United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/3-86-002
January 1986

Air

EPA

Emission Factors For Equipment Leaks Of VOC And HAP

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Under EPA Contract
No. 68-02-3889

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

January 1986

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GLOSSARY

Average emission factor - the per component mass emission rate applicable to populations of sources, not individual component measurements.

Leak definition - the monitoring instrument reading selected as the trigger value for initiating some action such as maintenance; e.g., 10,000 ppmv is the leak definition used by EPA.

Leak frequency - the percentage of sources (a particular equipment type and service) determined to be leaking based upon a chosen leak definition.

Leak rate - see mass emissions rate.

Leaking emission factor - the per component mass emission rate associated with the population of sources with screening values at or above the leak definition.

Mass emissions rate - the quantity of volatile organic compound(s) released to the atmosphere in terms of total mass per unit time.

Monitoring instrument - portable hydrocarbon analyzer meeting the performance specifications given in Method 21.

Non-leaking emission factor - the per component mass emission rate associated with the population of sources with screening values less than the leak definition.

Screening value - monitoring instrument reading generally given in concentration units; e.g., ppmv.

1.0 OVERVIEW

One of the first major efforts in the field of fugitive hydrocarbon emissions was the Joint Refinery Study initiated by the Los Angeles County APCD, the California State Department of Public Health, and the U. S. Public Health Service in August 1955. Additional studies were made subsequent to this original work. But it was not until the mid- to late-1970's that a renewed interest was sparked by two events.

The Clean Air Act, originally passed in 1970, laid out the groundwork for the U. S. Environmental Protection Agency (EPA) to set standards of performance for newly constructed, modified, or reconstructed sources of air pollution which may endanger the public health or welfare. Since these New Source Performance Standards (NSPS) were to be promulgated for a large number of industries or industry segments, a ranking was developed in accordance with the 1977 amendments so that those industries with the highest potential for impacting public health would be examined first. The Synthetic Organic Chemical Manufacturing Industry (SOCMI) was placed first on the Priority List of industry categories as the single most significant contributor to air pollution.

Around this same time, an extensive study of atmospheric emissions from petroleum refining was conducted. The study was initiated to evaluate existing and developing refining emissions control technologies and to assess the potential impact of atmospheric emissions from refining on the surrounding environment. As the program began, fugitive emissions (i.e., emissions from various types of equipment such as valves, pumps, compressors, pressure relief devices, and connectors) were found to be a large (if not the largest) source of hydrocarbon emissions from refining. As a result, the scope of the Refining Study was expanded to include the quantification of fugitive emissions. This particular objective was given added emphasis as a result of the Clean Air Act and its emissions offsets regulations, which require emission factors for evaluating compliance.

Subsequent to the refinery assessment, EPA's research group conducted additional studies in chemical plants. Twenty-four separate chemical units were evaluated. Of these units, six were studied more closely for the effectiveness of emission control techniques. These new data, coupled with a review of data from other studies, were compiled into an Additional Information Document (AID) on fugitive emissions of VOC in SOCMI. The AID details EPA's conclusions about how to estimate emissions and emissions reductions for fugitive emissions of VOC.

The concepts behind fugitive emissions and their control are relatively simple; however, the understanding of fugitive emissions data is quite complex. Not surprisingly, the estimates of emissions, emission reductions, and costs still draw the bulk of comments and questions from regulatory personnel as well as industry representatives. This document addresses the development of emission factors for fugitive VOC emissions (or equipment leaks of VOC). The comments and questions most often raised are given below with a brief response. Detailed responses are contained in the substantial literature generated by EPA to support the fugitive emission standards.

1. My emissions are already low because of OSHA regulations. Why, then, are there also environmental emissions standards for equipment leaks?

