040	364	394	497
1984	98.3	106	135	3,050	3,290	4,180	498	538	683
1985	127	137	173	3,940	4,250	5,360	644	695	876
5-year total	366	396	500	11,350	12,270	15,500	1,855	2,005	2,530

^aEstimated total VOC fugitive emission reduction from Model Units A, B, and C.

^bBased on 1.55×10^{13} joules/kg²¹: This may be slightly over estimated if safety/relief valves are controlled by a closed vent and flare system.

^cBased on 5.8×10^6 Btu/bbl crude oil.

7.5 OTHER ENVIRONMENTAL CONCERNS

7.5.1 Irreversible and Irretrievable Commitment of Resources

Implementation of any of the various alternatives is not expected to result in any irreversible or irretrievable commitment of resources. As previously noted, the regulatory alternatives should help to save resources due to the energy savings associated with the reductions in emissions.

7.5.2 Environmental Impact of Delayed Standards

As it was indicated above, implementation of the standards will only have minor impacts on water and solid wastes. Consequently, delaying the standards would have essentially no impact on these problems. However, a delay in implementing the alternatives would have a greater impact on air pollution and associated energy losses. The air and energy impacts of delayed standards are shown in Table 7-7. The emission reductions and associated energy savings shown would be irretrievably lost at the rates shown for each of the five years.

7.6 REFERENCES

1. Wetherold, R. G., L. P. Provost, D. D. Rosebrook, and C. D. Smith. Emission Factors and Frequency of Leak Occurrence for Fittings in Refinery Process Units. EPA Contract No. 68-02-2665, 600/2-79-44.
2. Tichenor, B. A., K. C. Hustvedt, and R. C. Weber. Controlling Petroleum Refinery Fugitive Emissions Via Leak Detection and Repair. Draft. Symposium on Atmospheric Emissions from Petroleum Refineries, Austin, Texas.
3. Ref. 2.
4. Ref. 1.
5. Ref. 2.
6. Ref. 1.
7. Ref. 2.
8. Ref. 2.
9. Ref. 1.

10. Ref. 2.
11. Ref. 1.
12. Ref. 2.
13. Ref. 2.
14. Ref. 1.
15. Ref. 2.
16. Letter from Charles A. Muela, Radian Corporation, to K. C. Hustvedt, EPA Office of Air Quality Planning and Standards. May 11, 1979. Replacement Rate of Process Unit in the Organic Chemical Industry.
17. The American Economy, Prospects for Growth to 1991. New York: McGraw-Hill, 1979.
18. Letter from Vincent Smith, Research Triangle Institute, to Russell L. Honerkamp, Radian Corporation. November 30, 1979. Projected Number of Affected Facilities and Average Product Value in SOCFI.
19. Memo from J. R. Blacksmith, Radian Corporation, to K. C. Hustvedt, EPA. December 14, 1979. Average Energy Value of SOCFI Chemicals.
20. American Petroleum Institute. Petroleum Facts and Figures. Washington, D.C. 1971.
21. Ref. 19.

8. COST ANALYSIS

8.1 COST ANALYSIS OF REGULATORY ALTERNATIVES

8.1.1 Introduction

The costs of implementing the regulatory alternatives for controlling fugitive emissions of volatile organic compounds (VOC) from the synthetic organic chemicals manufacturing industry (SOCMI) are presented in the following sections. A detailed description of the model units and regulatory alternatives being considered in this analysis is presented in Chapter 6. Three different model units (A, B, and C) have been chosen to represent the range of emission source populations that exist in SOCMI units. Regulatory Alternative I (no controls) is used as the baseline, and Regulatory Alternatives II, III, and IV are increasingly restrictive control alternatives.

8.1.2 New Facilities

8.1.2.1 Capital Costs. The bases for the capital costs for the model units are presented in Table 8-1. The capital cost estimates for each model unit under each regulatory alternative are given in Table 8-2. Regulatory Alternative I requires no control of VOC emissions. Consequently, there are no capital costs associated with this alternative.

The capital costs for the model units are the same under Regulatory Alternative II as under Regulatory Alternative III, since the only change is the monitoring frequency. These costs reflect the purchase of two VOC monitoring instruments and caps for all open-ended lines. It is assumed that one monitoring instrument is used as a standby spare.

Under Regulatory Alternative IV, like II and III, two monitoring instruments and caps for all open-ended lines are purchased. In addition, there are several other capital expenditures. All single seal pumps in

TABLE 8-1. CAPITAL COST DATA

Item	Value used in analysis (last quarter 1978 \$)
1. Monitoring instrument	2 x 4250 = 8500/model unit ^a
2. Caps for open-ended lines	45/line ^b
3. Double mechanical seals	575/pump (new) ^c 850/pump (retrofit) ^d
4. Flush oil system for double mechanical seals	1500/pump ^{e,f}
5. Closed vents for degassing reservoirs of compressors and double seal pumps	6530/compressor ^g 3265/pump ^{g,h}
6. Rupture disks for relief valves	1730/relief valve (new) ⁱ 3110/relief valve (retrofit) ^j
7. Closed loop sampling connections	460/sample connection ^k

^aOne instrument used as a spare (Ref. 1). Cost from Ref. 2.

^bBased on installation of a 2.5 cm. screwed valve. Cost (1967) = \$12 (Ref. 3, p. 450).
Cost index = 278.1 ÷ 113 (Ref. 4 and 5). Installation = 1 hour at \$15/hour (Ref. 6, 7, 8).

^cFrom Ref. 6, p. IV-3. Seal cost = \$560. Single seal credit = \$225. Shop installation = \$240.

^dFrom Ref. 10, p. IV-3. Seal cost = \$560. Field installation = \$290.

^eFrom Ref. 11, p. IV-3. Pressurized reservoir system = \$700. Flush system cooler = \$800.

^fPumps that have double mechanical seals without regulatory requirement may not have the cost of a flush system added. The flush system is assumed to be an integral part of the double seal system.

^gFrom Ref. 12, pp. IV-8, 9. Based on installation of a 122 m. length of 5.1 cm. diameter, schedule 40 carbon steel pipe at a cost of \$5200; plus three 5.1 cm. cast steel plug valves and one metal gauze flame arrestor at a cost of \$1330. These costs include connection of the degassing reservoir to an existing enclosed combustion device or vapor recovery header. Cost of a control device added specifically to control the degassing vents is, therefore, not included.

^hThis cost is based on the assumption that two pumps (such as a pump and its spare) are connected to a single degassing vent.

ⁱCost of rupture disk assembly from Ref. 13, p. IV-8. One 7.6 cm. rupture disk, stainless steel = \$195. One 7.6 cm. rupture disk holder, carbon steel = \$325. One 0.6 cm. pressure gauge, dial face = \$15. One 0.6 cm. bleed valve, carbon steel, gate = \$25. Installation = \$240. In order to allow in-service disk replacement, a block valve must be installed upstream of the rupture disk. Cost (1967) from Ref. 14, p. 451, for one 7.6 cm. gate valve = \$240. Cost index = 278.1 ÷ 113 (Ref. 15 and 16). Installation = 10 hours at \$15/hour (Ref. 17, 18, 19). In order to prevent damage to the relief valve by disk fragments, an offset mounting is required. Cost (1967) from Ref. 20, p. 450 for one 10.2 cm. tee and one 10.2 cm. elbow = \$7.30. Cost index = 278.1 ÷ 113 (Ref. 21 and 22). Installation = 8 hours at \$15/hour (Ref. 23, 24, 25).

^jCosts for the rupture disk, holder, and block valve are the same as for the new applications. An additional cost is added to replace the de-rated relief valve. No credit is assumed for the used relief valve. Cost (1967) for one 7.6 cm. pressure reducing valve, stainless steel body and trim from Ref. 3, p. 452 = \$500. Cost index = 278.1 ÷ 113 (Ref. 26 and 27). Installation = 10 hours at \$15/hour (Ref. 28, 29, 30).

^kBased on installation of a 6 m. length of 2.5 cm. diameter, schedule 40, carbon steel pipe and three 2.5 cm. carbon steel ball valves. Costs from Ref. 31, p. IV-8. Installation = 18 hours at \$15/hour.

TABLE 8-2. CAPITAL COST ESTIMATES FOR NEW MODEL UNITS
(thousands of last quarter 1978 dollars)

Capital cost item ^a	Regulatory alternative			
	I	II	III	IV
Model Unit A				
1. Monitoring instrument		8.50	8.50	8.50
2. Caps for open-ended lines		4.68	4.68	4.68
3. Double mechanical seals				
• Seals				1.68
• Installation				1.20
4. Flush oil system for double mech. seals				7.5
5. Vents for compressor degassing reservoirs				6.53
6. Vents for pump degassing reservoirs				26.1
7. Rupture disks for relief valves				
• Disks				2.14
• Holders, block valves, installation				16.8
8. Closed loop sampling connections				12.0
Total	0.0	13.2	13.2	87.1
Model Unit B				
1. Monitoring instrument		8.50	8.50	8.50
2. Caps for open-ended lines		18.7	18.7	18.7
3. Double mechanical seals				
• Seals				6.36
• Installation				4.56
4. Flush oil system for double mech. seals				28.5
5. Vents for compressor degassing reservoirs				13.1
6. Vents for pump degassing reservoirs				94.7
7. Rupture disks for relief valves				
• Disks				8.19
• Holders, block valves, installation				64.4
8. Closed loop sampling connections				47.8
Total	0.0	27.2	27.2	295
Model Unit C				
1. Monitoring instrument		8.50	8.50	8.50
2. Caps for open-ended lines		57.5	57.5	57.5
3. Double mechanical seals				
• Seals				20.1
• Installation				14.4
4. Flush oil system for double mech. seals				90.0
5. Vents for compressor degassing reservoirs				52.2
6. Vents for pump degassing reservoirs				297
7. Rupture disks for relief valves				
• Disks				25.4
• Holders, block valves, installation				199
8. Closed loop sampling connections				147
Total	0.0	66.0	66.0	911

^aFrom Tables 6-1 and 8-1.

light liquid service must have double mechanical seals installed. This is at a cost of \$575/pump. A flush oil system (\$1500/pump) must also be used in conjunction with the double mechanical seals. Existing pumps with double mechanical seals are assumed to have a flush oil system already incorporated. Hence, there is no additional capital expenditure for the double seals or flush system.

Also, under Regulatory Alternative IV, compressor seals and pump seals must have the seal oil degassing vents that are connected to a control device such as a vapor recovery system or an enclosed combustion device. The cost is estimated to be \$6530 per compressor and \$3265 per pump. This cost is based on the assumption that one closed vent system is required for each compressor. Since main pumps and spares are generally located in close proximity to each other, one closed vent system is required for each pair of pumps. These costs are based on connecting the closed vent system to an existing control device.

The costs of purchasing and installing rupture disks is \$1590 per relief valve. The rupture disks are to be installed upstream of relief valves in gas service. The cost includes the purchase of a shutoff valve to allow the disk to be replaced after overpressure relief.

The closed loop sampling connection costs are based on an estimate of \$460 per sampling connection for installation of 6m. of pipe and three valves.

8.1.2.2 Annual Costs. With the implementation of Regulatory Alternatives II, III, or IV, visual and/or instrument monitoring of potential sources of fugitive VOC emissions will be required. A summary of the requirements for the different alternatives is presented in Chapter 6. Tables 8-3, 8-4, and 8-5 give the monitoring labor-hour requirements for Regulatory Alternatives II, III and IV, respectively. The labor-hour requirements are calculated by taking the product of the number of workers needed to monitor a component (1 for visual, 2 for instrument), the time required to monitor, the number of components in the model unit, and the number of times the component is monitored per year. Monitoring labor costs are then calculated based on \$15 per hour.^{32,33,34} Regulatory Alternative III has the highest annual monitoring costs.

TABLE 8-3. ANNUAL MONITORING AND LEAK REPAIR LABOR REQUIREMENTS
FOR REGULATORY ALTERNATIVE II

Source type	Monitoring									Leak repair						
	Number of components per model unit			Type of ^a monitoring	Monitoring time, ^b min	Times monitored per year	Monitoring labor-hours required ^c			Estimated number of leaks per year ^d			Repair time, hrs	Leak repair labor-hours required ^e		
	A	B	C				A	B	C	A	B	C		A	B	C
Pumps (light liquid)																
Single mechanical seals	5	19	60	Instrument Visual	5 0.5	1 52	1.0 2.2	3.2 8.2	10.0 26.0	1	1	3	80 ^b	80	80	240
Double mechanical seals	3	10	31	Instrument Visual	5 0.5	1 52	1.0 1.3	1.7 4.3	5.2 13.4	1	1	2	80 ^b	80	80	160
Valves (in-line)																
Gas	90	365	1117	Instrument	1	4	12.0	49.0	149.0	4	15	45	1.13 ^f	4.5	17.0	50.9
Light liquid	84	335	1037	Instrument	1	1	2.8	11.2	34.6	3	9	25	1.13 ^f	3.4	10.2	28.3
Safety/relief valves (gas service)	11	42	130	Instrument	8	4	11.7	44.8	139.0				0 ^g	0	0	0
Valves on open-ended lines ^h																
Gas	9	37	115	Instrument	1	4	1.2	4.9	15.3	1	2	5	1.13 ^e	1.1	2.3	5.7
Light liquid	47	189	581	Instrument	1	1	1.6	6.3	19.4	2	6	14	1.13 ^e	2.3	6.8	15.8
Compressor seals	1	2	8	Instrument	10	4	1.3	2.7	10.7	1	1	2	40 ^b	40	40	80

^a2 workers for instrument monitoring, 1 for visual. Ref. 35, p. 4-3.

^bRef. 36.

^cMonitoring labor-hours = number of workers a number of components a time to monitor (total is minimum of 1 hr).

^dFrom Table 4-2.

^eLeak repair labor-hours = number of leaks x repair time.

^fWeighted average based on 75 percent of the leaks repaired on-line, requiring 0.17 hour per repair, and on 25 percent of the leaks repaired off-line, requiring 4 hours per repair. Ref. 37, p. 8-12.

^gIt is assumed that these leaks are corrected by routine maintenance at no additional labor requirements. Ref. 38.

^hThe estimated number of leaks per year for open-ended valves is based on the same percent of sources used for in-line valves. This represents leaks occurring through the stem and gland of the open-ended valve. Leaks through the seat of the valve are eliminated by adding caps for Regulatory Alternatives II, III, IV.

TABLE 8-4. ANNUAL MONITORING AND LEAK REPAIR LABOR REQUIREMENTS
FOR REGULATORY ALTERNATIVE III.

Source type	Monitoring									Leak repair						
	Number of components per model unit			Type of ^a monitoring	Monitoring time, ^b min	Times monitored per year	Monitoring labor-hours required ^c			Estimated number of leaks per year ^d			Repair time, hrs	Leak repair labor-hours required ^e		
	A	B	C				A	B	C	A	B	C		A	B	C
Pumps (light liquid)																
Single mechanical seals	5	19	60	Instrument Visual	5 0.5	12 52	10.0 2.2	38.0 8.2	120.0 26.0	1	3	9	80 ^b	80	240	720
Double mechanical seals	3	10	31	Instrument Visual	5 0.5	12 52	6.0 1.3	20.0 4.3	62.0 13.4	1	2	5	80 ^b	80	160	400
Valves (in-line)																
Gas	90	365	1117	Instrument	1	12	36.0	146.0	446.8	6	22	68	1.13 ^f	6.8	24.9	76.8
Light liquid	84	335	1037	Instrument	1	12	33.6	134.0	414.8	7	25	75	1.13 ^f	7.9	28.3	84.8
Safety/relief valves (gas service)	11	42	130	Instrument	8	12	35.2	134.4	416.0				0 ^g	0	0	0
Valves on open-ended lines ^h																
Gas	9	37	115	Instrument	1	12	3.6	14.8	46.0	1	3	7	1.13 ^e	1.1	3.4	7.9
Light liquid	47	189	581	Instrument	1	12	18.8	75.6	232.4	4	14	42	1.13 ^e	4.5	15.8	47.5
Compressor seals	1	2	8	Instrument	10	12	4.0	8.0	32.0	1	1	2	40 ^b	40	40	80

^a2 workers for instrument monitoring, 1 for visual. Ref. 39.

^bRef. 40.

^cMonitoring labor-hours = number of workers x number of components x time to monitor (total is minimum of 1 hr).

^dFrom Table 4-2.

^eLeak repair labor-hours = number of leaks x repair time.

^fWeighted average based on 75 percent of the leaks repaired on-line, requiring 0.17 hour per repair, and on 25 percent of the leaks repaired off-line, requiring 4 hours per repair. Ref. 41.

^gIt is assumed that these leaks are corrected by routine maintenance at no additional labor requirements. Ref. 42.

^hThe estimated number of leaks per year for open-ended valves is based on the same percent of sources used for in-line valves. This represents leaks occurring through the stem and gland of the open-ended valve. Leaks through the seat of the valve are eliminated by adding caps for Regulatory Alternatives II, III, IV.

TABLE 8-5. ANNUAL MONITORING AND LEAK REPAIR LABOR REQUIREMENTS FOR REGULATORY ALTERNATIVE IV.

Source type	Monitoring									Leak repair						
	Number of components per model unit			Type of ^a monitoring	Monitoring time, ^b min	Times monitored per year	Monitoring labor-hours required ^c			Estimated number of leaks per year ^d			Repair time, hrs	Leak repair labor-hours required ^e		
	A	B	C				A	B	C	A	B	C		A	B	C
Pumps (light liquid)																
Single mechanical seals converted to double seals	5	19	60	Instrument	5	0 ^f	0	0	0	0 ^f	0 ^f	0 ^f	80 ^b	0	0	0
Double mechanical seals	3	10	31	Instrument	5	0 ^f	0	0	0	0 ^f	0 ^f	0 ^f	80 ^b	0	0	0
				Visual	0.5	52	2.2	8.2	26.0							
				Visual	0.5	52	1.3	4.3	13.4							
Valves (in-line)																
Gas	90	365	1117	Instrument	1	12	36.0	146.0	446.8	6	22	68	1.13 ^g	6.8	24.9	76.8
Light liquid	84	335	1037	Instrument	1	12	33.6	134.0	414.8	7	25	75	1.13 ^g	7.9	28.3	84.8
Safety/relief valves (gas service)	11	42	130	Instrument	8	0 ^f	0	0	0	0 ^f	0 ^f	0 ^f	0 ^{f, h}	0	0	0
Valves on open-ended lines ⁱ																
Gas	9	37	115	Instrument	1	12	3.6	14.8	46.0	1	3	7	1.13 ^g	1.1	3.4	7.9
Light liquid	47	189	581	Instrument	1	12	18.8	75.6	232.4	4	14	42	1.13 ^g	4.5	15.8	47.5
Compressor seals	1	2	8	Instrument	10	0 ^f	0	0	0	0 ^f	0 ^f	0 ^f	40 ^b	0	0	0

^a2 workers for instrument monitoring, 1 for visual. Ref. 43.

^bRef. 44.

^cMonitoring labor-hours = number of workers a number of components x time to monitor (total is a minimum of 1 hr).

^dFrom Table 4-2.

^eLeak repair labor-hours = number of leaks x repair time.

^fNo monitoring or leak repair required because equipment specifications eliminate leak potential.

^gWeighted average based on 75 percent of the leaks repaired on-line, requiring 0.17 hour per repair, and on 25 percent of the leaks repaired off-line, requiring 4 hours per repair. Ref. 45.

^hIt is assumed that these leaks are corrected by routine maintenance at no additional labor requirements. Ref. 46.

ⁱThe estimated number of leaks per year for open-ended valves is based on the same percent of sources used for in-line valves. This represents leaks occurring through the stem and gland of the open-ended valve. Leaks through the seat of the valve are eliminated by adding caps for Regulatory Alternatives II, III, IV.

Leak repair labor is the cost of repairing those components in which leaks develop after initial repair. The leaks are discovered during the periodic monitoring required by the regulatory alternatives. The number of estimated leaks and the labor hours required for repair are given in Tables 8-3, 8-4, and 8-5. Leak repair labor is calculated based on \$15 per hour.^{47, 48, 49} Maintenance labor costs are greatest under Regulatory Alternative III and least under Alternative IV. The costs are reduced under Alternative IV because the required installation of double mechanical seals with seal oil degassing vents eliminates the most time-consuming repair items.

Administrative and support costs are estimated at 40 percent of the sum of monitoring and leak repair labor costs. Monitoring labor, leak repair labor, and administrative/support costs are the recurring annual costs for each Regulatory Alternative.

8.1.2.3 Annualized Costs. The bases for the annualized control costs are presented in Table 8-6. The annualized capital, maintenance, and miscellaneous costs are calculated by taking the appropriate factor from Table 8-6 and applying it to the corresponding capital cost from Table 8-2. The capital recovery factors were calculated using the equation:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

where i = interest rate, expressed as a decimal,

n = economic life of the component, years.

The interest rate used was 10 percent (last quarter 1978). The expected life of the monitoring instrument is 6 years compared to 10 years for other control equipment components. Double seals and rupture disks are assumed to have a 2 year life.

The implementation of any of the Regulatory Alternatives (except I) will result in the initial discovery of leaking components. It is estimated that fewer leaks will be found at subsequent inspections. The cost of repairing initial leaks is amortized over a 10-year period, since this is a one-time cost. Repair of leaks found at subsequent inspections is included as a recurring annual cost in 8.1.2.2. The estimated

TABLE 8-6. DERIVATION OF ANNUALIZED LABOR, ADMINISTRATIVE, MAINTENANCE AND CAPITAL CHARGES

1. Capital recovery factor for capital charges	
• Double seals and rupture disks	$0.58 \times \text{capital}^a$
• Other control equipment	$0.163 \times \text{capital}^b$
• Monitoring instruments	$0.23 \times \text{capital}^c$
2. Annual maintenance charges	
• Control equipment	$0.05 \times \text{capital}^d$
• Monitoring instruments	\$2700 ^e
3. Annual miscellaneous charges (taxes, insurance, administration)	
• Control equipment	$0.04 \times \text{capital}^f$
• Monitoring instruments	$0.04 \times \text{capital}^f$
4. Labor charges	\$15/hour ^g
5. Administrative and support costs to implement regulatory alternative	$0.4 \times (\text{monitoring labor} + \text{maintenance labor})^h$
6. Annualized charge for initial leak repairs	$\Sigma(\text{estimated number of leaking components per model unit}^i \times \text{repair time}^i) \times \$15/\text{hr}^g \times 1.4^h \times 0.163^j$

^aApplies to cost of seals (\$335) and disk (\$195) only. Two year life, ten percent interest.