Environmental emissions standards for equipment leaks have different purposes from OSHA regulations. Indeed, they may even result in different environmental benefits. Environmental standards focus on reducing the total quantity of emissions, in this case VOC emissions, to the atmosphere. On the other hand, OSHA regulations, unlike environmental standards, do not necessarily limit mass emissions directly. OSHA regulations permit control of emission sources by substitution of chemicals with less hazardous materials, process modifications, worker rotation, process or worker isolation, ventilation controls, or modification of work practices. Such control measures are focused on reducing occupational exposure (as a concentration), not necessarily reducing mass emissions of VOC to the atmosphere.

The idea of workplace concentration reduction is the key to OSHA regulations. It is often thought that OSHA regulations result in concentrations in the workplace well below 10,000 ppmv, the concentration level used to identify leaking components under the environmental regulations. An important distinction is that environmental standards call for measurement of VOC concentration at the leak interface, not in the surrounding area. Field studies have shown that the concentration of VOC decreases exponentially with increasing distance from the leak interface. Thus, a leak determined at the interface will rarely be seen at a distance only 20 cm from the surface and yet substantial quantities of VOC may be emitted from such a leak. Dispersion and dilution of the VOC into the surrounding area mask the severity of emissions from the leak. As a result, while OSHA regulations may well reduce the concentration of VOC in the workplace, they do not guarantee that the total mass emissions from leaks are also reduced.

I already control my emissions under the Control Techniques Guideline. Am I subject to more environmental standards for equipment leaks?

There are several environmental regulatory programs in existence: National Ambient Air Quality Standards (NAAQS), State Implementation Plans (SIP's), National Emission Standards for Hazardous Air Pollutants (NESHAP's), and New Source Performance Standards (NSPS's). All of these types of regulations work toward meeting the goals of the Clean Air Act.

The control techniques guideline documents (CTG) are presentations of what is considered by EPA to be "reasonably available control technology" (RACT). RACT-based environmental regulations are established by States to correct existing air pollution problems, focusing on existing sources in particular. The control techniques discussed in the CTG for SOCMI fugitive emission sources are completely consistent and compatible with standards set under other environmental programs. The resultant control levels may vary due to differences in the frequency of monitoring or the use of equipment control techniques.

RACT-based standards would not be duplicative with standards set under other environmental programs. NSPS's are applicable only to newly constructed, modified, or reconstructed facilities. Since they apply to new facilities, the requirements of NSPS are generally more stringent than those of RACT-based standards set for existing facilities. In the case of fugitive emissions control, for example, NSPS-based standards would require monitoring of equipment more frequently than required under RACT-based standards.

Similarly, NESHAP's are established for all facilities, new or existing. Again, the difference between requirements of NESHAP's and RACT-based standards is basically the degree of stringency. NESHAP's require more frequent monitoring than RACT-based standards for fugitive emission sources. Furthermore, NESHAP's often require the use of control equipment where RACT-based standards may only require work practices such as leak detection and repairs. Since NESHAP's are applicable to existing sources, as well as new sources, their more stringent requirements would need to be met, in excess of RACT-based standards for existing sources.

In terms of emissions estimates, process units complying with the RACT-based standards presented in the CTG would indeed exhibit lower emissions than would be presented by the simple use of the SOCMI emission factors. As shown in Table 4-3 of this document varying degrees of emission reduction are achievable under the different standards (NSPS, NESHAP, CTG). Emissions from process units complying with the CTG can be estimated by applying the proper efficiency to the estimated uncontrolled emissions.

2. Emissions from my process unit are lower than the SOCMI factors indicate. I control the emissions by looking for leaks, sometimes smelling for them. Why should my unit be covered by these standards?

The chemical industry is comprised of numerous processes producing a large number of chemicals. Each process unit may by itself emit a relatively small amount of VOC; however, the total amount of VOC from the industry is significant. Therefore, individual processes or units are not exempted.