^bTen year life, ten percent interest. From Ref. 50, pp. IV-3,4.

^cSix year life, ten percent interest. From Ref. 51, pp. IV-9,10.

^dFrom Ref. 52, pp. IV-3,4.

^eIncludes materials and labor for maintenance and calibration. Cost (last quarter 1977) from Ref. 53, p. 4-2. Cost index = $221.7 \div 209.1$ (Ref. 54 and 55).

^fFrom Ref. 56, pp. IV-3,4,9,10.

^gIncludes wages plus 40 percent for labor-related administrative and overhead costs. Cost (last quarter 1977) from Ref. 6, pp. 4-4,5. Cost index = $190.3 \div 180.9$ (Ref. 58 and 59).

^hFrom Ref. 60, pp. IV-9,10.

ⁱShown in Tables 8-18, 8-19, 8-20.

^jInitial leak repair amortized for ten years at ten percent interest.

percentage of initial leaks per component is shown in Table 4-2. This percentage is applied to the number of components in the model unit under consideration. Fractions are rounded up to the next integer, since in practice it is the whole valve, or seal, that is replaced and not just part of one. The time required to repair each component type is given in Table 8-7. The initial repair cost is determined by taking the product of the number of initial leaks, the repair time, and the labor rate, \$15 per hour.^{61, 62, 63} Forty percent is added for administrative and support costs. Finally, the total is multiplied by 0.163, the capital recovery factor. As shown in Table 8-7, the cost of initial leak repair under Regulatory Alternative IV is substantially less for each of the model units than under Alternatives II and III. The main reason for this reduction is the required installation of double mechanical seals and seal oil degassing vents that reduce the leak potential of pumps and compressors. Although the total number of pumps and compressors is not great, the repair time for a single pump or compressor seal is very much greater than the repair time for a valve.

8.1.2.4 Recovery Credits. The annual VOC emissions, total emission reductions, and annual recovered product credits for each model unit under each Regulatory Alternative are shown in Table 8-8. Regulatory Alternative I represents the uncontrolled emissions from each model unit. The annual emission reduction is calculated by subtracting the controlled emission factor from the uncontrolled emission factor for each source. To obtain an annual rate, the result is multiplied by 8760 hours per year. The recovery credit is figured at \$360 per Mg of recovered product.⁶⁴

8.1.2.5 Net Annualized Costs. The net annualized costs, shown in Tables 8-9, 8-10, and 8-11, are determined by subtracting the annual recovered product credit from the total cost before credit. For example, Model Unit A, under Regulatory Alternative II has a net annualized credit of \$3300, as a result of \$12,100 in costs and \$15,400 for recovery credits.

8.1.2.6 Cost Effectiveness. The cost effectiveness of each regulatory alternative for each model unit is shown in Table 8-12. Regulatory Alternatives II and III have a net annualized credit for all model units, and cost effectiveness numbers are negative. Since Regulatory Alternative

TABLE 8-7. LABOR-HOUR REQUIREMENTS FOR INITIAL LEAK REPAIR

Source type	Number of components per model unit			Regulatory alternative II					Regulatory alternative III					Regulatory alternative IV										
				Estimated number of initial leaks ^b			Repair time, hrs	Labor-hours required		Estimated number of initial leaks ^b			Repair time, hrs	Labor-hours required		Estimated number of initial leaks ^b			Repair time, hrs	Labor-hours required				
	A	B	C	A	B	C		A	B	C	A	B		C	A	B	C	A		B	C			
Pumps (light liquid)																								
Single mechanical seal	5	19	60	2	5	14	80 ^C	160	400	1120	2	5	14	80 ^C	160	400	1120	0 ^e	0 ^e	0 ^e	80 ^C	0	0	0
Double mechanical seal	3	10	31	1	3	8	80 ^C	80	240	640	1	3	8	80 ^C	80	240	640	0 ^e	0 ^e	0 ^e	80 ^C	0	0	0
Valves (in-line)																								
Gas	90	365	1117	9	37	112	1.13 ^d	10	42	127	9	37	112	1.13 ^d	10	42	127	9	37	112	1.13 ^d	10	42	127
Light liquid	84	335	1037	11	41	125	1.13 ^d	12	46	141	11	41	125	1.13 ^d	12	46	141	11	41	125	1.13 ^d	12	46	141
Safety/relief valves ^a (gas service)	11	42	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 ^e	0 ^e	0 ^e	0	0	0	0
Valves on open-ended lines ^f																								
Gas	9	37	115	1	4	12	1.13 ^d	1	5	14	1	4	12	1.13 ^d	1	5	14	1	4	12	1.13 ^d	1	5	14
Light liquid	47	189	581	6	23	70	1.13 ^d	7	26	79	6	23	70	1.13 ^d	7	26	79	6	23	70	1.13 ^d	7	26	79
Compressor seals	1	2	8	1	1	3	40 ^C	40	40	120	1	1	3	40 ^C	40	40	120	0 ^e	0 ^e	0 ^e	40 ^C	0	0	0

^aIt is assumed that these leaks are corrected by routine maintenance at no additional labor requirements. Ref. 65

^bBased on the percent of sources leaking at $\geq 10,000$ ppm. From Table 4-2.

^cRef. 66

^dWeighted average based on 75 percent of the leaks repaired on-line, requiring 0.17 hours per repair, and on 25 percent of the leaks repaired off-line, requiring 4 hours per repair. Ref. 67.

^eNo maintenance required because equipment specification eliminates leak potential.

^fThe estimated number of initial leaks for open-ended valves is based on the same percentage of sources used for in-line valves. This represents leaks occurring through the stem and gland of the open-ended valve. Leaks through the valve seat are eliminated by adding caps for Regulatory Alternatives II, III, IV.

TABLE 8-8. RECOVERY CREDITS.

Regulatory alternative	Model unit A			Model unit B			Model unit C		
	VOC emissions, Mg/yr	Emission reduction from uncontrolled, Mg/yr	Recovered ^a product value, \$/yr	VOC emissions, Mg/yr	Emission reduction from uncontrolled, Mg/yr	Recovered ^a product value, \$/yr	VOC emissions, Mg/yr	Emission reduction from uncontrolled, Mg/yr	Recovered ^a product value, \$/yr
I	67.2	--	--	257	--	--	800	--	--
II	24.5	42.7	15,400	93.7	163	58,800	293	507	182,500
III	20.8	46.4	16,700	79.8	177	63,800	249	551	198,400
IV	8.46	58.7	21,100	34.3	223	80,200	106	694	249,800

^aLast quarter 1978 dollars. Based on an average price of \$360/Mg. Ref. 68.

TABLE 8-9. ANNUALIZED CONTROL COST ESTIMATES FOR MODEL UNIT A
(thousands of last quarter 1978 dollars).

Cost item	Regulatory alternative			
	I	II	III	IV
Annualized capital charges				
1. Control equipment				
a. Instrument		1.96	1.96	1.96
b. Caps		.763	.763	.763
c. Double seals				
• Seals				0.974
• Installation				.196
d. Flush oil system				1.22
e. Vents - pumps and compressors				5.32
f. Rupture disks				
• Disks				1.24
• Holders, etc.				2.74
g. Closed loop sampling				1.96
2. Initial leak repair		1.06	1.06	0.10
Operating costs				
1. Maintenance charges				
a. Instrument		2.70	2.70	2.70
b. Caps		.234	.234	.234
c. Double seals				0.144
d. Flush oil system				.375
e. Vents - pumps and compressors				1.63
f. Rupture disks				.950
g. Closed loop sampling				0.60
2. Miscellaneous (taxes, insurance, administration)				
a. Instrument		.340	.340	.340
b. Caps		.187	.187	.187
c. Double seals				.115
d. Flush oil system				0.30
e. Vents - pumps and compressors				1.31
f. Rupture disks				.758
g. Closed loop sampling				.48
3. Labor				
a. Monitoring labor		0.54	2.26	1.43
b. Leak repair labor		3.17	3.30	0.304
c. Administrative and support ^a		1.51	2.22	0.692
Total before credit	0.0	12.1	15.0	29.0
Recovery credits ^b	0.0	15.4	16.7	21.1
Net annualized cost	0.0	(-3.3)	(-1.7)	7.9

^aBased on 40 percent of monitoring plus leak repair labor. Ref. 69.

^bBased on an average price of \$360/Mg. Ref. 70

^c(-xx) ⇒ net credit

TABLE 8-10. ANNUALIZED CONTROL COST ESTIMATES FOR MODEL UNIT B
(thousands of last quarter 1978 dollars)

Cost item	Regulatory alternative			
	I	II	III	IV
Annualized capital charges				
1. Control equipment				
a. Instrument		1.96	1.96	1.96
b. Caps		3.05	3.05	3.05
c. Double seals				
• Seals				3.69
• Installation				.743
d. Flush oil system				4.65
e. Vents - pumps and compressors				17.6
f. Rupture disks				
• Disks				4.75
• Holders, etc.				10.5
g. Closed loop sampling				7.79
2. Initial leak repair		2.73	2.73	0.41
Operating costs				
1. Maintenance charges				
a. Instrument		2.7	2.7	2.7
b. Caps		.935	.935	.935
c. Double seals				.546
d. Flush oil system				1.42
e. Vents - pumps and compressors				5.39
f. Rupture disks				3.63
g. Closed loop sampling				2.39
2. Miscellaneous (taxes, insurance, administration)				
a. Instrument		0.34	0.34	0.34
b. Caps		.748	.748	.748
c. Double seals				.437
d. Flush oil system				1.14
e. Vents - pumps and compressors				4.31
f. Rupture disks				2.90
g. Closed loop sampling				1.91
3. Labor				
a. Monitoring labor		2.04	8.75	5.74
b. Leak repair labor		3.54	7.69	1.09
c. Administrative and support ^a		2.23	6.58	2.73
Total before credit	0.0	20.3	35.5	93.5
Recovery credits ^b	0.0	58.8	63.8	80.2
Net annualized cost ^c	0.0	(-38.5)	(-28.3)	13.3

^aSee footnote from preceeding Table 8-9, Ref. 71.

^bBased on an average price of \$360/Mg. Ref.72.

^c(-xx)⇒ net credit

TABLE 8-11. ANNUALIZED CONTROL COST ESTIMATES FOR MODEL UNIT C
(thousands of last quarter 1978 dollars)

Cost item	Regulatory alternative			
	I	II	III	IV
Annualized capital charges				
1. Control equipment				
a. Instrument		1.96	1.96	1.96
b. Caps		9.37	9.37	9.37
c. Double seals				
• Seals				11.7
• Installation				2.35
d. Flush oil system				14.7
e. Vents - pumps and compressors				56.9
f. Rupture disks				
• Disks				14.7
• Holders, etc.				32.4
g. Closed loop sampling				24.0
2. Initial leak repair		7.67	7.67	1.23
Operating Costs				
1. Maintenance charges				
a. Instrument		2.70	2.70	2.70
b. Caps		2.88	2.88	2.88
c. Double seals				1.72
d. Flush oil system				4.50
e. Vents - pumps and compressors				17.5
f. Rupture disks				11.2
g. Closed loop sampling				7.35
2. Miscellaneous (taxes, insurance, administration)				
a. Instrument		0.340	0.340	0.340
b. Caps		2.30	2.30	2.30
c. Double seals				1.38
d. Flush oil system				3.60
e. Vents - pumps and compressors				14.0
f. Rupture disks				8.98
g. Closed loop sampling				5.88
3. Labor				
a. Monitoring labor		6.33	27.14	17.7
b. Leak repair labor		8.71	21.3	3.25
c. Administrative and support ^a		6.02	19.4	8.38
Total before credit	0.0	48.3	95.1	283.
Recovery credits ^b	0.0	182.	198.	250.
Net annualized cost ^c	0.0	(-134.)	(-103.)	33.0

^aBased on 40 percent of monitoring plus leak repair labor. Ref.73 .

^bBased on an average price of \$360/Mg. Ref. 74.

^c(-xx) ⇒ net credit.

TABLE 8-12. COST EFFECTIVENESS FOR MODEL UNITS
(last quarter 1978 dollars)

Regulatory alternative	Model unit A ^a				Model unit B ^b				Model unit C ^c			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
Total capital cost (\$1000)	0.0	13.2	13.2	87.1	0.0	27.2	27.2	295	0.0	66.0	66.0	911
Total annualized cost (\$1000)	0.0	12.1	15.0	29.0	0.0	20.3	35.5	93.5	0.0	48.3	95.1	283
Total annual recovery credit (\$1000)	0.0	15.4	16.7	21.1	0.0	58.8	63.8	80.2	0.0	182.	198.	250.
Net annualized cost (\$1000) ^d	0.0	(-3.3)	(-1.7)	7.9	0.0	(-38.5)	(-38.3)	13.3	0.0	(-134.)	(-103.)	33.0
Total VOC reduction (Mg/yr)	0.0	42.7	46.4	58.7	0.0	163	177	223	0.0	507	551	694
Cost effectiveness (annual \$/Mg VOC) ^d	-	(-77.3)	(-36.6)	135.	-	(-236.)	(-160.)	59.6	-	(-264.)	(-187.)	47.6

^a52 percent of the units in the SOCM I are similar to Model Unit A. Ref. 75.

^b33 percent of the units in the SOCM I are similar to Model Unit B. Ref. 76.

^c15 percent of the units in the SOCM I are similar to Model Unit C. Ref. 78.

^d(-xx) = Control method net credit

IV is the only one with a positive net cost, comparisons of cost effectiveness in the normal sense are meaningless. The highest cost of VOC control under Regulatory Alternative IV is for model unit A. Although this cost (\$128/Mg) is much larger than the cost for model unit C (\$40/Mg), the total annualized cost for model unit A is only \$7500. This amount is insignificant compared to the annual operating cost of the process unit itself.

8.1.3 Modified/Reconstructed Facilities

8.1.3.1 Capital Costs. The bases for determining the capital costs for modified/reconstructed facilities are presented in Table 8-1. The capital costs for these units are the same under Regulatory Alternatives II and III as are those for new units. There are no costs associated with Alternative I. The capital costs for the monitoring instruments, the caps for open-ended lines, the flush-oil systems, the vents for degassing reservoirs, and the closed loop sampling connections are also the same as for new units.

The estimated cost of retrofitting double mechanical seals for single seal pumps is estimated at \$850 per pump. This figure includes \$560 for a new double mechanical seal plus \$290 labor for field installation.

Rupture disks for relief valves, required under Regulatory Alternative IV, are estimated to cost \$2970 per relief valve. The original relief valve must be replaced with a larger relief valve. Credit for the removed valve is not included.

The total capital cost estimates for modified/reconstructed facilities are presented in Table 8-13. As noted above, the costs associated with Regulatory Alternatives I, II, and III are the same as for new units.

8.1.3.2 Annualized Costs. The annualized control costs for modified/reconstructed units, presented in Table 8-14, are derived from the same basis as new units (see Table 8-2). The only changes from new unit costs occur under Regulatory Alternative IV because of the increased capital costs for double mechanical seals and rupture disks. The recovered product credits for the modified/reconstructed units are the same as for the new model units.

TABLE 8-13. CAPITAL COST ESTIMATES FOR MODIFIED/
RECONSTRUCTED FACILITIES
(thousands of last quarter 1978 dollars)

Capital cost item ^a	Regulatory alternative IV ^b		
	Model unit		
	A	B	C
1. Monitoring instrument	8.5	8.5	8.5
2. Caps for open-ended lines	4.68	18.7	57.5
3. Double mechanical seals			
• Seals	2.8	10.6	33.6
• Installation	1.45	5.51	17.4
4. Flush oil systems for double mechanical seals	7.50	28.5	90.0
5. Vents for compressor degassing reservoirs	6.53	13.1	52.2
6. Vents for pump degassing reservoirs	26.1	94.7	297
7. Rupture disks for relief valves			
• Disks	2.14	8.19	25.4
• Holders, block valves, installation	16.8	64.4	199
• Replacement relief valve and installation	15.2	58.0	179
8. Closed loop sampling connections	<u>12.0</u>	<u>47.8</u>	<u>147</u>
Total	104	358	1107

^aFrom Tables 6-1 and 8-1.

^bFor Regulatory Alternatives I, II, III the capital costs for modified/reconstructed facilities are the same as for new units (Table 8-2).

TABLE 8-14. ANNUALIZED CONTROL COST ESTIMATES FOR MODIFIED/
RECONSTRUCTED MODEL UNITS UNDER REGULATORY ALTERNATIVE IV^a
(thousands of last quarter 1978 dollars)

Cost item	Model unit A ^b	Model unit B ^c	Model unit C ^d
Annualized capital charges			
1. Control equipment			
a. Instrument	1.96	1.96	1.96
b. Caps	.763	3.05	9.37
c. Double seals			
• Seals	1.62	6.15	19.5
• Installation	.236	0.898	2.84
d. Flush oil system	1.22	4.65	14.7
e. Vents for pumps and compressors	5.32	17.6	56.9
f. Rupture disks			
• Disks	1.24	4.75	14.7
• Holders, etc.	2.74	10.5	32.4
• Relief valves	2.48	9.45	29.2
g. Closed loop sampling	1.96	7.79	24.0
2. Initial leak repair	0.10	0.41	1.23
Operating costs			
1. Maintenance charges			
a. Instrument	2.70	2.70	2.70
b. Caps	.234	.935	2.88
c. Double seals	0.213	0.806	2.55
d. Flush oil system	.375	1.42	4.50
e. Vents for pumps and compressors	1.63	5.39	17.5
f. Rupture disks	1.71	6.53	20.2
g. Closed loop sampling	.60	2.39	7.35
2. Miscellaneous (taxes, insurance, administration)			
a. Instrument	.340	.340	.340
b. Caps	.187	.748	2.30
c. Double seals	0.170	.644	2.04
d. Flush oil system	0.30	1.14	3.60
e. Vents for pumps and compressors	1.31	4.31	14.0
f. Rupture disks	1.37	5.22	16.2
g. Closed loop sampling	.480	1.91	5.88
3. Labor			
a. Monitoring labor	1.43	5.74	17.7
b. Leak repair labor	0.304	1.09	3.25
c. Administrative and support ^e	0.692	2.73	8.38
Total before credit	33.7	111.	338.
Recovery credits ^f	21.1	80.2	250.
Net annualized cost	12.6	30.8	88.
Total VOC reduction (Mg/yr)	58.7	223.	694
Cost effectiveness (\$/Mg VOC)	215.	138.	127.

^aFor Regulatory Alternatives I, II, III, the annualized control costs and cost effectiveness for modified/reconstructed facilities are the same as for new units (Tables 8-7, 8-8, 8-9).

^b52 percent of existing units are similar to Model Unit A. Ref. 78.

^c33 percent of existing units are similar to Model Unit B. Ref. 79.

^d15 percent of existing units are similar to Model Unit C. Ref. 80.

^eBased on 40 percent of monitoring plus leak repair labor. Ref. 81.

^fBased on an average price of \$360/Mg. Ref. 82.

8.1.3.3 Cost Effectiveness. The cost effectiveness figures for modified/reconstructed facilities are also shown in Table 8-14. The cost effectiveness under Regulatory Alternatives I, II, and III is the same as for the new model units. The cost effectiveness under Regulatory Alternative IV is a net cost of \$134 per Mg for Model Units B and C, and \$208 per Mg for Model Unit A.

8.1.4 Projected Cost Impacts

The regulatory alternatives are assumed to go into effect by 1981, using 1980 as the base year. The industry is estimated to grow at a rate of 5.9 percent.⁸³ SOCOMI facilities are estimated to be replaced at a rate based on a 20-year equipment life (see Appendix E). The estimated numbers of projected new units are presented in Tables 7-5, 7-6, and 7-7. The estimated costs to the industry for the years 1981 through 1985 are presented in Tables 8-15 through 8-17. Capital costs shown are only for units which begin operation in the indicated year. All other costs shown are for all units subject to NSPS in the indicated year.

TABLE 8-15. NATIONWIDE COSTS FOR THE INDUSTRY UNDER REGULATORY ALTERNATIVE II
(last quarter 1978 dollars)

Cost item ^a	1981	1982	1983	1984	1985
Total capital cost (\$1000) ^b	3,800	4,040	4,280	4,490	4,790
Total annualized cost (\$1000) ^c	2,990	6,160	9,530	13,100	16,800
Total annual recovery credit (\$1000)	8,070	16,700	25,800	35,300	45,500
Net annualized cost (\$1000) ^d	(-5,080)	(-10,500)	(-16,300)	(-22,200)	(-28,700)

^aFrom Tables 8-2, 8-9, 8-10, 8-11.

^bCapital costs for model units which begin operation in the years shown.

^cAnnualized costs for all model units subject to NSPS in the years shown.

^d(-xx) ⇒ net credit

TABLE 8-16. NATIONWIDE COSTS FOR THE INDUSTRY UNDER REGULATORY ALTERNATIVE III
(last quarter 1978 dollars)

Cost item ^a	1981	1982	1983	1984	1985
Total capital cost (\$1000) ^b	3,800	4,040	4,280	4,490	4,790
Total annualized cost (\$1000) ^c	4,990	10,300	15,900	21,800	23,100
Total annual recovery credit (\$1000)	8,770	18,100	28,000	38,400	49,400
Net annualized cost (\$1000) ^d	(-3,780)	(-7,800)	(-12,100)	(-16,600)	(-21,300)

^aFrom Tables 7-6, 8-7, 8-8, 8-9.

^bCapital costs for model units which begin operation in the years shown.

^cAnnualized costs for all model units subject to NSPS in the years shown.

^d(-xx) ⇒ net credit

TABLE 8-17. NATIONWIDE COSTS FOR THE INDUSTRY UNDER REGULATORY ALTERNATIVE IV
(last quarter 1978 dollars)

Cost item ^a	1981	1982	1983	1984	1985
Total capital cost (\$1000) ^b	41,200	44,000	46,500	48,700	51,900
Total annualized cost (\$1000) ^c	13,000	27,000	41,700	57,100	73,500
Total annual recovery credit (\$1000)	11,100	22,900	35,400	48,500	62,400
Net annualized cost (\$1000) ^d	1,900	4,100	6,300	8,600	11,100

^aFrom Tables 7-6, 8-7, 8-8, 8-9.

^bCapital costs for model units which begin operation in the years shown.

^cAnnualized costs for all model units subject to NSPS in the years shown.