EPA recognizes the wide variability of leak percentages on a unit process basis throughout the industry. Of the 24 units surveyed in the 24-unit study, 15 demonstrated overall leak frequencies for valves in gas/vapor and light liquid services of less than 2 percent. Environmental standards, therefore, provide alternatives for units that exhibit low-leak characteristics. For example, an owner or operator of a process unit may elect to comply with a performance limit of 2 percent leaking valves. In such a case, the routine leak detection and repair practices required by the basic rule would not be followed. Instead, the process unit would be screened (using Reference Method 21) on an annual basis to demonstrate that the unit does indeed demonstrate the low leak characteristics of less than 2 percent of valves leaking.

EPA selected this value based upon cost and emissions analyses which showed that monthly leak detection and repair for valves is not a cost effective control technique for process units exhibiting very low leak characteristics. These characteristics may result from the nature of the chemicals processed, tight plant design, or enhanced maintenance.

> Fugitive emissions from my process unit are lower than estimated using SOCMI factors. I have verified the low leak rates by measuring the concentration and flow rate at the ventilation outlet.

It may well be true that actual fugitive emissions from any given process unit are lower than the emissions estimated using the average SOCMI emission factors. The SOCMI factors, however, are applicable to the industry at large, and should be applied to any individual unit where the leak frequencies for equipment have not been established by a rigorous application of Reference Method 21. Concentration and ventilation flowrates give an indication of the magnitude of fugitive emissions; they would not necessarily provide an accurate estimate of total VOC fugitive emissions. For process units that would have ventilation outlets, all potential sources of fugitive emissions are not generally enclosed in the building. Also, large buildings that house chemical process units are not generally air tight; therefore, some VOC may not be accounted for in the ventilation air.

Furthermore, the evaluation of fugitive emissions from an enclosed building represents a complex measurement problem. All emission points from the building would need to be measured simultaneously for 3 hours to constitute an emissions test. This is the only way to ensure that all emissions from non-vented sources would be accounted for. Since fan curves are inaccurate for emissions measurements, EPA flow measurement methods would need to be employed. These methods require obstruction-free ducting on either side of the fan, a situation not always found in ventilation applications. Finally, when applied to the estimation of hazardous air pollutants, the analytical techniques used must be capable of speciation of organic constituents. Common detectors are not always adequate for this task.

Concentration and ventilation flow rate could indicate that emissions are lower than estimated by SOCMI factors. This technique, however, would not be sufficient to prove that emissions are low. There is an acceptable alternative to estimating emissions. Conducting a rigorous Method 21 survey would lead to computing percent leaking values (leak frequency) for all equipment types. These values could then be used to construct unit-specific overall emission factors using "leaking" and "nonleaking" emission factors as described in Section 3.3.3. Using such a procedure would develop emission factors consistent with the vast amount of fugitive VOC emissions data gathered to date. The unit-specific emission factors, applied to the equipment counts for the process unit, lead to the overall estimate of VOC emissions. As noted in this document, pre-survey maintenance would invalidate the results of the survey and estimates.

3. It is not appropriate to use petroleum refinery test data to determine SOCMI emission factors.

The development of VOC emission factors for equipment leaks is founded on the concept that equipment leaks VOC at the same rate regardless of the industry or process unit. Total emissions or average emission rates may vary, however, based upon the relative percentage of leaks found in different process units. In developing VOC emission factors for equipment leaks in SOCMI, EPA examined and considered every study available. This evaluation, explained in the AID, makes it clear that the data contained in the Maintenance Study and 24-Unit Study are not the sole source of data on fugitive emissions. Numerous studies have been conducted and these were reviewed in the AID, pointing out both strengths and weaknesses associated with each study. To gain maximum utility of the data from these studies, interpretation of the data is required, drawing upon the strong points of a study while considering its weaknesses. This evaluation and interpretation of the data was done in the context of the whole base of fugitive emissions work; it was not done just for isolated studies. Based upon this review and analysis, it was determined that the relevant data from different studies had to be merged and transformed to provide a useful method for estimating emissions. One of the most important studies was the Petroleum Refining Assessment.

The Petroleum Refining Assessment was an enormous study of VOC emissions from all facets of refining. A major goal of the work was the investigation of fugitive emissions and the development of emission factors that could be used to estimate fugitive VOC emissions. The research program, therefore, was designed to gather data that would lend itself to generation of such factors. As a result, the mass emissions data collected during the Petroleum Refining Assessment represent the best available data on VOC emissions from fugitive emission sources. Mass emissions data were gathered on sources in chemical units to evaluate the effects of maintenance on emissions. The data were not collected with emission factor development as the primary goal; therefore, these mass emissions data do not represent the highest quality data on mass emission of VOC from fugitive emission sources.

The work done in petroleum refineries and subsequent studies in chemical process units indicated that actual mass emissions (as described by emission factors) are related to the number of leaking components compared to the number of non-leaking components. The mass emissions data from the Petroleum Refining Assessment served as the basis of emission factor development for fugitive VOC sources in SOCMI. Recognizing that leak frequencies for equipment in SOCMI were different from those reported in the Refining Assessment, EPA used leak frequency data for SOCMI to weight the mass emissions data from the Petroleum Refining Assessment in generating the SOCMI average emission factors. This procedure is detailed in the AID and in this report. In the AID, EPA compared the emission factors generated using this approach with the factors developed as part of the study of maintenance effects in chemical units. The factors were found to be similar except in the case of gas/vapor service valves. Therefore, the chemical unit data were used to generate the emission factor for valves in gas/vapor service.

4. Using average SOCMI emission factors overestimates emissions from my process unit, because of the inherent nature of the chemicals I use, their volatility, their value, etc.

In gathering data on the SOCMI, EPA sampled a number of vastly different chemical process units. Characteristics of individual chemicals were considered in selecting the process units sampled during the 24-Unit Study. Hi-volume, low-priced chemicals were included, as were lower-volume, higher-priced chemicals. Chemicals with widely divergent volatilities were included along with chemicals that are particularly odoriferous. Not surprisingly, the frequencies of leaks found ranged from nearly zero to thirty percent. Leak frequencies provide an indication of the relative quantity of mass emissions and it is apparent from this range of leak frequencies that fugitive emissions from some units will be higher and some lower than estimates based on the SOCMI factors. The mass emissions estimates generated by EPA using the average SOCMI emissions factors represent an average that is applicable to industry-wide emissions estimates. Without conducting a rigorous Method 21 survey to determine the leak frequency (thereby generating average emission factors based on the leak/no-leak factor components), the average SOCMI emission factors stand as the best estimators of fugitive VOC emissions currently available.

5. I have measured emission rates for some sources in my plant. Why aren't these measurements better than the estimates EPA supports?

The emission factors supported by EPA are based upon a vast amount of data gathered on fugitive VOC emission sources using rigorous sampling protocols. The factors for each equipment type have been developed considering two types of data: leak frequency data and mass emissions data. The <u>entire distribution</u> of mass emissions from each class of sources has been considered. For example, 76 individual measurements of mass emission from gas valves were taken across the distribution of screening values (i.e., analyses measurements) to develop a mass emissions correlation to be applied to screening data. Similar distributions of mass emissions measurements are necessary for each equipment type to develop the correlations used in generating average emissions factors.

Furthermore, the correlations represent only part of what goes into the emissions factors. Screening data (i.e, screening values for all equipment components are needed to ensure that the entire distribution of screening values is included in emission factor development.

Limited, isolated measurements of emission rates for "some" sources, therefore, are not representative of the entire distribution of sources in the process unit. Only by considering the entire distribution can the emission factor be representative.

6. How do I estimate emissions for my plant...

   (A) if I have no data?

   (B) if I have some measurements?

   (C) if I have done a rigorous Method 21 survey?