^d(-xx) ⇒ net credit

8.2 OTHER COST CONSIDERATIONS

Environmental Safety and Health Statues which are applicable to SOCFI plants are listed in Table 8-18. The provisions, requirements, and regulations listed are those which may cause an outlay of funds by an organic chemical manufacturer.

Specific costs of each of these provisions or requirements to the industry defined as SOCFI were unavailable. Total costs to SOCFI for complying with environmental, safety and health standards were also unavailable.

The entire chemical industry is planning to spend an estimated \$639 million on pollution control in 1979 according to a McGraw-Hill Survey.⁸⁴ Although this is a sizeable sum of money, the industry has enjoyed three decades of rapid growth and high profits. The economic health of the industry is better than that of many other industries.⁸⁵ The substantial pollution problems encountered in the industry and the large expenditures necessary for this solution are expected to affect the smaller firms more adversely than the larger firms. However, few plant closings are expected due solely to costs of compliance with standards and regulations.⁸⁶

The costs incurred by SOCFI in complying with all health, safety, and environmental requirements are not expected to prevent compliance with the proposed NSPS for fugitive emissions.

TABLE 8-18. STATUTES THAT MAY BE APPLICABLE TO SOCM

Statute	Applicable provision, regulation or requirement of statute	Approximate cost incurred due to enactment of statute	
		Model unit	Industry
Clean Air Act and Amendments	• State implementation plans	Total	\$249 million ^a
	• National emission standards for hazardous air pollutants		
	Benzene fugitive emissions		
	• New source performance standards		
	Air oxidation		
	Volatile organic liquid storage		
	• PSD construction permits		
	• Non-attainment construction permits		
Clean Water Act (Federal Water Pollution Act)	• Discharge permits	Total	\$414 million ^b
	• Effluent limitations guidelines		
	• New source performance standards		
	• Control of oil spills and discharges		
	• Pretreatment requirements		
	• Monitoring and reporting		
	• Permitting of industrial projects that impinge on wetlands or public waters		
	• Environmental impact statements		
Resource Conservation and Recovery Act	• Permits for treatment, storage, and disposal of hazardous wastes	Total	\$200 million ^c
	• Establishes system to track hazardous wastes		Superfund-less than 2% of profits or \$200 million maximum annual rate on petrochemical feedstock ^d
	• Establishes recordkeeping, reporting, labelling and monitoring system for hazardous wastes		Production costs for the industry are expected to increase by an average of 0.6% and a maximum of 5%. ^e
	• Superfund		
Toxic Substances Control Act	• Premanufacture notification	Total	\$100-200 million per year ^f
	• Labelling, recordkeeping		Preinventory notification cost: \$1200-1500 per chemical ^g
	• Reporting requirements		
	• Toxicity testing		

(Continued)

TABLE 8-18. (Cont.)

Statute	Applicable provision, regulation or requirement of statute	Approximate cost incurred due to enactment of statute	
		Model unit	Industry
Occupational Safety and Health Act	<ul style="list-style-type: none"> • Walking-working surface standards • Means of egress standards • Occupational health and environmental control standards • Hazardous material standards • Personal protective equipment standards • General environmental control standards • Medical and first aid standards • Fire protection standards • Compressed gas and compressed air equipment • Welding, brazing, and cutting standards 	Total	\$220/year per worker ^h
Coastal Zone Management Act	<ul style="list-style-type: none"> • States may veto federal permits for plants to be sited in coastal zone 		
Power Plant and Industrial Fuel Use Act	<ul style="list-style-type: none"> • Prohibits new, major, industrial power-plants which utilize fuel oil or natural gas 		
National Environmental Policy Act	<ul style="list-style-type: none"> • Requires environmental impact statements 		
Safe Drinking Water Act	<ul style="list-style-type: none"> • Requires underground injection control permits 		
Marine Sanctuary Act	<ul style="list-style-type: none"> • Ocean pumping permits • Recordkeeping and reporting 		

^aExpenditure, by entire chemical industry, on air pollution control; SOCFI's portion of expenditure not delineated. (Ref.87)

^bExpenditure, by entire chemical industry, on water pollution control; SOCFI's portion of expenditure not delineated. (Ref.83)

^cCost reflects entire organic industry; SOCFI's cost not delineated. (Ref.89)

^dCost reflects entire organic industry; SOCFI's cost not delineated. (Ref.90,91)

^eCost reflects entire organic industry; SOCFI's cost not delineated. (Ref. 92)

^fCost incurred by entire chemical industry; SOCFI's portion of expenditure not delineated. (Ref. 93)

^gCost incurred by entire chemical industry; SOCFI's portion of expenditure not delineated. (Ref. 94)

^hCost incurred by entire chemical industry; SOCFI's portion of expenditure not delineated. (Ref. 95)

8.3 REFERENCES

1. Erikson, D. G., and V. Kalcevic. Emissions Control Options for the Synthetic Organic Chemical Manufacturing Industry, Fugitive Emissions Report. Draft Report. EPA Contract No. 68-02-2577. Knoxville, Tennessee, Hydrosience, Inc., March 1979. p. IV-9.
2. Letter from Guy C. Amey, Century Systems Corporation, to James C. Serne, PES, Inc. October 17, 1979. Cost data for VOC monitoring instrument.
3. Peters, Max S., and K. D. Timmerhaus. Plant design and Economics for Chemical Engineers. Second Edition. New York, McGraw-Hill. 1968.
4. Kohn, P. M. CE Cost Indexes Maintain 13-Year Ascent. Chem. Eng. 18(11):189-190. May 1978.
5. Economic Indicators. Chem. Eng. Vol. 87 #1. January 14, 1980.
6. Ref. 5.
7. Environmental Protection Agency, Chemical and Petroleum Branch. OAQPS Guideline Series. Control of Volatile Organic Compound Leaks from Petroleum Refinery Equipment. EPA-450/2-78-036, OAQPS No. 1.2-111. June 1978. p. 4-5.
8. Economic Indicators. Chem. Eng. Vol 86 #2. January 15, 1979.
9. Ref. 1, p. IV-3.
10. Ref. 1, p. IV-3.
11. Ref. 1, p. IV-3.
12. Ref. 1, pp. IV-8, 9.
13. Ref. 1, p. IV-8.
14. Ref. 3, p. 451.
15. Ref. 4.
16. Ref. 5.
17. Ref. 5.
18. Ref. 7.

19. Ref. 8.
20. Ref. 3, p. 450.
21. Ref. 4.
22. Ref. 5.
23. Ref. 5.
24. Ref. 7.
25. Ref. 8.
26. Ref. 4.
27. Ref. 5.
28. Ref. 5.
29. Ref. 7.
30. Ref. 8.
31. Ref. 1, p. IV-8.
32. Ref. 5.
33. Ref. 7.
34. Ref. 8.
35. Ref. 7, p. 4-3.
36. Letter with Attachments from J. M. Johnson, Exxon Company, U.S.A., to Robert T. Walsh, U. S. EPA. July 28, 1977.
37. Ref. 1, p. B-12.
38. Ref. 36.
39. Ref. 7, p. 4-3.
40. Ref. 36.
41. Ref. 1, p. B-12.
42. Ref. 36.

- 43. Ref. 7, p. 4-3.
- 44. Ref. 36.
- 45. Ref. 1, p. 8-12.
- 46. Ref. 36.
- 47. Ref. 5.
- 48. Ref. 7.
- 49. Ref. 8.
- 50. Ref. 1, pp. IV-3, 4.
- 51. Ref. 1, pp. IV-9, 10.
- 52. Ref. 1, pp. IV-3, 4.
- 53. Ref. 7, p. 4-2.
- 54. Ref. 5.
- 55. Ref. 8.
- 56. Ref. 1, pp. IV-3, 4, 9, 10.
- 57. Ref. 7, pp. 4-4. 5.
- 58. Ref. 5.
- 59. Ref. 8.
- 60. Ref. 1, pp. IV-9, 10.
- 61. Ref. 5.
- 62. Ref. 7.
- 63. Ref. 8.
- 64. Letter from Vincent Smith, Research Triangle Institute to Russell L. Honerkamp, Radian Corporation. November 30, 1979. Projected Number of Affected Facilities and Average Product Value in SOCFI.
- 65. Ref. 36.
- 66. Ref. 36.

- 67. Ref. 1, p. B-12.
- 68. Ref. 64.
- 69. Ref. 1, pp. IV-9, 10.
- 70. Ref. 64.
- 71. Ref. 1, pp. IV-9, 10.
- 72. Ref. 64.
- 73. Ref. 1, pp. IV-9, 10.
- 74. Ref. 64.
- 75. Ref. 1, p. IV-1.
- 76. Ref. 1, p. IV-1.
- 77. Ref. 1, p. IV-1.
- 78. Ref. 1, p. IV-1.
- 79. Ref. 1, p. IV-1.
- 80. Ref. 1, p. IV-1.
- 81. Ref. 1, pp. IV-9, 10.
- 82. Ref. 64.
- 83. Letter from Vincent Smith, Research Triangle Institute, to Russell L. Honerkamp, Radian Corporation. August 13, 1979. Growth Rate of SOCM1.
- 84. News Flashes. Chemical Engineering, Vol. 86, No. 12. 1979. p. 77.
- 85. Environmental Quality, The Ninth Annual Report of the Council on Environmental Quality. U.S. Government Printing Office, Washington, D.C. December 1978.
- 86. Ref. 85.
- 87. Ref. 85.
- 88. Ref. 85.
- 89. Solid Waste Facts, A Statistical Handbook. U. S. Environmental Protection Agency, Office of Public Awareness. U. S. Government Printing Office, Washington, D. C. August 1978.

90. EPA Charges Chemical Trade Seeks Lowest Denominator as its Position on Superfund. Chemical Marketing Reporter. N.Y. (216) 10. McGraw-Hill, Sept. 3, 1979. p.3.
91. Tough Version of Superfund Would Cook Industry, \$1.6 Billion for Cleanup. Chemical Marketing Reporter. N.Y. (215) (25). McGraw-Hill, Jan. 18, 1979.
92. Ref. 85.
93. Preproposal of Premanufacture Notification Notice Form and Provision of Rules 40 CFR Part 720. 44(201) Oct. 16, 1979.
94. Ref. 93.
95. Cost of Government Regulation Study. Arthur Anderson and Co., Washington, D.C. March 1979.

9. ECONOMIC ANALYSIS

9.1 Industry Profile

9.1.1 Introduction

The synthetic organic chemicals manufacturing industry (SOCMI) has been defined as the producers of 378 synthetic organic chemicals, listed in Appendix F. This profile gives a general qualitative description of the industry, supported by quantitative information wherever possible. Because SOCMI does not directly correspond to industrial classifications used for reporting information by secondary data sources, a weighting technique was used to develop industry statistics (see Appendix E1).

Synthetic organic chemicals (SOCs) are substances containing at least carbon and hydrogen. They exhibit three basic molecular structures: aliphatic or acyclic, cyclic, and combinations of aliphatic and cyclic. Acyclic compounds are composed groups of atoms arranged in a straight chain. Examples are alcohols, ethers, ketones, and carbohydrates. Cyclic compounds have the atoms of their component elements arranged in the form a closed ring. Examples include aromatic hydrocarbons, napthenes, and thiazoles. Certain amino acids and terpene hydrocarbons represent combinations of cyclic and aliphatic molecular structures.¹

SOCMI chemicals may be used as primary feedstocks, chemical intermediates, or end use chemicals. Primary feedstocks are produced from crude raw materials and used in the manufacture of other chemicals. Chemical intermediates are the product of primary feedstocks and are also used to produce other chemicals. End use chemicals are products of chemical intermediates and/or primary feedstocks and are used either as final goods or as inputs to production processes outside the chemical industry. Many synthetic organic chemicals are used in more than one of these categories. Figure 3.1 illustrates the general relationships among the various organic chemicals.

Detailed flow charts identifying inputs and product uses for many of the SOCMIs chemicals have been presented elsewhere.²

9.1.2 Production Processes and Capacities

Most of the SOCMIs chemicals produced in the United States are derived from crude petroleum and natural gas. Oil, shale, coal, and biomass (non-prehistoric plant tissue) are also sources of primary feedstocks.³ A wide variety of processes are used to manufacture the 378 synthetic organic chemicals included in the definition of SOCMIs. Frequently individual chemicals can be manufactured in several different ways. Consequently, as relative prices change, chemical producers may alter the mix of primary feedstocks used to produce SOCIs.

After chemical feedstocks are manufactured from petroleum, natural gas, and other raw materials, they are processed into chemical intermediates and end use chemicals. Some of the chemicals included in SOCMIs are the product of a simple distillation process, while others are produced from a series of cracking processes.

The 1976 Organic Chemical Producers Data Base⁴ reports 1,270 units producing SOCMIs chemicals in the United States.* Table 9-1 presents a distribution of those units and estimated capacity by state. New Jersey, Texas, and California have the largest number of units producing SOCMIs chemicals. Texas and Louisiana have the largest total production capacities. These states are major producers because of their petroleum deposits and good sea port facilities. Table 9-2 presents a geographical distribution of units by reported capacity. Approximately 12 percent of these units produce fewer than 5,000 Mg. Another 12 percent of the units have production capacities in excess of

*The 1976 version of the Organic Chemical Producers Data Base is used because it was the most recent version available.

TABLE 9-1. ESTIMATED ANNUAL PRODUCTION CAPACITY
BY STATE, 1976^a

State	Number of units	Percentage of units reporting capacity	Estimated total capacity, ^a (10 ³ Mg)
Total	1,270	40	319,835
Alabama	25	52	5,174
Alaska	2	50	399
Arizona	1	00	91
Arkansas	12	33	1,982
California	120	23	19,650
Colorado	5	20	644
Connecticut	18	26	2,765
Delaware	14	50	2,031
Florida	14	43	3,257
Georgia	20	30	3,459
Hawaii	1	00	91
Idaho	2	50	97
Illinois	85	31	16,517
Indiana	31	26	3,551
Iowa	11	64	1,698
Kansas	1	00	390
Kentucky	27	56	6,062
Louisiana	54	74	31,810
Maine	1	00	390
Maryland	17	35	2,160
Massachusetts	27	48	4,835
Michigan	28	25	9,735
Minnesota	6	17	574
Mississippi	15	47	1,999
Missouri	16	37	4,072
Montana	1	100	222
Nebraska	4	100	103
Nevada	2	50	122
New Hampshire	5	40	483
New Jersey	131	24	28,070
New York	52	19	10,586
North Carolina	50	38	7,283
Ohio	88	26	14,576
Oklahoma	9	78	702
Oregon	17	53	3,838
Pennsylvania	75	27	14,634
Puerto Rico	13	85	7,259
Rhode Island	8	00	815
South Carolina	27	48	3,875
Tennessee	24	46	6,809
Texas	126	76	77,189
Utah	4	25	628
Vermont	1	100	2
Virgin Islands	2	100	643
Virginia	22	68	3,581
Washington	13	46	2,502
West Virginia	24	63	9,242
Wisconsin	18	22	3,514
Wyoming	1	100	24

^aCapacities were estimated by calculating the mean of reported unit capacity for each chemical. This was substituted for any missing values of unit capacity for each chemical. If no units reported capacity for a chemical, then the mean of all chemicals was substituted for the missing value. Estimated capacity represents the sum of reported capacities, means of reported capacity for some specific chemicals, and industry mean reported capacity for other chemicals.

TABLE 9-2. DISTRIBUTION OF UNITS BY UNIT CAPACITY AND REGION, 1976⁴

Number of units											
Region	Unit capacity ranges (10 ³ Mg)								Units reporting capacity	Units not reporting capacity	Total units
	0-5	5-10	10-25	25-50	50-100	100-250	250-500	500+			
North east	17	5	12	16	17	10	5	1	83	235	318
New England	7	0	4	5	4	0	1	0	21	39	60
Mid-Atlantic	10	5	8	11	13	10	4	1	62	196	258
North central	16	5	13	13	13	17	6	3	86	202	288
East	13	3	10	9	9	16	6	2	68	182	250
West	3	2	3	4	4	1	0	1	18	20	38
9-4 South	23	7	34	38	44	50	34	50	280	200	480
East south central	2	3	12	8	5	9	3	4	46	45	91
West south central	4	3	10	18	20	24	24	44	147	54	201
South Atlantic	17	1	12	12	19	17	7	2	87	101	188
West	3	2	17	12	5	8	3	0	50	119	169
Mountain	0	1	3	2	0	0	0	0	6	10	16
Pacific	3	1	14	10	5	8	3	0	44	109	153
Total	59	19	76	79	79	85	48	54	499	756	1,255

500,000 Mg. Seventy-five percent of these large facilities are located in the southwest central region of the United States, which includes Texas and Louisiana. Table 9-3 presents the total reported capacity for each region by unit size.

9.1.3 Production and Sales

Production and sales data for the SOCFI are presented in Table 9-4. The production of SOCFI chemicals increased from 58,050 Gg in 1968 to 84,530 Gg in 1978, at an average annual growth rate of approximately 3.5 percent. However, output levels have fluctuated widely since 1974. The effects of the oil embargo, the increase in energy and feedstock prices, and the sharply reduced demand resulting from a major economic recession caused the industry to cut back production by 13.2 percent in 1975. In 1976 output rose only slightly, but, in 1977, as real prices for energy and feedstocks fell, the economy recovered, and the need to increase inventories became urgent, production increased by 50.4 percent. In 1978 energy and feedstock prices began to increase again and the need to replenish inventories disappeared. Output declined that year by 28.6 percent. Nevertheless, production in 1978 was greater than in 1974, suggesting that the industry may have substantially adjusted to the shocks experienced in 1974 and 1975.

Sales and production trends were virtually identical over the period 1967-1978.* The two variables are likely to remain highly correlated in the future, because the industry's feedstock requirements are closely tied to its production levels. The absolute level of sales was much lower than the level of production (45.6 percent of production) over the period 1967 to 1978. The

*The estimated correlation coefficient for the two variables over this period is 0.97.

TABLE 9-3. DISTRIBUTION OF INDUSTRY CAPACITY BY UNIT CAPACITY AND REGION, 1976⁴

Region	Industry capacity								Total
	Unit capacity (10 ³ Mg)								
	0-5	5-10	10-25	25-50	50-100	100-250	150-500	≥500	
North east	37.7	43.1	199.2	548.4	1,177.6	1,392.6	1,811.2	742.5	5,952
New England	19.1	--	70.8	176.9	263.1	--	299.4	--	829
Mid-Atlantic	18.6	43.1	128.4	371.5	914.5	1,392.6	1,511.8	742.5	5,123
North central	42.2	38.8	205.9	478.1	953.0	2,544.7	2,024.9	2,430.8	8,718
East	38.1	22.5	142.4	350.2	664.1	2,406.8	2,024.9	1,906.9	7,556
West	4.1	16.3	63.5	127.9	288.9	137.9	--	523.9	1,163
South	62.9	58.8	605.6	1,442.0	3,236.1	8,369.	11,910.9	67,600.5	93,287
East south									
central	1.3	23.6	204.6	299.4	316.2	1,494.6	984.5	3,132.6	6,457
West south									
central	12.2	28.8	194.6	710.8	1,532.3	4,411.7	8,596.6	63,197.8	78,685
South Atlantic	49.4	6.4	206.4	431.8	1,387.6	2,463.5	2,329.8	1,270.1	8,145
West	5.0	13.2	298.4	477.2	342.5	1,055.1	1,024.2	--	3,216
Mountain	--	6.4	48.5	72.6	--	--	--	--	127
Pacific	5.0	6.8	249.9	404.6	342.5	1,055.1	1,024.2	--	3,088
Caribbean	--	--	--	109.8	72.6	--	1,324.1	5,659.1	7,166
Total	147.8	153.9	1,309.1	3,055.5	5,781.8	13,362.2	18,095.3	76,432.9	118,339

TABLE 9-4. ANNUAL PRODUCTION AND SALES OF SYNTHETIC ORGANIC CHEMICALS^a

Year	Production ^a (Gg)	Sales volume ^a (Gg)	Sales value ^a (\$10 ⁶)	Average unit value ^a (\$/kg)
1967	51,380	23,440	3,085.55	0.13
1968	58,050	26,960	3,411.91	0.13
1969	65,210	30,360	3,590.07	0.11
1970	68,140	32,090	3,702.20	0.12
1971	69,020	33,020	3,724.03	0.11
1972	76,740	36,930	4,173.97	0.11
1973	81,220	39,420	4,991.53	0.13
1974	83,720	38,450	9,357.99	0.24
1975	72,660	32,920	8,411.34	0.26
1976	76,030	32,520	10,187.76	0.29
1977	114,320	49,470	15,317.72	0.31
1978	84,530	35,310	12,951.16	0.36

^aSee Appendix E1 for a discussion of the methodology used to compute these data.

difference between output and sales represents captive consumption, indicating that the industry has a relatively high degree of vertical integration.

9.1.4 Resource Use

Estimates of employment, assets, cost of materials and energy used in SOCM I from 1972 to 1976 are presented in Table 9-5. In general, resource use increased with production. Total industry employment, including administrative, clerical, marketing and service employees as well as production workers, increased 5 percent from 1972 to 1976. Employment of production workers increased 4.1 percent during this period, although the number of production workers declined during the adjustment period following the 1973-74 oil embargo. Cost of materials increased substantially during the 1972-1976 period; however, much of this increase can be attributed to rapidly increasing prices of crude petroleum. Consumption of energy for heat and power has fluctuated, resulting in an overall decrease of about 1 percent from 1972 to 1976. Value of assets increased each year from 1972 to 1976. The total increase during that period was approximately 53 percent, much of which can be accounted for by changes in the value of buildings and equipment. The stock of physical assets increased at a much slower rate.

9.1.5 Consumption

The chemicals in SOCM I have a wide variety of end uses as fuels, solvents, pesticides, and pigments, and as feedstocks for the production of plastics, synthetic fibers and textiles, soaps and detergents, rubber products, medicines and fertilizers. It is not possible to estimate consistently apparent consumption, because import and export data presented in Table 9-6 for SOCM I are not compatible with the production and sales data presented in Table 9-4. However, it is probable that historical consumption trends have

TABLE 9-5. SOCMI RESOURCE USE⁶

Year	Total employment (10 ³)	Production workers (10 ³)	Total assets (\$10 ⁶)	Cost of materials (\$10 ⁶)	Energy purchased for heat and power (10 ⁹ joules)
1972	130.6	83.2	12,287.8	5,338.5	1,220.1 ^a
1973	132.3	85.1	13,048.3	6,311.8	1,286.6 ^a
1974	130.1	84.0	13,919.5	10,388	1,322.7 ^a
1975	132.7	82.7	16,198.2	11,569	1,154.4 ^a
1976	137.1	86.6	18,788.3	14,503.1	1,202.4

^aThese data were estimated by multiplying the 1976 estimate of energy use by the ratio of production in each of the previous years to 1976 production levels. Thus, for example, energy use in 1972 was estimated by multiplying energy use in 1976 by the ratio of production in 1972 to production in 1976.