For process units where no emissions data are available, estimates of fugitive VOC emissions should be made using equipment counts and the typical average emission factors developed for SOCMI. The development of these factors given in this document, was explained in the Additional Information Document (AID) for VOC equipment leaks.

In some cases, isolated emission rate measurements may have been made. These measurements serve to give the owner or operator a "sense" of the quantity of mass emissions that might be emitted from the process unit. Again, however, the average SOCMI factors must be employed to estimate emissions when only isolated mass emissions measurements have been made. Isolated measurements do not represent the entire distribution of screening values and mass emission rates present in a process unit.

The alternative to using the average SOCMI factors is to employ complete leak frequency data gathered using a rigorous Method 21 survey on all equipment types. In so doing, the leak/no-leak approach described within can be used to estimate emission factors for the specific process unit screened. The resultant "custom" emission factors would then be applied to the equipment counts for the specific process unit to derive the total fugitive VOC emissions estimate for the process unit. This procedure is illustrated for an example case in Section 3.5.

The initial step in generating surrogate emission factors is to use a rigorous Method 21 survey on all sources in the process unit. Method 21 survey is the promulgated method developed by EPA that is used to monitor equipment for leaks. "Rigorous" means that all sources must be screened and that no maintenance of sources should be conducted prior to screening. Conducting maintenance immediately prior to conducting the Method 21 survey would bias the leak frequencies generated and thus invalidate the subsequent emissions estimates based upon the leak frequencies.

Emissions estimated in this manner should be reviewed on a continual, i.e., annual, basis. For example, as time passes, the leak frequencies noted for individual equipment types in a process unit may change. An annual testing using a rigorous Method 21 survey would ensure that emissions estimates made using "custom" emission factors would remain representative of the process unit.

7. I am not interested in total VOC emissions. How do I estimate emissions of a specific pollutant?

The estimates of VOC emissions represented by the average SOCMI emission factors are total VOC emissions. In many instances, only one component in the VOC stream is of interest and the estimate of emissions need only reflect the specific pollutant. In order to reflect compound-specific emissions, the estimates, (or emission factor) should be apportioned to reflect the single compound (or component) of interest. As illustrated in Section 3.5, a simple mass fraction approach can be applied; that is, for equipment in VOC service containing X weight percent of the compound of interest, the emission factor could be apportioned by X/100 to reflect emissions of only the single compound.

8. The control costs associated with leak detection and repair are too high, particularly in light of low emissions reduction.

EPA based its estimates of cost on cost data gathered from industrial sources during standards development activities. The time estimates used for equipment monitoring (i.e., screening) and for repair (of valves) were based on information supplied by industry. Cost and cost effectiveness analyses were conducted for control of individual equipment types and for complete process units. The costs of regulatory alternatives for equipment types were judged to be reasonable. Likewise, for process units considered on the average, the costs were found to be reasonable.

EPA recognized, however, that not all process units could be considered the model unit average SOCMI norm, described by model equipment counts and average SOCMI emission factors. There are tools to examine regulatory alternatives, as applied to an entire industry. Therefore, EPA considered alternative control options for those situations where costs became unreasonable with respect to the amount of emissions controlled. An example of alternative standards allowed by EPA is the 2 percent leaking performance limit for valves. In its analysis of regulatory alternatives, EPA determined that the costs of control for process units with less than 1 percent leaking valves were too high for the relatively small emissions reductions achievable by routine leak detections and repair (monthly). To allow for variability in measurements, EPA provided a limit of 2 percent leaking. As evidenced by data gathered during the 24-Unit Study, there are process units which exhibit low leak characteristics. Owners or operators of such units could opt for meeting a 2 percent (or lower) performance limit of leaking valves, as demonstrated by an annual Method 21 performance test.

2.0 FUGITIVE EMISSION SOURCES

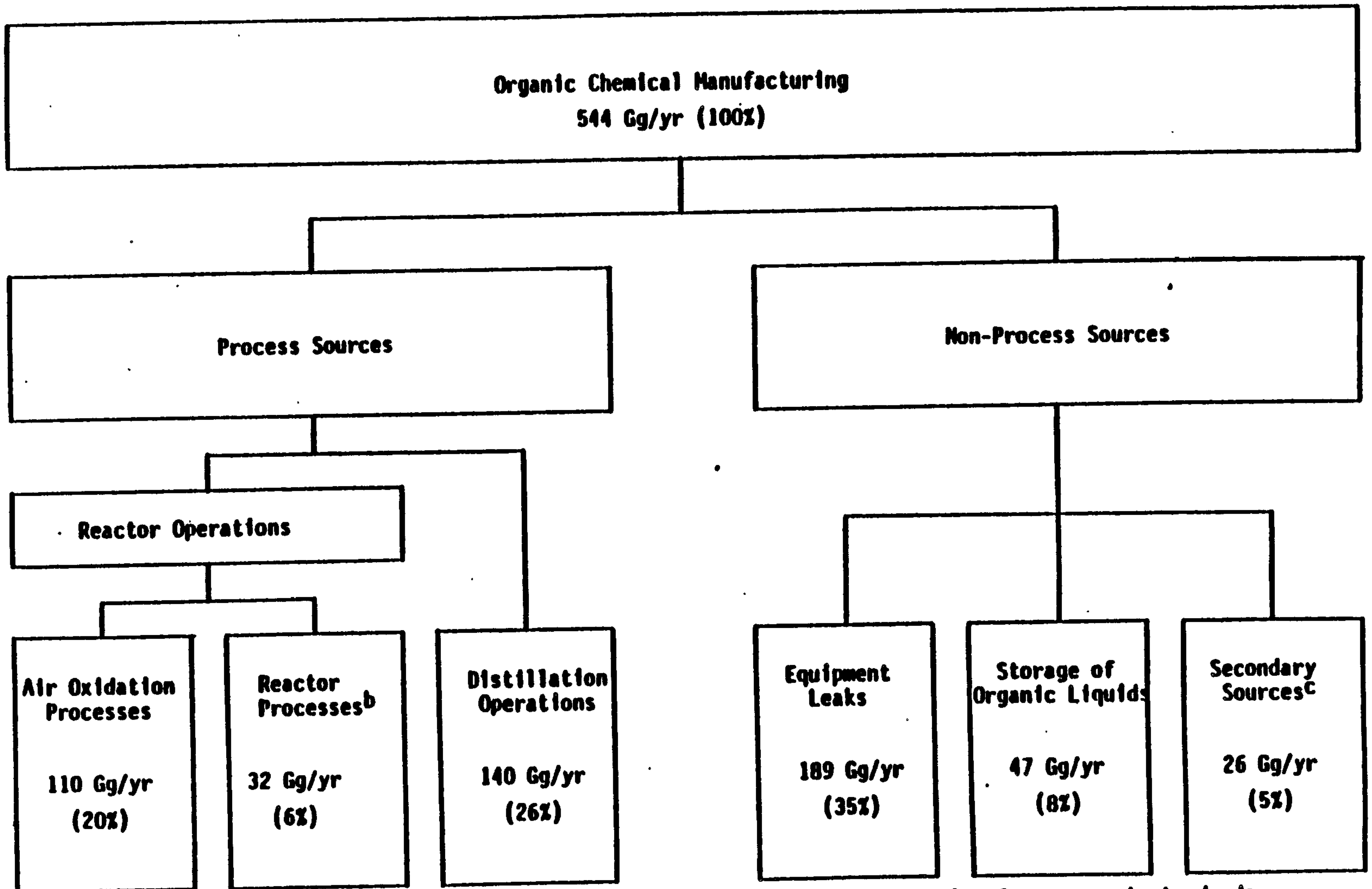
The term <u>fugitive emissions</u> used in the context of volatile organic compounds (VOC) refers to leaks from equipment such as valves, pumps, compressors, etc. The term fugitive emissions, also called equipment leaks, means the loss of VOC through the sealing mechanism separating the process fluid (contained in the equipment) from the atmosphere.