TABLE 9-6. INDUSTRIAL ORGANIC CHEMICALS:
U.S. IMPORTS AND EXPORTS, 1966-77^a

Year	Imports (\$10 ⁶)	Exports ^a (\$10 ⁶)
1966	48	211
1967	48	231
1968	67	292
1969	84	290
1970	91	336
1971	129	304
1972	150	320
1973	169	484
1974	259	930
1975	205	779
1976	294	1,008
1977	326	995

^aIncludes exports of some finished products. Figures include estimates and are not strictly comparable with imports or production.

been similar to historical production and sales trends. Certainly, over the period 1967-1978, consumption increased, although since 1974, if the sales data presented in Table 9-4 can be regarded as an indicator of consumption, consumption exhibited wide year-to-year variations for the reasons discussed in Section 9.1.3.

9.1.6 Prices

The general level of prices for SOCFI chemicals more than tripled between 1967 and 1978. Most of the increase occurred after 1973. From 1967 to 1973, the average unit price of SOCFI chemicals remained close to \$0.12/kg. Following the 1973-1976 adjustments in oil prices, average prices in SOCFI doubled, rising to \$0.24/kg. After that time average unit prices increased at a rate of approximately 11 percent annually, to a price of \$0.36/kg in 1978. It is important to realize that these are average prices per unit of all SOCFI chemicals. In 1976, prices for individual chemicals ranged from \$0.11/kg for formaldehyde to \$4.30/kg for benzophenone. Changes in the unit price for individual chemicals may vary substantially from the changes in average prices. Table 9-4 presents annual statistics of production, sales volume, sales value and average unit value for the industry. The data are weighted using the procedures described in Appendix E1 to reflect the behavior of the industry as accurately as possible.

9.1.7 International Trade

Chemical imports were first made subject to tariffs at the beginning of the 20th century. The tariffs were initiated to protect the infant chemical industry from foreign competition. Since 1936, tariffs have been progressively lowered on chemical products.⁷ The U.S. International Trade Commission reports 824 benzenoid intermediates on which tariffs are collected. Of these, 179 are assessed duties competitively using import prices as the

basis for tariffs. Another 430 of these products are classified noncompetitive, with tariffs based on U.S. domestic prices. The competitive status of 15 products is not available.⁸ The remainder are not tariffed.

Accurate data concerning imports and exports of SOCOMI chemicals are not available. The most reasonable approximation of trade statistics for SOCOMI are provided by the U.S. International Trade Commission.⁵ Annual value of imports and exports for the period 1966-1977 is presented in Table 9-6. In each of these years, U.S. exports exceeded U.S. imports of industrial organic chemicals. Table 9-7 presents imports, exports and trade balance of industrial organic chemicals in 1976 and 1977 between the United States and its principal trading partners. These countries include West Germany, Italy, the United Kingdom, Switzerland, France, Belgium, the Netherlands, Canada, Japan, Mexico, Brazil and Argentina. In 1977 the U.S. experienced a deficit in its balance of trade in chemicals with West Germany, Japan, Italy, the United Kingdom, Switzerland and France. It experienced a surplus in its balance of trade in chemicals with Belgium, Canada, the Netherlands, Mexico, Argentina and Brazil. Table 9-8 presents the value of imports for consumption from principle sources from 1972 to 1977. These imports amounted to a total of about \$326 million in 1977.

9.1.8 Industry Growth

A number of forecasts of economic growth in the organic chemical industry are available. The annual growth rate used here, 5.9 percent, was estimated by McGraw Hill¹⁰ for the basic organic chemicals industry. The McGraw Hill estimate was selected for the following reasons. First, the growth rate was calculated for a group of chemicals which closely corresponds to the 378 SOCOMI chemicals. Second, the method used by McGraw Hill to develop the growth rate is internally consistent and takes account of forecasted develop-

TABLE 9-7. INDUSTRIAL ORGANIC CHEMICALS:
U.S. TRADE, BY PRINCIPAL TRADING PARTNERS, 1976 AND 1977^a
(\$10³)

Source	Imports ^a	Exports ^b	Trade balance
1976:			
West Germany	94,768	10,487	- 84,281
Japan	61,228	27,380	- 33,848
Italy	30,678	N.A. ^c	- 30,000
United Kingdom	24,709	15,497	- 9,212
Switzerland	17,280	2,681	- 14,599
France	12,371	11,401	- 970
Belgium	2,154	46,779	44,625
Canada	8,081	93,471	85,390
Netherlands	8,987	178,111	169,124
Mexico	3,452	63,964	60,512
Argentina	1,927	N.A. ^c	- 1,500
Brazil	98	59,444	59,346
All other	28,103	498,985	470,882
Total	293,836	1,008,200	714,364
1977:			
West Germany	105,172	5,038	-100,134
Japan	65,770	30,736	- 35,034
Italy	32,711	N.A. ^c	- 32,500
United Kingdom	31,132	27,458	- 3,674
Switzerland	21,956	6,541	- 15,415
France	15,763	N.A. ^c	- 15,500
Belgium	9,839	61,126	51,287
Canada	7,270	82,676	75,406
Netherlands	4,858	156,581	151,723
Mexico	4,673	62,965	58,292
Argentina	3,353	6,283	2,930
Brazil	538	78,512	77,974
All Other	22,865	477,469	454,604
Total	325,900	995,385	669,485

^aData represent customs import value, the value appraised by the U.S. Customs Service in accordance with the legal requirements of sec. 402 and 402a of the Tariff Act of 1930, as amended.

^bIncludes exports of some finished products. Figures include estimates and are not strictly comparable with imports.

^cN.A. = Not available.

TABLE 9-8. INDUSTRIAL ORGANIC CHEMICALS:
U.S. IMPORTS FOR CONSUMPTION, BY PRINCIPAL SOURCES, 1972-77^a
(\$10³)^a

Source	1972	1973	1974	1975	1976	1977
West Germany	66,085	72,715	84,059	62,145	94,768	105,172
Japan	36,181	29,793	65,027	49,243	61,228	65,770
Italy	11,305	10,705	17,323	19,073	30,678	32,711
United Kingdom	7,605	10,433	21,119	18,820	24,709	31,132
Switzerland	11,593	16,063	15,846	14,773	17,280	21,956
France	1,611	4,233	8,585	9,797	12,371	15,763
Belgium	1,220	7,919	10,494	1,871	2,154	9,839
Canada	4,301	5,515	4,826	4,352	8,081	7,270
Netherlands	5,067	4,724	10,291	6,738	8,987	4,858
Mexico	35	486	1,812	388	3,452	4,673
Argentina	3	--	--	657	1,927	3,353
All other	5,031	6,892	19,190	17,625	28,201	23,403
Total	150,037	169,478	258,572	205,482	293,836	325,900

^aCustoms import value, the value appraised by the U.S. Customs Service in accordance with the legal requirements of sec. 402 and 402a of the Tariff Act of 1934, as amended.

ments in the U.S. economy. Third, the projections are developed for the the period 1979-1991, entirely covering the forecast period of interest in this study (1981-1985).

In order to estimate the number of new model units covered by the regulatory alternatives, it is assumed that the number of operating facilities will grow at the same rate as the industry's output. It is further assumed that any regulatory alternative will take effect on January 1, 1981, and therefore that the fifth year of the impact analysis is 1985. In 1976 (the most recent year for which data are available), 1,334 facilities manufactured SOCFI chemicals in the U.S.¹¹ If the industry grows at an annual rate of 5.9 percent, by the beginning of 1981 this number will have risen to 1,678 facilities and by the end of 1985 to 2,235 facilities. Thus, an estimated 557 units built to provide additional capacity for the industry will be covered by the regulatory alternatives.

The regulatory alternatives will also cover units constructed to replace existing capacity which "wears out" during the period. The number of replacement units is estimated on the basis of the following assumptions. First, units have a working life of 20 years. Second, the historical growth rate for SOCFI prior to 1977 was 6 percent per year. Using these assumptions, it is estimated that 274 new units will be required to replace the part of the existing capacity that will "wear out" over the period 1981 to 1985. The methodology used to compute this estimate is described in detail in Appendix E2.

The estimates for entirely new units, combined with estimates for replacement facilities, indicate a total of 831 units that will be affected by the regulation. To estimate the number of A, B and C model units (identified in Section 6.1) that will be constructed between 1981 and 1985, it is

assumed that the mix of model units will not change over time, and that the percentages of A, B and C model units are as follows:

Model unit	Percent of existing units
A	52
B	33
C	15

If these percentages are applied to the estimate of the total number of units presented above, they imply that 432 A units, 274 B units and 125 C units will be affected by the regulatory alternatives.

9.2 Economic Impact Analysis

9.2.1 Market Structure and Financial Profile

SOCMI producers manufacture 378 chemicals, each of which has its own national and regional markets. Consequently, SOCMI firms encounter a wide range of market situations for the different chemicals they produce. Many SOCMI chemicals, for example, formaldehyde, urea and benzene, are manufactured by a relatively large number of firms using an array of different processes. The products have a wide range of end uses in which substitute materials can often be used. Thus industry-wide elasticities of demand for the chemicals are relatively high. In this type of market situation, producers have little or no ability to pass on cost increases to consumers in the form of higher market prices. Other SOCMI chemicals, for example, succinonitrile, isoamylene, and methyl butynol, are manufactured by a small number of producers and in some cases only one producer, and have no close substitutes in their end uses. In these oligopolistic and monopolistic markets, producers may be able to exercise considerable influence on market prices and to pass on a large part or all of any production cost increases in the form of higher prices.

The ability of firms to pass on cost increases in the form of price increases is influenced by the extent to which the industry is vertically and horizontally integrated. There is extensive vertical integration within the SOCFI. Captive consumption in the industry averaged 53.7 percent* of total output during the period 1967-1978, and this ratio varied only slightly from year to year. The precise degree of horizontal integration within SOCFI is difficult to evaluate because it varies considerably among products. However, a general assessment of the industry-wide situation may be made using the capacity share data presented in Table 9-9. These data suggest that no one company or group of companies has a dominant position within the industry. In 1976, the top four companies owned only 18.3 percent and the top twenty firms 45.4 percent of total SOCFI capacity. There is no reason to believe that the extent of industry-wide market concentration has altered significantly since that time.

Data on the returns on equity, returns on debt, returns on preferred stock, debt-asset ratios, equity-asset ratios and preferred stock-asset ratios were collected for a sample of 100 chemical manufacturing firms for the most recent available years.† These data are presented in Table E3-2. The data have been used to estimate the cost of capital to firms in the SOCFI, using the assumption that the sample of firms in Table E3-2 is unbiased and normally distributed. A detailed discussion of the methodology used to estimate the cost of capital is presented in Appendix E3.

The estimated cost of capital, presented in Table 9-10, is used in Section 9.2.3 to estimate the economic impacts of SOCFI fugitive emissions regu-

*This figure is estimated from data presented in Table 9-4.

†Data on the ratio variables and rates of return were available for 1977 and 1978, respectively.

TABLE 9-9. INDUSTRY CONCENTRATION, 1976⁴

Number of firms	Percent of firms	Estimated capacity (gg)	Percent of industry capacity
Top 4	0.72	58.75	18.3
Top 8	1.43	91.82	28.6
Top 20	3.58	145.75	45.4
Top 40	7.17	186.68	58.1

TABLE 9-10. ESTIMATED COST OF CAPITAL FOR FIRMS IN SOCMI^a

	Aftertax cost of capital	Pretax cost of capital
Mean	10.807%	20.783%
Standard deviation	0.930	1.789
Minimum	8.015%	15.414%
Maximum	12.798%	24.612%

^aSee Appendix E3 for details of the data and methodology used to estimate the cost of capital for firms in SOCMI.

latory alternatives. Note that the average aftertax cost of capital for chemical firms is 10.8 percent. On a pretax basis, this figure increases to 20.8 percent. If, as was assumed, capital costs are normally distributed, then 95 percent of the firms in the industry face aftertax costs of capital in the range of 9.0 percent to 12.7 percent and pretax costs of capital in the range of 17.2 percent to 24.4 percent.

9.2.2 Regulatory Alternatives

The four regulatory alternatives being considered are described in detail in Section 6.2. The baseline regulatory alternative (alternative I) does not require producers to implement additional control techniques. Consequently, model units complying with this alternative would not incur any incremental costs* and no economic impacts would result from its implementation. Regulatory alternatives II, III, and IV require successively more stringent equipment inspections and equipment specifications. Firms complying with regulatory alternatives II, III, and IV would therefore incur incremental costs, and consequently economic impacts would result from their implementation.

9.2.3 Economic Methodolgy

9.2.3.1 Regulatory Scenarios

Economic impacts are estimated for regulatory alternatives II, III and IV, but not for regulatory alternative I, since firms will not incur incremental costs in complying with that alternative. The economic impacts associated with alternatives II, III and IV are estimated under two alterna-

*Incremental costs of a regulatory alternative are those additional costs a firm incurs in meeting the regulatory alternative that it would not incur in meeting the baseline alternative.

tive assumptions about firm pricing behavior: (1) full cost absorption and (2) full cost pricing. Combining the three regulatory alternatives with the two alternative pricing models yields six regulatory scenarios:

	<u>Regulatory Alternative</u>	<u>Pricing Policy</u>
<u>Scenario 1</u>	Alternative II	Full Cost Absorption
<u>Scenario 2</u>	Alternative II	Full Cost Pricing
<u>Scenario 3</u>	Alternative III	Full Cost Absorption
<u>Scenario 4</u>	Alternative III	Full Cost Pricing
<u>Scenario 5</u>	Alternative IV	Full Cost Absorption
<u>Scenario 6</u>	Alternative IV	Full Cost Pricing

Under full cost absorption, the affected firm bears the full incremental costs of environmental controls, accepting a lower rate of return on its capital investment. Under full cost pricing, the firm adjusts product prices so as to maintain its current aftertax rate of return on capital investment.

The alternative assumptions about firm pricing behavior are associated with different market conditions in the affected industry. In both cases, firms are assumed to have no monopsony power in resource markets. Thus, they cannot pass back cost increases to resource suppliers. In the cost absorption case, the domestic industry as a whole is assumed to be a price taker, unable to affect the market price of its product either because of the exist-

ence of close product substitutes, or because of strong international competition in domestic and foreign markets. However, full cost pricing will take place if the industry produces a commodity for which no domestic or imported substitutes exist, or if the industry has constant costs. A constant-cost industry is one in which unit costs remain constant as industry output increases. Firms in such industries experience constant returns to scale.

In fact, firms in SOCFI face a wide variety of product market situations (see Section 9.2.1). Some firms will be able to fully pass through cost increases to consumers in the form of higher prices. Some will be able to pass on only a part of the cost increases. Others will be forced to fully absorb all regulatory control costs, leaving product prices unchanged. Consequently, the full cost pass through and full cost absorption scenarios evaluated below provide estimates of the maximum range of possible price and rate of return impacts for the different products and firms in SOCFI.

9.2.3.2 Estimation of Regulatory Price Impacts Under Full Cost Pricing

Under full cost pricing, the firm is assumed to respond to cost increases by adjusting product price to maintain a target rate of return on investment. The required price change (dP) may be calculated using the following equation:*

$$dP = \frac{dTOC + r \, dK/(1-t)}{Q} \quad (1)$$

where

dP = required change in product price

dTOC = total annual operating costs of compliance

dK = total initial costs of compliance

Q = total annual unit output

*The derivations of Equations (1) and (2) are presented in Appendix E4.

r = target rate of return

t = tax rate

9.2.3.3 Estimation of Rate of Return Impacts Under Full Cost Absorption

Under full cost absorption, an increase in facility production costs results in a lower rate of return on investment for the firm, because market conditions prohibit it from passing on cost increases to the consumer. The impact on the facility's rate of return on investment is given by the following equation:

$$-dr = \frac{r \cdot dK + (1-t) dTOC}{K} \quad (2)$$

where

dr = change in rate of return, and

K = preregulation level of capital investment.

Note that pretax rate of return impacts may be calculated by setting the tax rate variable, t , equal to zero in Equations (1) and (2). Also note that price and rate of return impacts are estimated on the assumption that capacity utilization rates remain constant (that is, Q remains unchanged). To the extent that the regulatory alternatives result in decreases (increases) in capacity utilization rates, price and rate of return impacts will be larger (smaller) than those estimated using Equations (1) and (2) because of economies of scale in the use of control techniques.

9.2.3.4 Other Economic Impacts

The price and rate of return impacts estimated by the above techniques are used to make a quantitative assessment of the probable impacts of the regulatory alternatives II, III, and IV on industry growth, new facility openings, the replacement of existing facilities, and investment levels. These data are then used to assess the extent of interindustry and macroeconomic impacts associated with the various regulatory alternatives.

9.2.3.5 Estimation Data

Estimation of price and rate of return impacts for different model units requires data on the following variables: (1) total acquisition and installation costs of the control equipment (dK), (2) total annual operating costs of the control equipment and monitoring procedures (dTOC), (3) the preregulation capital stock (K), (4) the target rate of return (r), (5) the tax rate (t), and (6) model unit production levels (Q). Data on dK and dTOC for each of the three model units identified as representative of the industry* were obtained from Section 8.1. The tax rate is assumed to be 48 percent. Data on model unit production levels were obtained from the 1976 Organic Chemical Producers Data Base for each of the units covered by the regulatory alternatives. The 831 model units are assumed to be distributed by capacity in an identical manner to the 1,105 units for which both value of product and quantity data are available in the 1976 Organic Chemical Producers Data Base. Thus, the number of new units with a given capacity, say 100 Gg, is assumed to be equal to the number of units in the Organic Chemical Producers Data Base with the same capacity, multiplied by the ratio of the number of new units to the number of units in the data base (831/1,105). Actual unit output levels are obtained by applying a capacity utilization rate to the estimated unit capacities.

To evaluate industry-wide impacts, the cost data from Section 8.1 were adjusted to allow for higher or lower product recovery credits for chemicals with a value greater or less than \$0.36/kg. For such chemicals, product recovery credits were estimated by multiplying estimated product savings by the price of the chemical in question.

*See Chapter 6 for a detailed discussion of the model units.

Data on the value of the preregulation capital stock for plants of different capacities were calculated as follows. A capital-capacity coefficient for firms in SOCFI was obtained by dividing the estimated total value of industry assets in 1976 by the volume of output produced in that year.* The estimate of the capital-output coefficient was converted into a capital-capacity coefficient by multiplying the capital-output coefficient by an assumed industry-wide capacity utilization rate. The assumed capacity utilization rate for 1976 was 50 percent. This capacity utilization estimate was based on the assumption that the typical capacity utilization for the industry is 75 percent. In 1976, output was 9.2 percent below the industry-wide high level of output achieved in 1974. Between 1974 and 1976 it is probable that some additions to industry capacity were made. Hence, the assumption of a 50 percent capacity utilization rate for 1976, though somewhat arbitrary, is not unreasonable. The 1976 capital-capacity coefficient was updated to last quarter 1978 dollars using the machinery and equipment price index computed by the United States Department of Commerce.¹² The capital-capacity coefficient estimated by the above procedure was \$125/Mg of product. This coefficient was multiplied by model unit capacity to obtain an estimate of K for each model unit considered in the analysis.

Estimates of pretax and post-tax rates of return used in the analysis are presented in Table 9-10. These data were obtained from an analysis of a sample of 100 firms in the SOCFI industry. Details of the analysis are contained in Appendix E3.

*See Tables 9-4 and 9-5 for data on production and total industry assets.

9.2.4 Economic Impacts

9.2.4.1 Rate of Return Impacts

Data on unit capacity, product value, capital investment and tax rates are available for 1,105 units in the 1976 Organic Chemical Producers Data Base.⁴ Price data were updated using the Chemical Marketing Reporter.¹³ Capital stock estimates were also expressed in 1978 prices. These data were used in conjunction with the cost information presented in Section 8.1 to calculate full cost absorption rate of return impacts of regulatory alternatives II, III, and IV for the 831 model units projected to be built. It is assumed in estimating the rate of return impacts presented here that the 831 new model units will have the same capacity and product value distributions as the units in the Organic Chemical Producers Data Base, and that capacity utilization for each unit is 50 percent. This relatively low capacity utilization rate is used to estimate unit output levels because it represents a feasible worst-case economic scenerio for the industry (that is, economic conditions similar to those experienced in 1976). As a result, actual impacts are likely to be less adverse than those presented below.

Rate of return impacts are estimated on the basis of these assumptions for each of the 831 new model units covered by the regulatory alternatives. It is probable that the assumption of a constant product price distribution also results in an overestimate of adverse rate of return and price impacts, since the prices of the products manufactured by SOCFI are expected to increase between 1979 and 1985 as energy and feedstock costs rise. Any real increase in product prices will raise the value of product recovery credits, lower the net costs of compliance associated with any given regulatory alternative, and thereby reduce adverse rate of return and price impacts.

Rate of return impacts for A, B and C average model units under each reg-

ulatory alternative are presented in Table 9-11. Each of these average model units is assumed to manufacture products valued at approximately \$0.36/kg, to have an annual capacity of 84,678 Mg and to have an existing cost of capital of 10.81 percent. These average model units differ only in terms of the complexity of the processes they use to manufacture the chemicals. The product value and rate of return data represent the means for each variable in the samples used in the analysis. Under regulatory alternatives II and III, each average model unit experiences a very small increase, not a decrease, in its aftertax rate of return on investment, regardless of the process it uses. This result is obtained because at a price of \$0.36/kg for recovered product, product recovery credits exceed total annualized costs of control. Under regulatory alternative IV, average model unit of types A and B experience small decreases in aftertax rates of return on investment. Model C units experience rate of return decreases amounting to 1.12 percentage points, still quite small adverse impacts.

The data presented in Table 9-11 suggest that some firms may benefit from the implementation of any regulatory alternative. These results are subject to the following qualifications. In the above analysis, it is assumed that firms will not independently implement the emissions controls proposed in the regulatory alternatives. In fact, if there are significant net cost reductions to be achieved from additional emissions controls, firms will voluntarily adopt them. Under such circumstances, the cost reductions associated with any regulatory alternative will be considerably smaller. Note that incentives for voluntary emissions controls increase as the value of the manufactured product increases. As some SOCM I producers manufacture highly valued products with prices in excess of \$0.50/kg, they are likely to be willing to use extensive emissions control techniques in the absence of any NSPS.