Fugitive emissions are generally more diffuse than most point sources of emissions, especially when considering the collective emissions from widely dispersed equipment within a processing plant. As noted by the emissions estimates presented in Figure 2-1, fugitive emissions contribute a large proportion of VOC emissions from the chemical industry overall (about 35 percent).[1]

As with process-related sources, fugitive emissions sources are readily identifiable pieces of equipment within a processing plant. But a major difference is in the number of sources found in any given process unit. While there may be only a few process-related sources within a process unit (e.g., a reactor train and associated distillation columns for purification), there can be hundreds or thousands of valves, pumps, flanges, compressors, and other fugitive emission sources within a process unit. And while fugitive emissions on a per component basis can be small, the collective total of emissions from all fugitive sources within a process unit can be large.

No single control technique is applicable to the control of all types of equipment leaks. Neither is a single emission limit universally applicable to equipment leaks. Rather, each type of fugitive emission source must be considered individually in establishing appropriate, applicable control techniques. Equipment controls, operational practices, and work practices are all valid approaches to reducing or eliminating VOC emissions from equipment leaks, depending on the equipment type.

Chemical process plants are comprised of numerous major equipment components such as reactors, accumulators, storage tanks, distillation columns, condensers, and heaters. There is also a large class of ancillary equipment,



[a]Estimates for process emissions sources estimated using best available information from current standards development programs (25 October 1982).

[b]Reactor processes category encompasses all processes other than air oxidation processes.

[c]Secondary and miscellaneous emissions estimated as 5 percent of the total of the other sources.

Figure 2-1. Estimated Emissions by Source Subcategories of SOCMI[2] most of which involves the transport of chemicals and control of chemical flow through the process unit. These components include:

- Valves
- Pumps
- Compressors
- Pressure Relief Devices
- Open-Ended Valves or Lines
- Sampling Connections
- Flanges and Other Connectors

These ancillary items of equipment are fugitive emission sources.

2.1 VALVES

The valve is one of the most basic, common elements found in the chemical plant. Valves are available in numerous designs for widely varying applications: gate, globe, control, plug, ball, check, and relief. Most of these valve designs (check and relief valves excepted) have a valve stem which operates to restrict or to open the valve for fluid flow. Typically the stem is sealed by a packing gland or O-ring to prevent leakage of process fluid to the atmosphere. Packing glands are the most commonly used sealing mechanism for valves, and a wide variety of packing materials are available to suit most operational requirements of temperature, pressure, and compatibility. Because of design and materials limitations, O-rings are much less common as the sealing mechanism for valves in chemical plants.

With time and prolonged use, the packing or sealing O-ring in the valve can fail. To eliminate the VOC leakage resulting from the seal failure, the valve packing and seals must be replaced or the valve body repaired or replaced. Leak detection and repair methods are effective means of reducing the leakage of VOC from this class of sources in a plant. Basically, a leak detection and repair (LDAR) program is a systematic program of routinely monitoring individual sources (in this case, valves) to identify those sources which are leaking.* Those leaking sources would then be targeted for repair

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*For different source types or industries, the definition of a leak may vary. For the purpose of this document, the leak definition is a screening value greater than or equal to 10,000 ppmv read on a portable organic compound analyzer, in accordance with Method 21.

(i.e., elimination of the "leak") and for subsequent follow-up monitoring to ensure that the repair had indeed been effective in eliminating the leak.

Maintenance or repair techniques can range from simple, on-line maintenance to complex techniques. Some basic types of maintenance that can be performed on a valve while it remains in-place and in service are:

(1) tightening or replacement of bonnet bolts,

(2) tightening of packing gland nuts, and

(3) injection of lubricant into the packing or seal.