TABLE 9-11. AVERAGE RATE OF RETURN IMPACTS^a

Model Units	Change in rate of return (percentage points)		
	Alternative II	Alternative III	Alternative IV
Unit A	+0.000	+0.000	-0.16
Unit B	+0.003	+0.001	-0.37
Unit C	+0.006	+0.005	-1.12

^aImpacts are estimated on the assumption that the initial aftertax rate of return on investment is 10.807 percent, the mean cost of capital presented in Table 9-10; the initial price of the product is \$0.36/kg; plant capacity is 84,678 Mg; and the capacity utilization rate is 50 percent.

Although in general firms will not be affected by the implementation of regulatory alternatives II, III, and IV, because of wide variation in productive capacity and value of product among model units, some will experience adverse rate of return impacts. Estimates of the numbers of model units experiencing rate of return decreases in excess of one and two percentage points as a result of the implementation of each regulatory alternative are presented in Table 9-12. These estimates were obtained by calculating rate of return impacts for each of the 831 new model units under the assumption that 52 percent, 33 percent, and 15 percent of all units of all sizes are A, B and C model units, respectively. Under regulatory alternatives II and III, the estimated number of adversely affected units is very small; only 6 and 12 units, out of a total of 831 model units, experience rate of return decreases of more than one percentage point. Under regulatory alternative IV, a much larger number of units, 93 in all, are estimated to experience rate of return decreases in excess of 1 percent under a full cost absorption scenario. It should be noted that most of these adversely affected units are B and C model units rather than A model units. In fact, all B and C model units with capacities in excess of 26,464 and 89,121 Mg, respectively, producing chemicals with prices exceeding \$0.15/kg, will experience rate of return impacts smaller than one percentage point even under alternative IV. The EPA estimates that virtually all B and C model units do in fact have capacities in excess of this figure,¹⁴ and furthermore, industry sources indicate that most produce chemicals that have prices in excess of \$0.15/kg.¹³ If the estimated impacts on B and C model units are ignored, only 25 units are likely to be adversely affected by regulatory alternative IV.

TABLE 9-12. MODEL UNITS EXPERIENCING SIGNIFICANT RATE OF RETURN IMPACTS
UNDER FULL COST ABSORPTION^a

Model units	Alternative II		Alternative III		Alternative IV	
	dr < -1%	dr < -2%	dr < -1%	dr < -2%	dr < -1%	dr < -2%
Unit A	6	4	7	5	25	12
Unit B	0	0	4	2	34	16
Unit C	0	0	1	0	34	20
Total	6	4	12	7	93	48

^adr denotes the percentage point change in firms' rates of return on investment.

9.2.4.2 Price Impacts

The potential price impacts of regulatory alternatives II, III, and IV are also estimated under the assumption that capacity and value of product distributions will remain constant over the forecast period, 1979-1985. The price impact estimates are therefore subject to the same limitations as the rate of return impact estimates discussed above. Potential price impacts for A, B, and C model units with average capacities of 84,678 Mg and product values of \$0.36/kg are presented in Table 9-13. Under regulatory alternatives II and III, price impacts are negative for each type of model unit because annual product recovery credits exceed the total annualized cost of the monitoring procedures and capital equipment required under these alternatives. Under regulatory alternative IV, extremely small positive price impacts occur. In general most units will not increase product prices as a result of the implementation of regulatory alternatives II, III, or IV. However, because of the variations in capacity and product value within the industry, some firms may have to raise product prices in order to maintain existing rates of return on investment. In some cases, the price increases required by individual facilities are in excess of 5 percent and even 6 percent of the current product price. Data on the estimated numbers of such units are presented in Table 9-14. These estimates are also obtained by calculating price impacts for each of the 831 new model units under the assumption that units are distributed among A, B, and C model units in the manner described above and operate at 50 percent of unit capacity. Under alternatives II and III, only five A and eight B model units would have to increase product prices by more than 5 percent. Under alternative IV, 30 units must increase prices by more than 5 percent to maintain preregulation rates of return on investment. However, it should be noted that these estimates may overstate the extent of

TABLE 9-13. AVERAGE PERCENTAGE PRICE IMPACTS OF REGULATORY ALTERNATIVES^a

Model units	Price changes (percent)		
	Alternative II	Alternative III	Alternative IV
Unit A	-0.000	-0.000	+0.000
Unit B	-0.002	-0.002	+0.000
Unit C	-0.009	-0.007	+0.733

^aImpacts are estimated on the assumption that the target rate of return is 10.807 percent, the average cost of capital presented in Table 9-10; the initial price of the product is \$0.36/kg; plant capacity is 84,678 Mg; and the capacity utilization rate is 50 percent.

TABLE 9-14. MODEL UNITS REQUIRING SIGNIFICANT PRICE INCREASES
TO MAINTAIN TARGET RATES OF RETURN

Model Units	Alternative II Price increase		Alternative III Price increase		Alternative IV Price increase	
	≥ 5%	≥ 6%	≥ 5%	≥ 6%	≥ 5%	≥ 6%
Unit A	4	4	4	4	6	5
Unit B	0	0	2	2	10	9
Unit C	0	0	0	0	14	12
Total	4	4	6	6	30	26

significant price impacts under regulatory alternative IV. Most of the units estimated to require price increases in excess of 5 percent are C model units. In fact, C model units that manufacture chemicals with prices in excess of \$0.15/kg and have capacities greater than 71,550 Mg do not have to increase product prices by more than 5 percent to maintain their target rates of return on investment. The EPA estimates that virtually all plants using processes with the same degree of complexity as that assumed for C model units have larger capacities and produce products with higher values than these.¹³ In addition, model units are assumed to operate at the relatively low capacity utilization rate of 50 percent.

A final caveat concerning price and rate of return impacts should be noted. The impact estimates presented in Tables 9-12 and 9-14 were developed on the assumption that feedstock prices are unaffected by the implementation of any regulatory alternative. However, as the industry extensively uses its own products as feedstocks, this assumption is not strictly valid and introduces a systematic upward bias in the estimated size of adverse rate of return and potential price impacts. The upward bias occurs because, in general, firms adopting alternative II, III, and IV control technologies will achieve net cost reductions and, at least in competitive markets, will tend to reduce rather than increase the prices of products used as feedstocks by the industry.

9.2.4.3 Investment Impacts

It is difficult to assess the impact of any of the standards on the number of units to be constructed between January 1, 1981, and December 31, 1985, because of the variations in these impacts across units. Some smaller facilities may not be erected as a result of the standard because of adverse impacts on rates of return and price competitiveness. Other larger facilities may be

built because production costs fall as a result of emissions reductions and product recovery credits. Therefore, in this analysis it is assumed that implementation of regulatory alternatives II, III, IV will have no measurable impact on the number of new facilities constructed between 1981 and 1985, the 5-year period following proposal of any regulatory alternative. Industry-wide investment impacts are therefore simply the incremental capital costs associated with the acquisition of the capital and monitoring equipment required under each regulatory alternative by the 831 new units expected to be constructed between 1981 and 1985.

Data on these investment impacts are presented in Table 9-15. The estimates are obtained by assuming that 432 A model plants, 274 B model units, and 125 C model units will be constructed and that, as a result of each regulatory alternative, these units incur incremental capital costs equal to those presented in Section 8.2. Under regulatory alternatives II and III, industry-wide investment impacts are quite small, less than \$22 million. Under regulatory alternative IV, they increase substantially to almost \$233 million. Nevertheless, even under regulatory alternative IV, the total 5-year investment impacts of any of the regulatory alternatives would be less than 1.14 percent of total industry assets in 1976 and less than 1.64 percent of the value of industry sales in 1978.* It appears, therefore, that the industry as a whole will not have much difficulty in obtaining the investment funds to acquire required control equipment under any of the regulatory alternatives.

*Data on total industry value of assets and industry sales are presented in Table 9-4 and 9-5.

TABLE 9-15. INVESTMENT IMPACTS

Model units	Number of model units	Incremental model unit costs of control (\$10 ⁶)	Incremental industry costs of control (\$10 ⁶)
<hr/>			
Regulatory alternative II			
Unit A	432	0.0132	5.7
Unit B	274	0.0272	7.5
Unit C	125	0.0660	8.3
Total	831	---	21.5
<hr/>			
Regulatory alternative III			
Unit A	432	0.0132	5.7
Unit B	274	0.0272	7.5
Unit C	125	0.0660	8.3
Total	831	---	21.5
<hr/>			
Regulatory alternative IV			
Unit A	432	0.0871	37.6
Unit B	274	0.2950	80.8
Unit C	125	0.9110	113.9
Total	831	---	232.3
<hr/>			

9.2.4.4 Employment Impacts

Regulatory alternatives II, III, and IV will each have small but measurable impacts on employment in SOCFI because they require firms to intensify monitoring and maintenance schedules to control fugitive emissions. Estimates of the number of additional workers required as a result of each regulatory alternative are presented in Table 9-16. The estimates were obtained by multiplying the projected numbers of each type of affected facility by the unit-by-unit, person-year monitoring and maintenance requirements for each standard presented in section 8.1.* The largest employment impacts (400 workers) are associated with regulatory alternative III, which requires more stringent monitoring programs than alternative II. Under alternative IV, some alternative III monitoring requirements are replaced by equipment controls, reducing incremental employment requirements to approximately 225 workers. The employment impacts of each of the standards are small relative to total employment in the industry, representing no more than 0.6 percent of the 1976 SOCFI work force in each case.

9.2.4.5 Total Annualized Costs of Control

Total incremental annualized costs of control for the fifth year following promulgation of alternatives II, III, or IV are presented in Table 9-17. Product recovery credits are calculated using the fourth quarter 1978 industry-wide average product price of \$0.36/kg. Under regulatory alternatives II and III, the industry as a whole is estimated to reduce annualized production costs by \$28.73 million and \$21.35 million, respectively. Under regulatory alternative IV, annualized production costs are estimated to

*A person-year is assumed to consist of 2,000 person-hours.

TABLE 9-16. EMPLOYMENT IMPACTS
(Person-years)

Model unit	Alternative II		Alternative III		Alternative IV	
	Unit	Industry	Unit	Industry	Unit	Industry
Unit A	0.1237	53.43	0.1855	80.14	0.0579	25.01
Unit B	0.1863	51.05	0.5079	139.16	0.2277	62.39
Unit C	0.5017	62.71	1.4532	181.65	1.0982	137.27
All units		167.19		400.95		224.67

TABLE 9-17. MODEL UNIT AND INDUSTRY ANNUALIZED CONTROL COSTS

Regulatory alternative	No. of model units	Incremental unit annualized costs without product recovery credit (\$10 ³)	Incremental unit annualized costs with product recovery credit ^a (\$10 ³)	Incremental industry annualized costs with product recovery credit ^a (\$10 ³)
Alternative II				
Unit A	432	12.1	- 3.3	- 1,430
Unit B	274	20.3	- 38.5	-10,550
Unit C	125	48.3	-134.0	-16,750
Total				-28,730
Alternative III				
Unit A	432	15.0	- 1.7	- 730
Unit B	274	35.5	- 28.3	- 7,750
Unit C	125	95.1	-103.0	-12,870
Total				-21,350
Alternative IV				
Unit A	432	29.0	7.9	3,410
Unit B	274	93.5	13.3	3,640
Unit C	125	283.0	33.0	4,120
Total				11,170

^aProduct recovery credits estimated on the basis of an assumed product value of \$0.36/kg.

increase by \$11.17 million. If the above estimates are accurate in the minimal sense that they indicate the direction in which production costs will move and their approximate order of magnitude, then it may be concluded that none of the regulatory alternatives will result in any measurable industry-wide increase in prices.

9.2.4.6 Interindustry Impacts

Interindustry impacts will be negligible, because net annualized costs of control are extremely small relative to the value of total industry output, representing less than 0.03 percent of the value of 1978 output in even the most adverse case (regulatory alternative IV).

9.3 Socio-Economic and Inflationary Impacts

The socio-economic and inflationary impacts of alternatives II, III and IV will be very small.

- (1) Annualized Costs: In the fifth year following promulgation, the regulatory alternatives, if implemented, are estimated to result in either annualized cost reductions or very small annualized cost increases. Consequently, none of the alternatives violates the regulatory criterion of \$100 million.
- (2) Price Impacts: Because industry-wide annualized costs of compliance for alternatives II, III and IV are estimated to be negative or extremely small relative to the value of industry output, none of the standards is likely to cause any industry-wide price increases.

REFERENCES

1. Condensed Chemical Dictionary. Rev. by Gessner Hawley, 8th ed. New York: Van Nostrand Reinhold Co, 1971.
2. Comer, James F. Synthetic Organic Chemicals Manufacturing Industry: Inputs and Product Uses. Prepared for the U.S. Environmental Protection Agency, 1979.
3. Proceedings of the Conference on Chemical Feedstock Alternatives. American Institute of Chemical Engineers, Houston, TX, 1977.
4. Radian Corp. "Organic Chemical Producers Data Base, 1976." Prepared for the U.S. Environmental Protection Agency under EPA Contract No. 68-03-2623. 1978.
5. United States International Trade Commission. Synthetic Organic Chemicals, U.S. Production and Trade. Washington, D.C., 1967-1978.
6. United States Department of Commerce. Annual Survey of Manufactures, Industry Profiles, 1976. Washington, D.C.
7. Russell, T.W.F., M.W. Swartzlander, and J. Wei. The Structure of the Chemical Processing Industries. New York: McGraw Hill, 1979. pp. 321-334.
8. United States International Trade Commission. Imports of Benzenoid Chemicals and Products, 1978. Washington, D.C., July 1979.
9. United States International Trade Commission. "Import Penetration of U.S. Markets for Cyclic Intermediates." Synthetic Organic Chemicals: U.S. Production and Sales -1977. Washington, D.C., 1978.
10. The American Economy, Prospects for Growth to 1991. New York: McGraw Hill, 1979.
11. Radian Corp. "Organic Chemical Producers Data Base, 1978." Prepared for the U.S. Environmental Protection Agency under EPA Contract No. 68-03-2623. 1979.
12. United States Department of Commerce. Survey of Current Business. Washington, D.C., 1976-1979.
13. Chemical Marketing Reporter. September 7, 1979.
14. Memo from Hustvedt, K.C. December 20, 1979. Model Unit Capacities.

APPENDIX C. EMISSION SOURCE TEST DATA

APPENDIX C

EMISSION SOURCE TEST DATA

The purpose of Appendix C is to describe testing results used in the development of the Background Information Document (BID) for fugitive emissions from the Synthetic Organic Chemicals Manufacturing Industry (SOCMI). The information in this appendix consists of a description of the tested facilities, and the sampling procedures and test results of fugitive emissions studies in SOCMI and the petroleum refining industry.

Considerable data exist concerning both the incidence and magnitude of fugitive emissions from petroleum refineries. The purpose of the SOCMI study was, in part, to support the use of emission factors generated during studies of emissions from petroleum refineries for similar sources in the Synthetic Organic Chemicals Manufacturing Industry. The results of the SOCMI study and data from a study of fugitive emissions from petroleum refineries are discussed in Section C.1.

Section C.2 consists of the results of three studies on the effects of maintenance on reducing fugitive VOC emissions from valves in petroleum refineries and one study on maintenance of valves in a SOCMI process unit. These results are included as an indication of the reduction in emissions which could be expected as a function of the designated action level, and by applying routine on-line maintenance procedures.

C.1 FUGITIVE EMISSIONS TEST PROGRAMS

The SOCMI test program conducted by EPA personnel and EPA contractors consisted of emissions testing in six chemical process units. Data were collected pertaining to the percentage of fugitive emission sources found to be leaking, as indicated by the VOC concentration measured at the source.

The results of a study on fugitive emissions from petroleum refineries are also discussed in this section. Data on fugitive emissions were obtained from thirteen refineries located in major refining areas throughout the

country. Data on the effects of maintenance were obtained at the last four of these refineries. These results are discussed later in Section C.2 of this Appendix.

The test procedures and the results obtained for each of these studies are described in detail in the following sections.

C.1.1 Description and Results of SOCFI Study

The objective of this test program was to gather data on the percentage of sources which leak (as defined by a VOC concentration at the leak interface of $\geq 10,000$ ppmv). To achieve this objective, an attempt was made to screen all potential leak sources (generally excluding flanges) on an individual component basis with a portable organic vapor analyzer. The test crews relied on plant personnel to identify equipment handling organics. Normally all pumps and compressor seals were examined, and the percentage of valves carrying VOC which were screened ranged from 33 to 85 percent. All tests were performed with a Century Systems Corporation Organic Vapor Analyzer, Model 108, with the probe placed as close to the source as possible. The results of this study are shown in Table C-1.

Six chemical process units were screened. Unit A is a chlorinated methanes production facility in the Gulf Coast area which uses methanol as feedstock material. The individual component testing was conducted during September 1978. Unit B is a relatively small ethylene production facility on the West Coast which uses an ethane/propane feedstock. Testing was conducted during October 1978. Unit C is a chlorinated methanes production facility in the Midwest. This plant also uses methanol as the basic organic feedstock. Over the last few years, several pieces of equipment have been replaced with equipment the company feels is more reliable. In particular, the company has installed certain types of valves which they have found do not leak "as much" as other valves.

The individual component testing was conducted during January 1979. Unit D is an ethylene production facility on the Gulf Coast, using an ethane/propane feed. The facility is associated with a major refinery, and testing was conducted during March 1979. Units E and F are part of an intermediate size integrated petroleum refinery located in the North Central United States. Testing was conducted during November 1978. Unit E is an aromatics extraction unit that produces benzene, toluene, and xylene by extraction from refined petroleum feedstocks. Unit E is a new unit and special attention was paid during the design and startup to minimize equipment leaks. All valves were repacked before startup (adding 2 to 3 times the original packing) and all pumps in benzene service had double mechanical seals with a barrier fluid. Unit F produces benzene by hydrodealkylation of toluene. Unit F was originally designed to produce a different chemical and was redesigned to produce benzene.

In general, chloromethane plants had fewer leaks than the ethylene production facilities.

C.1.2 Description and Results of Refinery Fugitive Emissions Study

Data concerning the leak frequencies and emission factors for various fugitive sources were obtained primarily at nine refineries. More complete information for compressors and relief valves emissions was obtained by sampling at four additional refineries. Refineries were selected to provide a range of sizes and ages and all of the major petroleum refinery processing units were studied. The type of process units and the number of each studied in the first nine refineries are listed in Table C-2.

TABLE C-1. FREQUENCY OF LEAKS FROM FUGITIVE EMISSION SOURCES IN
SYNTHETIC ORGANIC CHEMICAL UNITS

Equipment type	Unit A ^c Chloromethanes		Unit B ^c Ethylene		Unit C ^d Chloromethanes		Unit D ^e Ethylene		Unit E ^f BTX Recovery		Unit F ^f Toluene HDA	
	Number of sources tested	Percent with screening values ≥10,000 ppmv	Number of sources tested	Percent with screening values ≥10,000 ppmv	Number of sources tested	Percent with screening values ≥10,000 ppmv	Number of sources tested	Percent with screening values ≥10,000 ppmv	Number of sources tested	Percent with screening values ≥10,000 ppmv	Number of sources tested	Percent with screening values ≥10,000 ppmv
Valves	600	1	2301	19	658	0.1	862	14	715	1.1	427	7.0
Open-ended lines	52	2	386	11	- ^a		90	13	33	0.0	28	11.0
Pump seals	47	15	51	21	39	3	63	33	33 ^b	3.0	30	10.0
Compressor seals	- ^a		42	59	3	33	17	6	- ^a		- ^a	
Control valves	52	6	128	20	25	0	25	44	53	4.0	44	11.0
Pressure relief valves	7	0	- ^a		- ^a		- ^a		- ^a		- ^a	
Flanges	30	3	- ^a		- ^a		- ^a		- ^a		- ^a	
Drains	- ^a		- ^a		- ^a		39	10	- ^a		- ^a	

^a No data

^b Pump seals in benzene service have double mechanical seals

^c Source: Reference 1

^d Source: Reference 2

^e Source: Reference 3

^f Source: Reference 4

TABLE C-2. SAMPLED PROCESS UNITS FROM NINE REFINERIES
DURING REFINERY STUDY

Refinery process unit	Number of sampled units
Atmospheric distillation	7
Vacuum distillation	4
Thermal operations (coking)	2
Catalytic cracking	5
Catalytic reforming	6
Catalytic hydrocracking	2
Catalytic hydrotreating	2
Catalytic hydrorefining	7
Alkylation	6
Aromatics/isomerization	3
Lube oil manufacture	2
Asphalt manufacture	1
Fuel gas/light-ends processing	11
LPG	2
Sulfur recovery	1
Other	3

Source: Ref. 5

In each refinery, sources in six to nine process units were selected for study. The approximate number of sources selected for study and testing in each refinery is listed below:

Valves	250-300
Flanges	100-750
Pump seals	100-125
Compressor seals	10-20
Drains	20-40
Relief Valves	20-40

There were normally 500-600 sources selected in each refinery.

The distribution of sources among the process units was determined before the selection and testing of individual sources was begun. Individual sources were selected from piping and instrumentation diagrams or process flow diagrams before a refinery processing area was entered. Only those preselected sources were screened. In this way, bias based on observation of individual sources was theoretically eliminated.

The screening of sources was accomplished with portable organic vapor detectors. The principal device used in this study was the J. W. Bacharach Instrument Co. "TLV Sniffer". The components were tested on an individual basis, and only those components with VOC concentrations in excess of 200 ppmv were considered for further study.

A substantial portion of these leaking sources were enclosed and sampled to determine both the methane and nonmethane emission rates. An important result of this program was the development of a correlation between the maximum observed screening value (VOC concentration) and the measured nonmethane leak rate.

Emission factors and leak frequency information generated during this study are given in Table C-3.

C.1.3 Comparison of Fugitive Emissions Test Data

The results of the SOCFI study and those of the refinery emissions study are compared in Table C-4. Fugitive emission leak frequencies for similar source types appear to correlate, particularly for valves and pump seals.

TABLE C-3. LEAK FREQUENCIES AND EMISSION FACTORS FROM FUGITIVE SOURCES IN PETROLEUM REFINERIES

Equipment type	Percent of sources having screening values $\geq 10,000$ ppmv	Estimated emission factor for refinery sources, kg/hr-source
Valves	NA	NA
Gas service	10	0.021
Light liquid service	12	0.010
Heavy liquid service	0	0.0003
Pump seals	NA	NA
Light liquid service	23	0.12
Heavy liquid service	2	0.02
Compressor seals (hydrocarbon service)	33	0.44
Pressure relief valves	8	0.086
Gas service		0.16
Light liquid service		0.006
Heavy liquid service		0.009
Flanges	0	0.0003
Open-ended lines	NA	NA
Gas service		0.025
Light liquid service		0.014
Heavy liquid service		0.003

Source: Ref. 5

TABLE C-4. COMPARISON OF LEAK FREQUENCIES FOR FUGITIVE EMISSION SOURCES IN SOCFI UNITS AND PETROLEUM REFINERIES

Equipment type	Percent of SOCFI sources having screening values $\geq 10,000$ ppmv ^a	Percent of petroleum refinery sources having screening values $\geq 10,000$ ppmv
Valves (all)	11 ^c	NA
Gas service		10
Light liquid service		12
Heavy liquid service		0
Open-ended lines (all)	10	NA
Gas service		
Light liquid service		
Heavy liquid service		
Pump seals (all)	17	NA
Light liquid service		23
Heavy liquid service		2
Compressor seals (hydrocarbon service)	43	33
Pressure relief valves (all)	0	8
Gas service		
Light liquid service		
Heavy liquid service		
Flanges (all)	3	0

^aSource: Table C-1.^bSource: Table C-2.^cIncludes block and control valves.

C.2 MAINTENANCE TEST PROGRAMS

The results of four studies on the effects of maintenance on fugitive emissions from valves are discussed in this section. The first two studies were conducted by refinery personnel at the Union Oil Co. refinery in Rodeo, California, and the Shell Oil Co. refinery in Martinez, California. These programs consisted of maintenance on leaking valves containing fluids with vapor pressures greater than 1.5 Reid Vapor Pressure. The third study was conducted by Radian Corporation, under contract to EPA. Valves were selected and maintained at four refineries. The fourth study was conducted by EPA and EPA contractors at Unit D (ethylene unit). The study results and a description of each test program are given in the following sections.

C.2.1 Description and Results of the Union Maintenance Study⁶

The Union valve maintenance study consisted of performing undirected maintenance on valves selected from 12 different process units. Undirected maintenance consists of performing valve repairs without simultaneous measurement of the effect of repair on the VOC concentration detected. This is in contrast to directed maintenance where emissions are monitored during the repair procedure. With directed maintenance, repair procedures are continued until the VOC concentration detected drops to a specified level or further reduction in the emission level is not possible. Also, maintenance may be curtailed if increasing VOC concentrations result.

The Union data was obtained with a Century Systems Corporation Organic Vapor Analyzer, OVA-108. All measurements were taken at a distance of 1 cm from the seal.

Correlations developed by EPA have been used to convert this data from readings taken at one centimeter to equivalent readings at the leak interface.⁷ This facilitates comparison of data from different studies and allows the estimation of emission rates based on screening value-leak rate correlations.

The results of the Union study are given in Table C-5. Two sets of results are provided; the first includes all repaired valves with initial screening values greater than or equal to 5300 ppmv, and the second includes valves with initial screening values below 5300 ppmv. A screening value of 5300 ppmv, obtained with the OVA at 1 cm from the leak interface, is equivalent to a screening value of 10,000 ppmv measured by a Bacharach

TABLE C-5. SUMMARY OF MAINTENANCE STUDY RESULTS FROM THE UNION OIL CO.
REFINERY IN RODEO, CALIFORNIA^a

	All valves with initial screening values ≥5300 ppmv ^b	All valves with initial screening values <5300 ppmv
Number of repairs attempted	133	21
Estimated emissions before maintenance, kg/hr	9.72	0.323
Estimated emissions after maintenance, kg/hr	4.69	0.422
Number of successful repairs (<5300 ppmv after maintenance)	67	--
Number of valves with decreased emissions	124	13
Number of valves with increased emissions	9	8
Percent reduction in emissions	51.8	-30.5
Percent successful repairs	50.4	--
Percent of valves with decreased emissions	93.2	61.9
Percent of valves with increased emissions	6.8	38.1

^aSource: Ref. 6.

^bThe value 5300 ppmv, taken with the OVA-108 at 1 cm., generally corresponds to a value of 10,000 ppmv taken with a "TLV Sniffer" at 0 cm.

Instrument Co. "TLV Sniffer" directly at the leak interface. The OVA-1 cm readings have been converted to equivalent TLV-0 cm readings because:

- 1) EPA correlations which estimate leak rates from screening values were developed from TLV-0 cm data.
- 2) Additional maintenance study data exists in the TLV-0 cm format.
- 3) Method 21 specifies 0 cm screening procedures.

The results of this study indicate that maintenance on valves with initial screening values above 5300 ppm is much more effective than maintenance on valves leaking at lower rates. In fact, this study indicates that emissions from valves are reduced 51.8 percent for valves initially over 5300 ppmv while valves with lower initial screening values experienced an increase in emissions of 30.5 percent.

C.2.2 Description and Results of the Shell Maintenance Study⁸

The Shell maintenance program consisted of two parts. First, valve repairs were performed on 172 leaking valves. In the second part of the program, 163 of these valves were rechecked and additional maintenance was performed. The second part of the program was conducted approximately one month after the initial maintenance period. It was not determined whether the maintenance procedures were directed or undirected, based on the information reported by Shell.

VOC emissions were measured using the OVA-108 and readings were obtained one centimeter from the source. This data has been transformed to TLV-0 cm values as was the Union data. And, the same methods of data analysis described in Section C.2.1 have been applied to the Shell data. The results of the Shell maintenance study are given in Table C-6.

C.2.3 Description and Results of the EPA/Radian Maintenance Study⁹

Repair data were collected on valves located in four refineries. The effects of both directed and undirected maintenance were

TABLE C-6. SUMMARY OF MAINTENANCE STUDY RESULTS FROM THE SHELL OIL COMPANY REFINERY IN MARTINEZ, CALIFORNIA

	March maintenance		April maintenance	
	All repaired valves with initial screening values ≥ 5300 ppmv ^b	All repaired valves with initial screening values < 5300 ppmv	All repaired valves with initial (March) screening values ≥ 5300 ppmv	All repaired valves with initial (March) screening values < 5300 ppmv
Number of repairs attempted	161	11	152 ^d	11 ^e
Estimated emissions before maintenance, kg/hr ^c	11.08	0.159	2.95	0.060
Estimated emissions after maintenance, kg/hr ^c	2.66	0.0	0.421	0.0
Number of successful repairs (< 5300 ppmv after maintenance)	105	--	45	--
Number of valves with decreased emissions	161	11	151	11
Number of valves with increased emissions	0	0	1	0
Percent reduction in emissions	76.0	100.0	85.7	100.0
Percent successful repairs	65.2	--	83.3	--
Percent of valves with decreased emissions	100.0	100.0	99.3	100.0
Percent of valves with increased emissions	0.0	0.0	0.7	0.0

^aSource: Ref. 8.

^bThe value 5300 ppmv, taken with the OVA-108 at 1 cm., generally corresponds to a value of 10,000 ppmv taken with a "TLV Sniffer" at 0 cm.

^cShell reported the screening value of all valves which measured < 3000 ppmv (< 1500 ppm-TLV at 0 cm.) as non-leakers.

^dInitial value of 90 of these valves was < 1500 ppm-TLV at 0 cm., 54 valves screened ≥ 5300 (note nine valves from initial data set not rechecked in April).

^eInitial value of 10 of these valves was < 1500 ppm-TLV at 0 cm.

evaluated and other data, including valve size and type and the processes' fluid characteristics, was obtained. Screening data were obtained with the Pacharach Instrument Co. "TLV Sniffer" and readings were taken as close to the source as possible.

Unlike the Shell and Union studies, emission rates were not based on the screening value correlations. Rather each valve was sampled to determine emission rates and after maintenance using techniques developed by EPA during the refinery emission factor study. These values were used to evaluate emissions reduction.

The results of this study are given in Table C-7. Of interest here is a comparison of the emissions reduction for directed and undirected maintenance. The results indicate that directed maintenance is more effective in reducing emissions than is undirected maintenance, particularly for valves with lower initial leak rates. The results shown an increase in total emissions of 32.6% for valves with initial screening values less than 10,000 ppmv which were subjected to undirected maintenance. However, this increase is due to a large increase in the emission rate of only one valve.

C.2.4 Description and Results of Unit D (Ethylene Unit) Maintenance Study

Maintenance was performed by Unit D personnel. VOC concentration measurements were made using the OVA-108, and readings were obtained at the closest distance possible to the source. The results of this study are shown in Table C-8. Directed and undirected maintenance procedures were used. The results show that directed maintenance results in more repairs being successfully completed than when undirected maintenance is used.

C.2.5 Comparison of Maintenance Study Results

Generally speaking, the results of these maintenance programs would tend to support the following conclusions:

- A reduction in emissions may be obtained by performing maintenance on valves with screening values above 10,000 ppmv (measured at the source).
- The reduction in emissions due to maintenance of valves with screening values below 10,000 ppmv is not as dramatic and may result in increased emissions.

TABLE C-7. SUMMARY OF EPA REFINERY MAINTENANCE STUDY RESULTS

	Repaired values with initial screening values $\geq 10,000$ ppmv		Repaired values with initial screening values $< 10,000$ ppmv	
	Directed Maintenance	Undirected Maintenance	Directed Maintenance	Undirected Maintenance
Number of valves repaired	9	23	10	16
Measured emissions before maintenance kg/hr	0.107	1.809	0.0332	0.120
Measured emissions after maintenance kg/hr	0.0139	0.318	0.0049	0.159
Number of successful repairs (<10,000 ppmv after maintenance)	8	13	-	-
Number of valves with decreased emissions	9	21	6	15
Number of valves with increased emissions	0	2	4	1
Percent reduction in emissions	87.0	82.4	85.2	-32.6
Percent successful repairs	88.9	56.5	-	-
Percent of valves with decreased emissions	100.0	91.3	60.0	93.8
Percent of valves with increased emissions	0.0	8.7	40.0	6.3

Source: Ref.9

TABLE C-8. UNIT D ETHYLENE UNIT BLOCK VALVE REPAIRS

Action Level: $\geq 10,000$ ppm Instrument: "OVA-108" VOC detector
 Distance from Source: Maximum concentration at seal interface

Tag Number	Initial Reading ^a	Date Screened	Maintenance Attempted	Undirected Maintenance Reading	Directed Maintenance Readings			Comments
					1	2	3	
32	$\geq 10,000$	03/06/79	No	$\geq 10,000$	1,100			Only checked one valve with tag — meter lines
	$\geq 10,000$	03/06/79	No	$\geq 10,000$	$\geq 10,000$	$\geq 10,000$		Only checked one valve with tag
	$\geq 10,000$	03/06/79	No	$> 10,000$	$\geq 10,000$	$\geq 10,000$		Only checked one valve with tag
	$\geq 10,000$	03/06/79	Yes	2,000	100			
28	$\geq 10,000$	03/06/79	Yes	2,000				
16	$\geq 10,000$	03/06/79	Yes	$\geq 10,000$	$\geq 10,000$	$\geq 10,000$	700	Repaired when valve was backseated
10	$\geq 10,000$	03/06/79	Yes	100				
7	$\geq 10,000$	03/06/79	Yes	$\geq 10,000$	$\geq 10,000$			Bolts all the way down
4	$\geq 10,000$	03/06/79	Yes	200				
367	$\geq 10,000$	03/05/79	Yes	500				
366	$\geq 10,000$	03/05/79	No					Bolts need replacing
364	$\geq 10,000$	03/05/79	Yes	NC ^b				
362	$\geq 10,000$	03/05/79	Yes	$\geq 10,000$	$\geq 10,000$			Leak at gland, not stem — corrosion preventing good seating of gland

C-15

TABLE C-8. UNIT D ETHYLENE UNIT BLOCK VALVE REPAIRS (Continued)

Tag Number	Initial Reading ^a	Date Screened	Maintenance Attempted	Undirected Maintenance Reading	Directed Maintenance Readings			Comments
					1	2	3	
360	≥10,000	03/05/79	Yes	2,000				
359	≥10,000	03/05/79	Yes	4,000				
None	≥10,000	03/05/79	No	>>10,000	>>10,000			Mistagged originally so no initial repair attempted — tightened bolts — needs new packing
358	≥10,000	03/05/79	Yes	NC ^b				
361	≥10,000	03/05/79	Yes	≥10,000	≥10,000			Leak reduced but needs new packing
None	≥10,000	03/05/79	No	≥10,000	≥10,000			Near No. 361 — needs new packing
356	≥10,000	03/05/79	Yes	NC ^b				Was not leaking before maintenance (mistagged)
354	≥10,000	03/05/79	Yes	900				
352	≥10,000	03/05/79	Yes	NC ^b				
65	≥10,000	03/06/79	Yes	3,000				
64	≥10,000	03/06/79	Yes	1,000				
(gland)				≥10,000	≥10,000	7,000		Leak detected by soap solution — missed by instrument operator

TABLE C-8. UNIT D ETHYLENE UNIT BLOCK VALVE REPAIRS (Concluded)

Tag Number	Initial Reading ^a	Date Screened	Maintenance Attempted	Undirected Maintenance Reading	Directed Maintenance Readings			Comments
					1	2	3	
315	≥10,000	03/06/79	Yes	3,000				
311	NC ^b	03/06/79	Yes	NC ^b				Drain still ≥10,000
316	≥10,000	03/06/79	Yes	≥10,000	2,000			
313	≥10,000	03/06/79	Yes	≥10,000	≥10,000			All the way down on packing
312	≥10,000	03/06/79	Yes	≥10,000	≥10,000	5,000		All the way down on packing
314	≥10,000	03/06/79	No	≥10,000				Bad bolts — need replacing

^aAll readings are in parts per million by volume calibrated to hexane using OVA-108 detector.

^bNC = No change detected in reading above ambient level.

Directed maintenance is preferable to undirected maintenance for valve repair.

The information presented in Tables C-5, C-6, C-7, and C-8 has been compiled with the objective of placing the data on as consistent a basis as possible. However, some differences were unavoidable and others may have gone unrecognized, due to the limited amount of information concerning the details of methods used in each study. Therefore, care should be exercised before attempting to draw specific quantitative conclusions based on direct comparison of the results of these studies.

C.3 REFERENCES

1. Muller, Christopher, memo to files, U.S. Environmental Protection Agency, Emission Standards and Engineering Division, Research Triangle Park, N.C., January 18, 1979. (Plants A & B).
2. Muller, Christopher, memo to files, U.S. Environmental Protection Agency, Emission Standards and Engineering Division, Research Triangle Park, N.C., March 19, 1979. (Plant C).
3. Muller, Christopher, memo to files, U.S. Environmental Protection Agency, Emission Standards and Engineering Division, Research Triangle Park, N.C. (Plant D).
4. Hustvedt, K.C., trip report to James F. Durham, Chief, Petroleum Section, U.S. Environmental Protection Agency, January 5, 1979 (Plants E & F).
5. Wetherold, R.G., and L.P. Provost, Emission Factors and Frequency of Leak Occurrence for Fittings in Refinery Process Units. EPA-600/2-79-044. Radian Corporation, Austin, Texas, February 1979.
6. Valve Repair Summary and Memo from F.R. Bottomley, Union Oil Company, Rodeo, California, to Milton Feldstein, Bay Area Quality Management District, April 10, 1979.
7. Honerkamp, R.L., L.P. Provost, J.W. Sawyer, and R.G. Wetherold, Valve Screening Study at Six San Francisco Bay Area Petroleum Refineries, Final Report. Radian Corporation, Austin, Texas, February 6, 1979.
8. Valve Repair Summary and Memo from R.M. Thompson, Shell Oil Company, Martinez Manufacturing Complex, Martinez, California. To Milton Feldstein, Bay Area Quality Management District, April 26, 1979.
9. Radian Corporation, The Assessment of Environmental Emissions From Oil Refining, Draft report, Appendix B, detailed results, EPA Contract No. 68-02-2147, Exhibit B., Austin, Texas, August 1979.
10. Equipment Summary from Phillips Petroleum Company, Sweeney, Texas, March 14, 1979.

APPENDIX D. EMISSION MEASUREMENT AND CONTINUOUS MONITORING

APPENDIX D - EMISSION MEASUREMENT AND CONTINUOUS MONITORING

D.1 EMISSION MEASUREMENT METHODS

To develop data in support of standards for the control of fugitive emissions, EPA conducted leak surveys at six petroleum refineries and three synthetic organic chemical manufacturing plants. The resulting leak determination procedures contained in Reference Method 21 were developed during the course of this test program.

Prior to the first test, available methods for measurement of fugitive leaks were reviewed, with emphasis on methods that would provide data on emission rates from each source. To measure emission rates, each individual piece of equipment must be enclosed in a temporary cover for emission containment. After containment, the leak rate can be determined using concentration change and flow measurements. This procedure has been used in several studies,^(1,2) and has been demonstrated to be a feasible method for research purposes. It was not selected for this study because direct measurement of emission rates from leaks is a time-consuming and expensive procedure, and is not feasible or practical for routine testing.

Procedures that yield qualitative or semi-quantitative indications of leak rates were then reviewed. There are essentially two alternatives: leak detection by spraying each component leak source with a soap solution and observing whether or not bubbles were formed; and, the use of a portable analyzer to survey for the presence of increased organic compound concentration in the vicinity of a leak source. Visual, audible, or olfactory inspections are too subjective to be used as indicators of leakage in these applications. The use of a portable analyzer was selected as a basis for the method because it would have been difficult to establish a leak definition based on bubble formation rates. Also, the temperature of the component, physical configuration, and relative movement of parts often interfere with bubble formation.

Once the basic detection principle was selected, it was then necessary to define the procedures for use of the portable analyzer. Prior to performance of the first field test, a procedure was reported that conducted surveys at a distance of 5 cm from the components.⁽³⁾ This information was used to formulate the test plan for initial testing.⁽⁴⁾ In addition, measurements were made at distances of 25 cm and 40 cm on three perpendicular lines around individual sources. Of the three distances, the most repeatable indicator of the presence of a leak was a measurement at 5 cm, with a leak definition concentration of 100 or 1000 ppmv. The localized meteorological conditions affected dispersion significantly at greater distances. Also, it was more difficult to define a leak at greater distances because of the small changes from ambient concentrations observed. Surveys were conducted at 5 cm from the source during the next three facility tests.

The procedure was distributed for comment in a draft control techniques guideline documents. Many commentors felt that a measurement distance of 5 cm could not be accurately repeated during screening tests. Since the concentration profile is rapidly changing between 0 and about 10 cm from the source, a small variance from 5 cm could significantly effect the concentration measurement. In response to these comments, the procedures were changed so that measurements were made at the surface of the interface, or essentially 0 cm. Additional testing at two refineries and three chemical plants was performed by measuring volatile organic concentrations at the interface surface.

A complication that this change introduces is that a very small mass emission rate leak ("pin-hole leak") can be totally captured by the instrument and a high concentration result will be obtained. This has occurred occasionally in EPA tests and a solution to this problem has not been found.

The calibration basis for the analyzer was evaluated. It was recognized that there are a number of potential vapor stream compositions that can be expected. Since all analyzer types do not respond equally to different compounds, it was necessary to establish a reference calibration material. Based on the expected compounds and the limited

information available on instrument response factors, hexane was chosen as the reference calibration gas for EPA test programs. At the 5 cm measurement distance, calibrations were conducted at approximately 100 or 1000 ppmv levels. After the measurement distance was changed, calibrations at 10,000 ppmv levels were required. Commentors pointed out that hexane standards at this concentration were not readily available commercially. Consequently, modifications were incorporated in the method to allow alternate standard preparation procedures or alternate calibration gases.

The alternative of specifying a different calibration material for each type stream and normalization factors for each instrument type was not intensively investigated. There are at least four instrument types available that might be used in this procedure, and there are a large number of potential stream compositions possible. The amount of prior knowledge necessary to develop and subsequently use such factors would make the method prohibitively complicated. Based on EPA test results, the number of concentration measurements in the range where a variability of 2 or 3 would change the decision as to whether or not a leak exists is small in comparison to the total number of potential leak sources.

An alternative approach to leak detection was evaluated by EPA during field testing. The approach used was an area survey, or walk-through, using a portable analyzer. The unit area was surveyed by walking through the unit positioning the instrument probe within 1 meter of all valves and pumps. The concentration readings were recorded on a portable strip chart recorder. After completion of the walkthrough, the local wind conditions were used with the chart data to locate the approximate source of any increased ambient concentrations. This procedure was found to yield mixed results. In some cases, the majority of leaks located by individual component testing could be located by walkthrough surveys. In other tests, prevailing dispersion conditions and local elevated ambient concentrations complicated or prevented the interpretation of the results. Additionally, it was not possible to

develop a general criteria specifying how much of an ambient increase at a distance of 1 meter is indicative of a 10000 ppm concentration at the leak source. Because of the potential variability in results from site to site, routine walkthrough surveys were not selected as a reference or alternate test procedure.

D.2 CONTINUOUS MONITORING SYSTEMS AND DEVICES

Since the leak determination procedure is not a typical emission measurement technique, there are no continuous monitoring approaches that are directly applicable. Continual surveillance is achieved by repeated monitoring or screening of all affected potential leak sources. A continuous monitoring system or device could serve as an indicator that a leak has developed between inspection intervals. EPA performed a limited evaluation of fixed-point monitoring systems for their effectiveness in leak detection. The systems consisted of both remote sensing devices with a central readout and a central analyzer system (gas chromatograph) with remotely collected samples. The results of these tests indicated that fixed point systems were not capable of sensing all leaks that were found by individual component testing. This is to be expected since these systems are significantly affected by local dispersion conditions and would require either many individual point locations, or very low detection sensitivities in order to achieve similar results to those obtained using an individual component survey.

It is recommended that fixed-point monitoring systems not be required since general specifications cannot be formulated to assure equivalent results, and each installation would have to be evaluated individually.

D.3 PERFORMANCE TEST METHOD

The recommended fugitive VOC emission detection procedure is Method 21. This method incorporates the use of a portable analyzer to detect the presence of volatile organic vapors at the surface of the interface where direct leakage to the atmosphere could occur. The general approach of this technique assumes that if an organic leak exists, there will be an increased vapor concentration in the vicinity of the leak, and that the measured concentration is generally proportional to the mass emission rate of the organic compound.

Method 21 is designed for use in many different source categories and does not include the specification of a specific compound in instrument calibration or a leak definition in terms of VOC concentration. These criteria are given in the applicable standard.

There are at least four types of detection principles currently available in commercial portable instruments. These are flame ionization, catalytic oxidation, infrared absorption (NDIR) and photoionization. Two types (flame ionization and catalytic oxidation) are known to be available in factory mutual certified versions for use in hazardous atmospheres.

The recommended test procedure includes a set of design and operating specifications and evaluation procedures by which an analyzer's performance can be evaluated. These parameters were selected based on the allowable tolerances for data collection, and not on the performance of individual instruments. Based on manufacturers' literature specifications, many commercially available analyzers can meet these requirements.

The estimated purchase cost for an analyzer ranges from about \$1000 to \$5000 depending on the type and optional equipment. The cost of an annual monitoring program per unit, including semiannual instrument tests and reporting is estimated to be from \$3,000 to \$4,500. This estimate is based on EPA contractor costs experienced during previous test programs. Performance of monitoring by plant personnel may result in lower costs. The above estimates do not include any costs associated with leak repair after detection.

D.4 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. "Emission Factors and Frequency of Leak Occurrence Fittings in Refinery Process Units" Radian Corporation Contract No. 68-02-2147 and No. 68-02-2665, EPA Report No. 600/2-79-044, February 1979.

3. Telephone Communication: Paul Harrison, Meteorology Research, Inc. to K. C. Hustvedt, EPA, December 22, 1977.

4. EMB Report No. 77-CAT-6, "Miscellaneous Refinery Equipment VOC Sources at Arco, Watson Refinery and Newhall Refining Co." ESED, EPA, December, 1979.

5. "Control of Volatile Organic Compound Leaks from Petroleum Refinery Equipment," OAQPS Guideline Series, EPA-450/2-78-036, June, 1978.

APPENDIX E. METHODOLOGY FOR ECONOMIC ANALYSIS

APPENDIX E1: WEIGHTING PROCEDURES FOR THE ESTIMATION OF SOCM I
TIME-SERIES DATA

The chemicals produced by the synthetic organic chemicals manufacturing industry (SOCMI) do not directly correspond to the industrial classifications of organic chemicals used by sources reporting production and sales statistics. Consequently, the weighting procedure described below was used to generate data that reflect the SOCM I as accurately as possible.

Production and sales data for synthetic organic chemicals are reported annually in the United States International Trade Commission (ITC) report, Synthetic Organic Chemicals: U.S. Production and Sales. The report presents production, quantity of sales and value of sales data for 14 categories of chemicals. Four of these categories, Tar and Tar Crudes, Primary Products from Petroleum and Natural Gas for Chemical Conversion, Cyclic Intermediates, and Miscellaneous Cyclic and Acyclic Chemicals, contain SOCM I chemicals, as well as other chemicals. To derive appropriate estimates of data for the SOCM I chemicals, production, quantity of sales and value of sales for 1977 were estimated for all SOCM I chemicals included in each of the four categories. The estimates for SOCM I chemicals for each variable were then divided by the aggregate estimates for all chemicals within the category. Resulting ratios were used as weights to calculate estimates of production, quantity of sales and value of sales of SOCM I chemicals each in category over the period 1974-1978.

Prior to 1975, the chemicals included in the category, Miscellaneous Cyclic and Acyclic Chemicals, were reported as Miscellaneous Synthetic Organic Chemicals. A weighting scheme based on 1974 data for this category was developed using the procedure described above and was used to estimate pro-

duction and sales of SOCMi chemicals in this category for the period 1968-1974. Data on production and sales of SOCMi for the remaining three categories for the period 1968-1974 were estimated using the 1977 weights.

Table E1-1 presents the SOCMi chemicals included in each of the ITC categories. Table E1-2 presents the estimated ratios used to weight the ITC data in order to calculate production, quantity of sales and value of sales of SOCMi chemicals.

TABLE E1-1. SOCMI CHEMICALS INCLUDED IN ITC CATEGORY RATIOS

Tar and Tar Crudes*

Benzene	Xylene
Toluene	Solvent Naptha

Primary Products from Petroleum and Natural Gas for Chemical Conversion

Benzene	Ethylene
Cumene	Propylene
Cyclohexane	Butadiene and butylene fractions
Ethylbenzene	1, 3-Butadiene, grade for rubber
Napthalene	1-Butene
Styrene	Isobutylene
Toluene	Isoprene
Xylenes	Dodecene
o-Xylene	Petenes
p-Xylene	Nonene
All other aromatics and napthenes	Polybutene
Acetylene	

Cyclic Intermediates

Aniline	o-Dichlorobenzene
Benzoic acid	p-Dichlorobenzene
Biphenyl	Hydroquinone
Cresols	α-Methylstyrene
Cresylic acid, refined	Nitrobenzene
Cyclohexanone	Nonylphenol
Cylohexylamine	Phenol

Miscellaneous Cyclic and Acyclic Chemicals

Benzyl alcohol	Butylamines
Caprolactam	Ethylamines
Dioxane	Isopropylamine, mono-
p-Hydroxybenzoic acid	Methylamines
Maleic anhydride	All other amines
Ethanolamines	Pentaerythritol
Acenitrile	Propylene glycol
Acrylonitrile	All other polyhydric alcohols
Acetic acid	2-(2-Butoxyethoxy) ethanol (Diethyl-
Acetic anhydride	ylene glycol monobutyl ether)
Acrylic acid	2-[2-(2-Butoxyethoxy) ethoxy]
Adipic acid	ethanol (Triethylene glycol,
Fumaric acid	monobutyl ether)
Propionic acid	Diethylene glycol
Formaldehyde	Dipropylene glycol
Isobutyraldehyde	2-(2-Ethoxyethoxy) ethanol (Diethyl-
Acetone	ylene glycol monoethyl ether)

TABLE E1-1. (continued)

Miscellaneous Cylic and Acyclic Chemicals (continued)

2-Butanone (methyl ethyl ketone)	2-Methoxyethanol (ethylene glycol monomethyl ether)
4-Hydroxy-4-methyl-2-pentanone (Diacetone alcohol)	2-(2-Methoxyethoxy) ethanol (Diethylene glycol monomethyl ether)
4-Methyl-2-pentanone (methyl isobutyl ketone)	Polyethylene glycol
4-methyl-3-penten-2-one (Mesityl oxide)	Polypropylene glycol
All other ketones	Propylene glycol
n-Butyl alcohol (n-propylcarbinol)	Triethylene glycol
Methanol	Carbon tetrachloride
n-Butyl acetate	Chloroethane (ethyl chloride)
Ethyl acetate	Chloroform
Ethyl acrylate	Chloromethane (methyl chloride)
Isobutyl acetate	1-2-Dichloroethane (ethylene dichloride)
Methyl acetate	Dichloromethane (methylene chloride)
Methyl methacrylate	1-2-Dichloropropane (propylene dichloride)
Vinyl acetate	Tetrachloroethylene (perchloroethylene)
Ethylene glycol	Trichlorofluoromethane
Glycerol, synthetic	Carbon disulfide
1,1,1-Trichloroethane (methyl chloroform)	Ethylene oxide
Trichloroethylene	Ethyl ether
Vinyl chloride, monomer (chloroethylene)	Propylene oxide
All other chlorinated hydrocarbons	All other epoxides, ethers, and acetals
Chlorodifluoromethane	Phosgene (carbonyl chloride)
Dichlorodifluoromethane	

*Derived from coal. Does not duplicate data contained in other categories.

TABLE E1-2. RATIOS USED TO WEIGHT ITC DATA^a

	Production (1000 lbs)	Quantity (1000 lbs)	Value (1000 \$)
<u>Tar and Crudes</u>			
Total SOCMi Chemicals	3,265,976	1,543,188	976,660
ITC Grand Total	4,145,815	2,009,737	1,104,285
Ratio	78.78%	76.79%	88.44%
<u>Primary Products from Petroleum and Natural Gas</u>			
Total SOCMi Chemicals	93,517,108	38,873,142	4,120,327
ITC Grand Total	126,133,316	61,008,376	5,820,390
Ratio	74.14%	63.72%	70.79%
<u>Cyclic Intermediates</u>			
Total SOCMi Chemicals	15,699,616	6,139,015	1,878,235
ITC Grand Total	18,725,626	7,985,790	2,596,627
Ratio	83.84%	76.84%	72.33%
<u>Miscellaneous Cyclic and Acyclic Chemicals</u>			
Total SOCMi Chemicals	65,876,154	27,695,411	4,734,676
ITC Grand Total	86,968,069	38,753,311	7,919,082
Ratio	75.75%	71.47%	59.79%
<u>Miscellaneous Chemicals 1974 Figures</u>			
Total SOCMi Chemicals	73,670,360	34,817,621	3,607,825
ITC Grand Total	100,604,375	47,430,967	7,815,487
Ratio	73.23%	73.41%	46.16%

^a1977 figures except where indicated.

APPENDIX E2: REPLACEMENT INVESTMENT PROJECTIONS

The methodology used to project SOCFI replacement investment is described in this appendix. The projections are based on two key theoretical assumptions: (I) the historical growth rate of capacity, ρ , has been constant over time; and (II) model units have a fixed life of L years. These assumptions are summarized in the following equations:

$$K_T = (1+\rho)^L K_{T-L} \quad (1)$$

$$I_T \equiv \rho K_T + R_T \quad (2)$$

$$R_T = I_{T-L} \quad (3)$$

where

K = industry capacity,

I = gross investment,

R = replacement investment,

T = time subscript,

and K , I and R are measured in terms of model units.

Equation (1) is an algebraic restatement of assumption I. Equation (2) is simply a mathematical definition of gross investment, that is, gross investment, I_T , is equal to additions to new capacity, ρK_T , plus replacement investment, R_T . Equation (3) is an algebraic restatement of assumption II. Appropriately lagging Equation (2) and back substituting from (2) into (3), it can be shown that

$$R_T = \rho \sum_{i=1}^{\infty} K_{T-iL} \quad (4)$$

Further, by substituting for the various K_{T-iL} in Equation (4) using Equation (1), and rearranging terms, the following result is obtained:

$$R_T = K_{T-L} \sum_{i=0}^{\infty} \frac{\rho}{(1+\rho)^{iL}} \quad (5)$$

The expression $\sum_{i=0}^{\infty} \frac{\rho}{(1+\rho)^{iL}}$ is a constant and, if ρ is assumed to be 0.06 and

L to be 20, approximately equal to 0.087. Equation (5) can be used to project replacement investment in any year, T , if an estimate of the capital stock in the $(T-L)$ th year is available. For SOCFI, capital stock data are available for 1976. This information, together with an assumed historical growth rate of 6 percent, was used to estimate the capital stock for the years 1961 to 1965 by means of Equation (1). The resulting capital stock estimates are then used in Equation (5) to project replacement investment in SOCFI for each of the five years following proposal of any regulatory alternatives (1981-1985), on the basis of the empirical assumption that each model unit has a life of 20 years. The annual projections of replacement investment are then summed to obtain a projection of the number of replacement facilities subject to the provisions of any regulatory alternative in the fifth year following its proposal. The projections of replacement investment obtained by applying this methodology are presented in Table E2-1.

TABLE E2-1 PROJECTIONS OF REPLACEMENT INVESTMENT

Year	<u>Number of replacement capacity units</u>	
	Annual	Cumulative
1981	49	49
1982	51	100
1983	55	155
1984	58	213
1985	61	274

APPENDIX E3: METHODOLOGY FOR COMPUTING COST OF CAPITAL
TO SYNTHETIC ORGANIC CHEMICAL MANUFACTURERS

This appendix describes the process used to estimate the cost of capital for the chemical industry. The cost of capital for any new project is the cost of equity, debt, and preferred stock, weighted by the percentage of funds generated by each type of financing, that is,

$$k_c = k_e \frac{E}{I} + k_i \frac{D}{I} + k_p \frac{P}{I} \quad (1)$$

where

k_c \equiv cost of capital

k_e \equiv cost of equity capital

k_i \equiv cost of debt capital

k_p \equiv cost of preferred stock capital

E \equiv the amount of equity used to finance a given investment

D \equiv the amount of debt used to finance a given investment

P \equiv the amount of preferred stock used to finance a given investment

I \equiv the total funds needed for the investment

The first step in estimating Equation (1) is to determine the relevant weights for the three types of financing. It is assumed that the proportion of debt, equity, and preferred stock to be used on any new project will be the same as currently exists in the firm's capital structure. This implies that the firm is currently using the optimal mix of financing. Figures for the three types of funds came from the COMPUSTAT tapes, supplied by Standard & Poor's Corporation, for each firm's fiscal year ending in 1977. Common equity included the par value of common stock, retained earnings, capital

surplus, self-insurance reserves, and capital premium, while debt included all obligations due more than a year from the company's balance sheet date. Preferred stock represented the net number of preferred shares outstanding at year-end multiplied by the involuntary liquidating value per share.

The next step in calculating Equation (1) is to estimate the cost of equity financing. Two approaches are commonly used: the results derived from the capital-asset pricing model (CAPM) and the results derived from the dividend capitalization model (DCM). The CAPM examines the necessary returns on a firm's stock in relation to a portfolio comprised of all existing stocks, while the DCM evaluates the stream of dividends and the discount rate needed to arrive at the firm's existing share price. The required return on equity using the CAPM is:

$$k_e = i + \beta (k_m - i) \quad (2)$$

where

$i \equiv$ the expected risk free interest rate

$k_m - i \equiv$ the expected excess return on the market, and

$\beta \equiv$ the firm's beta coefficient.

The required return on equity using the DCM is:

$$k_e = \frac{D_1}{P_0} + g \quad (3)$$

where

$D_1 \equiv$ the dividend expected in period 1

$P_0 \equiv$ the share price at the beginning of period 1

$g \equiv$ the expected rate of dividend growth, assumed to be constant.

Figures for Equation (2) were developed in the following manner. The expected risk-free rate was assumed equal to the yield on a 3-month Treasury Bill, as reported in the October 1, 1979, Wall Street Journal. The current yield was 10.46 percent. This corresponds to the yield from a bond with no

possibility of default and offering no chance of a capital loss and is therefore riskless. The firm's beta coefficients came from the September 24, 1979, Value Line Investment Survey. The expected excess return equalled 2.9646 percent, the 5-year average (July 1974-June 1979) of the monthly excess returns on the Standard & Poor's 500 Stock Index multiplied by twelve.

Figures for Equation (3) came from two sources. Both share price and expected yearly dividends came from figures reported in the October 1, 1979, Wall Street Journal. The growth rate was calculated from data contained on the COMPUSTAT tapes. Three different growth rates were tried: the 5-year average growth of total assets, the 5-year average growth of per share earnings, and the 5-year average growth of dividends.

A number of theoretical reasons exist for preferring the CAPM approach to the DCM for estimating the required return on equity, but the figures calculated revealed a more practical justification. Using growth estimated from per share earnings or dividends resulted in a number of firms having negative required returns with the DCM method. Although using the growth in assets resulted in only one firm with a negative required return, several firms had extremely low returns (less than 10 percent). It is unreasonable to expect that stockholders would demand a return on their stock that is less than the existing yield on Treasury Bills, yet all three variants of the DCM method led to this conclusion for a number of firms. From these considerations it was decided to use the CAPM calculations as the required return on equity.

The third step in estimating Equation (1) is calculating the cost of debt financing. This would be a relatively easy estimation if interest rates did not change over time. Past yields on old issues of bonds would suffice. Since interest rates have been increasing, it was felt that a more forward-

looking rate was required. The method selected was to take the average yield as given in the October 1 - September 3, 1979, Moody's Bond Survey for the firm's bond ratings class as the necessary yield the firm must offer on long-term debt. The firm's ratings class came from the September 1979 Moody's Bond Record or the 1979 Moody's Industrial Manual. A small number of firms were not rated by Moody's. One firm was ranked in Standard and Poor's Bond Guide and this was used to approximate a Moody's bond class. Information on other firms was contained in the 1979 Moody's Industrial Manual or the Standard & Poor's Corporation Records, concerning bank notes, revolving credit, or term-loan agreements that tied the interest rate on these types of debt to the current prime rate. This was used as the necessary yield on long-term debt. Table E3-1 presents the yields by ratings class and the prime rate (as of October 1, 1979) used for the cost of debt funds.

TABLE E3-1. YIELDS BY RATING CLASS FOR COST OF DEBT FUNDS, 1979
(prime rate = 13.50 %)

<u>Ratings Class</u>	<u>Yield (percent)</u>
AAA	9.25
AA	9.59
A	9.72
BAA	10.38
BA	11.97
B	12.395

The yield on long-term debt does not represent the aftertax cost of debt financing since interest charges are tax deductible. To arrive at the after-

tax cost, the yield must be multiplied by one minus the marginal tax rate.

$$k_j = k(1 - t)$$

where

$k \equiv$ the yield on bonds

$t \equiv$ the marginal tax rate

It is assumed that the firms in the sample are profitable, so that taxes must be paid, and that their marginal tax rate is 48 percent.

The last step in estimating Equation (1) is to arrive at the cost of preferred stock financing. Unlike debt, preferred stock does not have a maturity date, so that the current yield should approximate the yield on new issues. The yield is:

$$k_p = \frac{D}{P}$$

where

$D =$ stated annual dividend

$P =$ the price of a share of preferred stock

The figures for dividends and share price came from the October 1, 1979, Wall Street Journal or, if not included in this source, from the January 1, 1979, listing in the Daily Stock Price Record. A number of firms did not have their preferred stock listed in either source, yet had preferred stock in their capital structures. All used less than 15 percent preferred stock, with the majority less than 5 percent. For these firms the yield on preferred stock was set equal to the yield on long-term debt.

Table E3-2 lists the cost of capital for all 100 firms in the sample, along with some of the components of Equation (1). These firms represent the best available sample of the approximately 600 firms in the industry. However, it is likely that on the average they are larger than the firms

TABLE E3-2. FINANCIAL DATA FOR 100 FIRMS IN SOCMI¹⁻¹¹

Name	Cost of Capital	Return On Equity	Return On Debt	Return On Preferred Stock	Proportion Of Equity	Proportion Of Debt	Proportion Of Preferred Stock
Abbott Labs	12.014	14.018	9.590	-- ^a	.77262	.216575	.010804
Akzona	10.276	13.276	10.380	--	.61914	.380859	.000
Alco Standard Corp.	12.151	13.425	15.120	--	.64134	.259343	.099317
Allied Chem Corp.	10.091	13.721	9.720	--	.58118	.418825	.000
American Cyanamid	11.083	13.425	9.590	--	.72252	.277480	.000
Armco Steel Corp.	10.588	13.276	9.720	6.461	.66880	.306858	.024337
Atlantic Richfield	9.749	13.128	9.590	--	.51602	.362174	.121802
Beatrice Foods	11.232	12.832	9.250	7.429	.79803	.194329	.007644
Bendix Corp.	11.118	13.425	9.720	3.333	.72911	.248140	.022754
Bethlehem Steel Corp.	10.913	14.018	9.720	--	.65360	.346402	.000
Borden Inc.	10.484	12.683	9.590	--	.71317	.285155	.001677
Borg-Warner Chem.	11.863	13.128	9.720	--	.82756	.145263	.027181
Brown Co.	9.813	12.387	12.395	--	.56680	.433202	.000
CPC International Inc.	11.638	13.128	9.590	--	.81691	.183087	.000
Celanese Corp.	10.181	13.128	11.970	10.084	.53511	.396896	.067997
Charter International Oil	9.175	14.166	12.395	--	.27557	.623167	.101265
Cities Service Co.	10.395	12.980	9.720	--	.67388	.326120	.000
Combustion Engineering	11.494	14.314	9.720	--	.68700	.296229	.016774
Continental Oil	10.881	13.721	9.590	2.564	.67568	.321308	.003009
Crompton & Knowles	11.298	13.425	14.450	--	.53329	.375634	.091078
Dart Indust.	10.689	14.166	9.720	4.211	.63113	.231645	.137221
Dayco Corp.	8.270	12.980	11.970	6.071	.30351	.666445	.030044
De Soto, Inc.	11.499	13.128	13.750	--	.72746	.272535	.000
Diamond Shamrock Corp.	9.790	13.721	9.720	--	.54639	.453615	.000
Dow Chemical	10.060	14.018	9.590	--	.56176	.438236	.000
Du Pont De Nemours	11.328	13.573	9.250	8.654	.72512	.232172	.042712
Eastern Gas & Fuel Associates	11.605	14.018	14.180	--	.63681	.363188	.000
Essex Chem. Corp.	12.502	14.166	12.395	--	.78453	.215465	.000

E-14

TABLE E3-2 (Continued)

Name	Cost of Capital	Return On Equity	Return On Debt	Return On Preferred Stock	Proportion Of Equity	Proportion Of Debt	Proportion Of Preferred Stock
Exxon Corp.	11.875	13.276	9.250	--	.83450	.165504	.000
FMC Corp.	10.183	13.573	9.720	6.250	.59257	.339730	.067701
Ferro Corp.	12.369	13.276	9.720	--	.88968	.110317	.000
Firestone Tire & Rubber	10.610	12.980	9.720	--	.70096	.299038	.000
Ford Motor Co.	12.069	13.276	9.250	--	.85743	.142565	.000
GAF Corp.	9.398	13.573	10.380	7.559	.44490	.387035	.168061
General Electric Co.	12.130	13.721	9.250	--	.82148	.178521	.000
General Motors Corp.	12.798	13.425	9.250	8.715	.91962	.063516	.016862
General Tire & Rubber	11.440	13.276	11.970	--	.73287	.258968	.008163
Georgia-Pacific Corp.	10.793	13.573	9.590	--	.67625	.323751	.000
Goodrich (B.F.) Co.	10.430	13.276	10.380	8.864	.62957	.349707	.020723
Goodyear Tire & Rubber Co.	10.101	12.980	9.720	--	.63679	.363210	.000
Gulf Oil Corp.	11.745	12.980	9.250	--	.84880	.151203	.000
Hercules Inc.	11.177	13.869	9.720	--	.69461	.305394	.000
Inland Steel	10.092	12.980	9.590	--	.62702	.352735	.020249
Insilco Corp.	9.339	13.276	11.970	7.752	.41885	.475634	.105511
Interlake, Inc.	11.331	13.128	9.720	--	.77736	.222640	.000
International Harvester	10.534	13.573	9.720	--	.63297	.348230	.018796
Kaiser Steel Corp.	11.688	14.018	14.000	--	.63274	.345717	.021539
Kraft Inc.	10.774	12.683	9.250	--	.75752	.242479	.000
Marathon Oil Co.	9.582	13.128	9.720	--	.56074	.439257	.000
Martin Marietta Chem.	11.238	13.276	9.720	--	.75212	.247882	.000
Mead Corp.	10.000	13.869	9.720	4.308	.56423	.398718	.037048
Merck & Co.	12.309	13.573	9.250	--	.85481	.143358	.001827
Minnesota Mining & Manuf.	12.572	13.869	9.250	--	.85677	.143235	.000
Mobil Oil Corp.	10.868	13.128	9.250	--	.72833	.271665	.000
Monsanto Co.	10.970	13.573	9.590	5.000	.69690	.300335	.002767
Morton-Norwich Products	10.726	13.721	9.720	--	.65441	.345589	.000

TABLE E3-2 (Continued)

Name	Cost of Capital	Return On Equity	Return On Debt	Return On Preferred Stock	Proportion Of Equity	Proportion Of Debt	Proportion Of Preferred Stock
National Distillers & Chem.	11.037	13.128	9.720	9.193	.73310	.251565	.015334
National Steel Corp.	9.909	12.683	9.590	--	.63946	.360538	.000
Northwest Indust.	8.015	13.869	10.380	2.9412	.32561	.617085	.057301
Owens-Corning Fiberglass	11.653	13.425	9.720	--	.78828	.211721	.000
PPG Industries	10.596	13.276	9.590	--	.67661	.323394	.000
Penwalt Corp.	9.013	13.276	9.720	7.529	.41712	.369200	.213675
Pfizer	11.244	14.018	9.590	--	.69289	.307113	.000
Phillips Petroleum Co.	11.670	13.721	9.250	--	.76982	.230179	.000
Procter & Gamble Co.	11.824	13.276	9.250	--	.82842	.171428	.000153
Quaker Oats Co.	10.946	13.573	9.720	9.008	.651578	.262094	.086328
Reeves Bros. Inc.	10.629	12.535	10.380	--	.732870	.267130	.000
Reichold Chems.	10.647	13.425	10.380	--	.571986	.295871	.132143
Republic Steel Corp.	11.305	13.425	9.720	--	.746819	.253181	.000
Riegel Textile Corp.	11.201	12.980	11.970	--	.736598	.263402	.000
Rockwell International	9.589	12.535	9.720	5.398	.602132	.309032	.088836
Rohn and Haas Co.	10.739	13.721	9.720	--	.655939	.344061	.000
SCM Corp.	10.835	14.018	10.380	--	.630766	.369234	.000
Scott Paper Co.	10.784	13.721	9.590	--	.660791	.333680	.005529
Shakespeare Co.	11.229	13.276	14.000	--	.658505	.341495	.000
Sherwin-Williams Co.	9.617	12.980	10.380	10.00	.523981	.422439	.053579
Squibb Corp.	11.266	14.018	9.590	--	.695345	.304655	.000
A. E. Staley Mfg. Co.	10.428	13.573	9.720	--	.629947	.368508	.001544
Stauffer Chemical Co.	10.188	13.425	9.720	--	.613351	.386649	.000
Sterling Drug	12.595	13.276	9.590	--	.917816	.082184	.000
Sun Chem. Corp.	10.427	13.573	12.395	--	.558689	.441311	.000
Sybron Corp.	10.786	13.869	9.720	--	.616191	.319517	.064292
Tenneco Inc.	9.155	12.980	10.380	3.887	.505890	.442129	.051981
Texaco	11.230	12.980	9.250	--	.785863	.214137	.000
Texfi Indust.	10.090	13.275	16.000	--	.356904	.643096	.000
Textron Inc.	10.085	13.425	9.720	6.222	.577353	.252757	.169890
Union Camp Corp.	11.359	13.276	9.590	--	.768639	.231361	.000
Union Carbide Corp.	10.775	13.573	9.590	--	.674170	.325830	.000

TABLE E3-2 (Continued)

Name	Cost of Capital	Return On Equity	Return On Debt	Return On Preferred Stock	Proportion Of Equity	Proportion Of Debt	Proportion Of Preferred Stock
Union Oil, Calif.	10.577	13.128	9.590	--	.663994	.295934	.040072
Uniroyal	10.514	13.425	11.970	16.000	.521603	.423786	.054611
U.S. Gypsum	10.726	13.276	9.590	5.539	.686341	.223477	.090182
U.S. Steel Corp.	10.919	13.573	9.590	--	.690912	.309088	.000
Upjohn Co.	11.052	13.573	9.590	--	.706383	.293617	.000
Vulcan Materials Co.	10.675	12.980	9.720	--	.709218	.290782	.000
Walter (Jim) Corp.	9.019	13.721	11.970	4.444	.398726	.491966	.109308
Westinghouse Electric Corp.	12.596	14.018	9.720	8.837	.838775	.155115	.006110
Weyerhaeuser Co.	10.402	14.166	9.590	5.957	.583685	.357341	.058973
Wheeling-Pittsburgh Steel	11.238	13.869	14.000	12.739	.512893	.381136	.105972
Whittaker Corp.	10.070	14.314	11.970	--	.457808	.517470	.024722
Wit Chem. Corp.	10.736	13.573	9.720	3.313	.673790	.292825	.033385

^aDashes indicated that data are unavailable.

excluded, as many small firms do not have to publish detailed financial records. This potential bias in the sample of firms used may have resulted in a slight underestimation of the industry's cost of capital.¹²

APPENDIX E4: METHODOLOGICAL CONSIDERATIONS

Price and Rate of Return Impacts

Let P denote product price, Q denote unit output, TOC denote total operating costs, K denote the amount of capital invested in the unit, r denote the rate of return on capital and t denote the tax rate in a given year. The aftertax rate of return on capital invested in the unit may then be defined as:

$$r = \frac{(1-t)(PQ - TOC)}{K} \quad (1)$$

where $[PQ - TOC]$ is the unit's pretax net revenues from its operations in that year. Now, assume that the unit is required to change its operating costs and level of capital investment in order to comply with the implementation of some regulatory alternative. Under the full cost absorption scenarios the unit will be unable to adjust the the price of its product or unit output. Consequently, the rate of return on investment, r , will change. The formula used to estimate this impact is obtained by totally differentiating Equation (1) with respect to TOC and K ; that is,

$$dr = - \frac{(1-t) dTOC}{K} + \frac{(1-t)(PQ - TOC) dK}{K^2} \quad (2)$$

Substituting in (2) from (1) and rearranging terms, it follows that:

$$-dr = \frac{(1-t) dTOC + rdK}{K} \quad (3)$$

Equation (3), identical to Equation (2) in section 9.2, is the formula used to calculate the full cost absorption rate of return impacts presented in Chapter 9.

Price impacts are estimated on the basis of the assumption that firms will be able to maintain the preregulation rate of return (r) by increasing

product prices. Thus, r is now a constant and P a variable. Rearranging terms in Equation (1), it may be shown that:

$$P = \frac{TOC + r K/(1-t)}{Q} \quad (4)$$

In full cost pass through scenarios, changes in TOC and K leave r and Q unaffected but result in a change in P . The formula for estimating this change in P may be obtained by total differentiating Equation (4) with respect to TOC and K ; that is,

$$dP = \frac{dTOC + r dK / (1-t)}{Q} \quad (5)$$

Equation (5), identical to Equation (1) in Section 9.2, is the formula used to estimate the full cost pass through price impacts presented in Chapter 9.

APPENDIX E REFERENCES

1. COMPUSTAT. New York: Standard & Poor's Corporation, 1978.
2. Daily Stock Price Record. New York: Standard & Poor's Corporation, 1979.
3. Moody's Bond Record. New York: Moody's Investors Service, Inc., September 1979.
4. Moody's Bond Survey. New York: Moody's Investors Service, Inc., October 1 - September 3, 1979.
5. Moody's Industrial Manual. New York: Moody's Investors Service, Inc., 1979.
6. Scherer, F. M., et al. The Economics of Multi-Plant Operation. Cambridge, Mass.: Harvard University Press, 1975.
7. Standard & Poor's Bond Guide. New York: Standard & Poor's Corporation, September 1979.
8. Standard & Poor's Corporation Records. New York: Standard & Poor's Corporation, September 1979.
9. Standard & Poor's Statistical Service. New York: Standard & Poor's Corporation, October 1979.
10. Value Line Investment Survey. New York: Arnold Bernhard & Co., Inc., September 24, 1979.
11. The Wall Street Journal. New York: Dow Jones & Company, October 1, 1979.

APPENDIX F - SYNTHETIC ORGANIC CHEMICALS MANUFACTURING INDUSTRY

	<u>OCPDB No.*</u>	<u>Chemical</u>
1	20	Acetal
2	30	Acetaldehyde
3	40	Acetaldo1
4	50	Acetamide
5	65	Acetanilide
6	70	Acetic acid
7	80	Acetic anhydride
8	90	Acetone
9	100	Acetone cyanohydrin
10	110	Acetonitrile
11	120	Acetophenone
12	125	Acetyl chloride
13	130	Acetylene
14	140	Acrolein
15	150	Acrylamide
16	160	Acrylic acid and esters
17	170	Acrylonitrile
18	180	Adipic acid
19	185	Adiponitrile
20	190	Alkyl naphthalenes
21	200	Allyl alcohol
22	210	Allyl chloride
23	220	Aminobenzoic acid

*The OCPDB Numbers are reference indices assigned to the various chemicals in the Organic Chemical Producers Data Base developed by EPA.

	OCPDB No.	Chemical
24	230	Aminoethylethanolamine
25	235	p-aminophenol
26	240	Amyl acetates
27	250	Amyl alcohols
28	260	Amyl amine
29	270	Amyl chloride
30	280	Amyl mercaptans
31	290	Amyl phenol
32	300	Aniline
33	310	Aniline hydrochloride
34	320	Anisidine
35	330	Anisole
36	340	Anthranilic acid
37	350	Anthraquinone
38	360	Benzaldehyde
39	370	Benzamide
40	380	Benzene
41	390	Benzenedisulfonic acid
42	400	Benzenesulfonic acid
43	410	Benzil
44	420	Benzilic acid
45	430	Benzoic acid
46	440	Benzoin
47	450	Benzonitrile
48	460	Benzophenone
49	480	Benzotrichloride

	OECD No.	Chemical
50	490	Benzoyl chloride
51	500	Benzyl alcohol
52	510	Benzyl amine
53	520	Benzyl benzoate
54	530	Benzyl chloride
55	540	Benzyl dichloride
56	550	Biphenyl
57	560	Bisphenol A
58	570	Bromobenzene
59	580	Bromonaphthalene
60	590	Butadiene
61	592	1-butene
62	600	n-butyl acetate
63	630	n-butyl acrylate
64	640	n-butyl alcohol
65	650	s-butyl alcohol
66	660	t-butyl alcohol
67	670	n-butylamine
68	680	s-butylamine
69	690	t-butylamine
70	700	p-tert-butyl benzoic acid
71	710	1,3-butylene glycol
72	750	n-butyraldehyde
73	760	Butyric acid
74	770	Butyric anhydride
75	780	Butyronitrile

	OCPDB No.	Chemical
76	785	Caprolactam
77	790	Carbon disulfide
78	800	Carbon tetrabromide
79	810	Carbon tetrachloride
80	820	Cellulose acetate
81	840	Chloroacetic acid
82	850	m-chloroaniline
83	860	o-chloroaniline
84	870	p-chloroaniline
85	880	Chlorobenzaldehyde
86	890	Chlorobenzene
87	900	Chlorobenzoic acid
88	905	Chlorobenzotrichloride
89	910	Chlorobenzoyl chloride
90	920	Chlorodifluoroethane
91	921	Chlorodifluoromethane
92	930	Chloroform
93	940	Chloronapthalene
94	950	o-chloronitrobenzene
95	951	p-chloronitrobenzene
96	960	Chlorophenols
97	964	Chloroprene
98	965	Chlorosulfonic acid
99	970	m-chlorotoluene
100	980	o-chlorotoluene
101	990	p-chlorotoluene

	OCPDB No.	Chemicals
102	992	Chlorotrifluoromethane
103	1000	m-cresol
104	1010	o-cresol
105	1020	p-cresol
106	1021	Mixed cresols
107	1030	Cresylic acid
108	1040	Crotonaldehyde
109	1050	Crotonic acid
110	1060	Cumene
111	1070	Cumene hydroperoxide
112	1080	Cyanoacetic acid
113	1090	Cyanogen chloride
114	1100	Cyanuric acid
115	1110	Cyanuric chloride
116	1120	Cyclohexane
117	1130	Cyclohexanol
118	1140	Cyclohexanone
119	1150	Cyclohexene
120	1160	Cyclohexylamine
121	1170	Cyclooctadiene
122	1180	Decanol
123	1190	Diacetone alcohol
124	1200	Diaminobenzoic acid
125	1210	Dichloroaniline
126	1215	m-dichlorobenzene
127	1216	o-dichlorobenzene

	OCPDB No.	Chemical
128	1220	p-dichlorobenzene
129	1221	Dichlorodifluoromethane
130	1244	1,2-dichloroethane (EDC)
131	1240	Dichloroethyl ether
132	1250	Dichlorohydrin
133	1270	Dichloropropene
134	1280	Dicyclohexylamine
135	1290	Diethylamine
136	1300	Diethylene glycol
137	1304	Diethylene glycol diethyl ether
138	1305	Diethylene glycol dimethyl ether
139	1310	Diethylene glycol monobutyl ether
140	1320	Diethylene glycol monobutyl ether acetate
141	1330	Diethylene glycol monoethyl ether
142	1340	Diethylene glycol monoethyl ether acetate
143	1360	Diethylene glycol monomethyl ether
144	1420	Diethyl sulfate
145	1430	Difluoroethane
146	1440	Diisobutylene
147	1442	Diisodecyl phthalate
148	1444	Diisooctyl phthalate
149	1450	Diketene
150	1460	Dimethylamine
151	1470	N,N-dimethylaniline
152	1480	N,N-dimethyl ether
153	1490	N,N-dimethylformamide

	<u>CCPDB No.</u>	<u>Chemical</u>
154	1495	Dimethylhydrazine
155	1500	Dimethyl sulfate
156	1510	Dimethyl sulfide
157	1520	Dimethyl sulfoxide
158	1530	Dimethyl terephthalate
159	1540	3,5-dinitrobenzoic acid
160	1545	Dinitrophenol
161	1550	Dinitrotoluene
162	1560	Dioxane
163	1570	Dioxolane
164	1580	Diphenylamine
165	1590	Diphenyl oxide
166	1600	Diphenyl thiourea
167	1610	Dipropylene glycol
168	1620	Dodecene
169	1630	Dodecylaniline
170	1640	Dodecylphenol
171	1650	Epichlorohydrin
172	1660	Ethanol
173	1661	Ethanolamines
174	1670	Ethyl acetate
175	1680	Ethyl acetoacetate
176	1690	Ethyl acrylate
177	1700	Ethylamine
178	1710	Ethylbenzene

	OCPDB No.	Chemicals
179	1720	Ethyl bromide
180	1730	Ethylcellulose
181	1740	Ethyl chloride
182	1750	Ethyl chloroacetate
183	1760	Ethylcyanoacetate
184	1770	Ethylene
185	1780	Ethylene carbonate
186	1790	Ethylene chlorohydrin
187	1800	Ethylenediamine
188	1810	Ethylene dibromide
189	1830	Ethylene glycol
190	1840	Ethylene glycol diacetate
191	1870	Ethylene glycol dimethyl ether
192	1890	Ethylene glycol monobutyl ether
193	1900	Ethylene glycol monobutyl ether acetate
194	1910	Ethylene glycol monoethyl ether
195	1920	Ethylene glycol monoethyl ether acetate
196	1930	Ethylene glycol monomethyl ether
197	1940	Ethylene glycol monomethyl ether acetate
198	1960	Ethylene glycol monophenyl ether
199	1970	Ethylene glycol monopropyl ether
200	1980	Ethylene oxide
201	1990	Ethyl ether
202	2000	2-ethylhexanol
203	2010	Ethyl orthoformate
204	2020	Ethyl oxalate

	OCEDB No.	Chemical
205	2030	Ethyl sodium oxalacetate
206	2040	Formaldehyde
207	2050	Formamide
208	2060	Formic acid
209	2070	Fumaric acid
210	2073	Furfural
211	2090	Glycerol (Synthetic)
212	2091	Glycerol dichlorohydrin
213	2100	Glycerol triether
214	2110	Glycine
215	2120	Glyoxal
216	2145	Hexachlorobenzene
217	2150	Hexachloroethane
218	2160	Hexadecyl alcohol
219	2165	Hexamethylenediamine
220	2170	Hexamethylene glycol
221	2180	Hexamethylenetetramine
222	2190	Hydrogen cyanide
223	2200	Hydroquinane
224	2210	p-hydroxybenzoic acid
225	2240	Isoamylene
226	2250	Isobutanol
227	2260	Isobutyl acetate
228	2261	Isobutylene
229	2270	Isobutyraldehyde
230	2280	Isobutyric acid

	OCFDB No.	Chemical
231	2300	Isodecanol
232	2320	Isooctyl alcohol
233	2321	Isopentane
234	2330	Isophorone
235	2340	Isophthalic acid
236	2350	Isoprene
237	2360	Isopropanol
238	2370	Isopropyl acetate
239	2380	Isopropylamine
240	2390	Isopropyl chloride
241	2400	Isopropylphenol
242	2410	Ketene
243	2414	Linear alkyl sulfonate
244	2417	Linear alkylbenzene
245	2420	Maleic acid
246	2430	Maleic anhydride
247	2440	Malic acid
248	2450	Mesityl oxide
249	2455	Metanilic acid
250	2460	Methacrylic acid
251	2490	Methallyl chloride
252	2500	Methanol
253	2510	Methyl acetate
254	2520	Methyl acetoacetate
255	2530	Methylamine
256	2540	n-methylaniline

	OCPPDB No.	Chemical
257	2545	Methyl bromide
258	2550	Methyl butynol
259	2560	Methyl chloride
260	2570	Methyl cyclohexane
261	2590	Methyl cyclohexanone
262	2620	Methylene chloride
263	2530	Methylene dianiline
264	2635	Methylene diphenyl diisocyanate
265	2640	Methyl ethyl ketone
266	2645	Methyl formate
267	2650	Methyl isobutyl carbinol
268	2660	Methyl isobutyl ketone
269	2665	Methyl methacrylate
270	2670	Methyl pentynol
271	2690	α -methylstyrene
272	2700	Morpholine
273	2710	α -naphthalene sulfonic acid
274	2720	β -naphthalene sulfonic acid
275	2730	α -naphthol
276	2740	β -naphthol
277	2750	Neopentanoic acid
278	2756	o-nitroaniline
279	2757	p-nitroaniline
280	2760	o-nitroanisole
281	2762	p-nitroanisole
282	2770	Nitrobenzene

	<u>OC.PDB No.</u>	<u>Chemical</u>
283	2780	Nitrobenzoic acid (o, m, and p).
284	2790	Nitroethane
285	2791	Nitromethane
286	2792	Nitrophenol
287	2795	Nitropropane
288	2800	Nitrotoluene
289	2810	Nonene
290	2820	Nonyl phenol
291	2830	Octyl phenol
292	2840	Paraldehyde
293	2850	Pentaerythritol
294	2851	n-pentane
295	2855	1-pentene
296	2860	Perchloroethylene
297	2882	Perchloromethyl mercaptan
298	2890	o-phenetidine
299	2900	p-phenetidine
300	2910	Phenol
301	2920	Phenolsulfonic acids
302	2930	Phenyl anthranilic acid
303	2940	Phenylenediamine
304	2950	Phosgene
305	2960	Phthalic anhydride
306	2970	Phthalimide
307	2973	β -picoline
308	2976	Piperazine

	CCPDB No.	Chemical
309	3000	Polybutenes
310	3010	Polyethylene glycol
311	3025	Polypropylene glycol
312	3063	Propionaldehyde
313	3066	Propionic acid
314	3070	n-propyl alcohol
315	3075	Propylamine
316	3080	Propyl chloride
317	3090	Propylene
318	3100	Propylene chlorohydrin
319	3110	Propylene dichloride
320	3111	Propylene glycol
321	3120	Propylene oxide
322	3130	Pyridine
323	3140	Quinone
324	3150	Resorcinol
325	3160	Resorcylic acid
326	3170	Salicylic acid
327	3180	Sodium acetate
328	3181	Sodium benzoate
329	3190	Sodium carboxymethyl cellulose
330	3191	Sodium chloroacetate
331	3200	Sodium formate
332	3210	Sodium phenate
333	3220	Sorbic acid
334	3230	Styrene
335	3240	Succinic acid

	OCPPDB No.	Chemical
336	3250	Succinitrile
337	3251	Sulfanilic acid
338	3260	Sulfolane
339	3270	Tannic acid
340	3280	Terephthalic acid
341	3290 & 3291	Tetrachloroethanes
342	3300	Tetrachlorophthalic anhydride
343	3310	Tetraethyllead
344	3320	Tetrahydronaphthalene
345	3330	Tetrahydrophthalic anhydride
346	3335	Tetramethyllead
347	3340	Tetramethylenediamine
348	3341	Tetramethylethylenediamine
349	3349	Toluene
350	3350	Toluene-2,4-diamine
351	3354	Toluene-2,4-diisocyanate
352	3355	Toluene diisocyanates (mixture)
353	3360	Toluene sulfonamide
354	3370	Toluene sulfonic acids
355	3380	Toluene sulfonyl chloride
356	3381	Toluidines
357	3390, 3391 & 3393	Trichlorobenzenes
358	3395	1,1,1-trichloroethane
359	3400	1,1,2-trichloroethane

	<u>CCPDB No.</u>	<u>Chemical</u>
360	3410	Trichloroethylene
361	3411	Trichlorofluoromethane
362	3420	1,2,3-trichloropropane
363	3430	1,1,2-trichloro-1,2,2-trifluoroethane
364	3450	Triethylamine
365	3460	Triethylene glycol
366	3470	Triethylene glycol dimethyl ether
367	3480	Triisobutylene
368	3490	Trimethylamine
369	3500	Urea
370	3510	Vinyl acetate
371	3520	Vinyl chloride
372	3530	Vinylidene chloride
373	3540	Vinyl toluene
374	3541	Xylenes (mixed)
375	3560	o-xylene
376	3570	p-xylene
377	3580	Xylenol
378	3590	Xylidine