These valve components are illustrated in Figure 2-2. But simple on-line techniques are not always applicable or effective in reducing emissions. For example, operational or safety requirements may prohibit repair of some valves such as control valves by simple means. Other valves simply cannot be repaired effectively on-line and cannot be removed from service. In some instances, repair of valves can be effected through more sophisticated repair techniques. An example would be the injection of a sealing fluid into the equipment. Though relatively expensive, sealant injection has been proven effective in petroleum refining applications in California where virtually complete elimination of leaks has been mandated.[3] In cases where maintenance or repair of valves is not possible, valve replacement may be required.

There are some valve types and designs that have little or no potential for leakage of process fluids: valves with "leakless" or "sealless" technology. Two examples are bellows sealed valves and diaphragm valves. Bellows seals are the most effective sealing mechanism for valves. Since the service life of the bellows can be quite variable, bellows seals are typically backed up with conventional packing glands. Bellows seals have been used primarily in the nuclear power industry where the relatively high cost can be justified by stringent safety requirements. Diaphragm valves, the other major type of "leakless" valve, use a diaphragm of some appropriate material to seal the process fluid from the stem of the valve. In some designs, the diaphragm acts as the flow control element as well as the sealing mechanism. Two

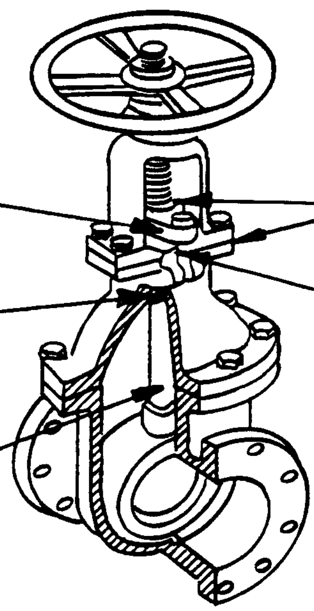


FIGURE 2-2. DIAGRAM OF A GATE VALVE

typical designs of diaphragm valves are shown in Figure 2-3. Diaphragm valves, however, are a source of fugitive emissions if the diaphragm fails.

2.2 PUMPS

Pumps are integral pieces of equipment in most chemical processes, providing the motive force for transporting fluids throughout a plant. The centrifugal pump is the chief design used in the SOCMI, but other pump types are also used. Leakage of process fluid to the atmosphere can occur where the moving pump shaft meets the stationary casing. To minimize such leakage, two sealing techniques are commonly applied: packed seals and mechanical seals.

Leak detection and repair programs, described earlier for valves, are also applicable to pumps with the potential to leak at the seal. Pumps with maintained mechanical seals generally leak less than do pumps with packed seals. Failure of a mechanical seal, however, can result in large emissions from the pump. Routine monitoring can effectively identify pump seal leaks and maintenance repair can reduce emissions.

Packed seals consist of a "stuffing box" in the pump casing. Specially selected packing materials (chosen on the basis of the process materials and environment) are compressed into the stuffing box with a packing gland, resulting in a tight seal around the shaft. Since the shaft must move, either rotationally or laterally, lubrication must be supplied to the packing and shaft to prevent excessive heat generation from the friction between the shaft and packing which could shorten the life of the equipment. Leaks may result from the degradation of the packing.

Leaks from packed seals can often be reduced by tightening the packing gland. But at some point, the packing will have deteriorated to the extent that it must be replaced. Often, pump packing can only be replaced when the pump is out of service.

Mechanical seals, single and dual, are used to seal pumps with rotating shafts. Both have the common attribute of a lapped seal face between a stationary element and a rotating seal ring. Although mechanical seals are not leakless sealing devices, the leakage of process fluid from the seal can be minimized by a properly installed and operating mechanical seal.

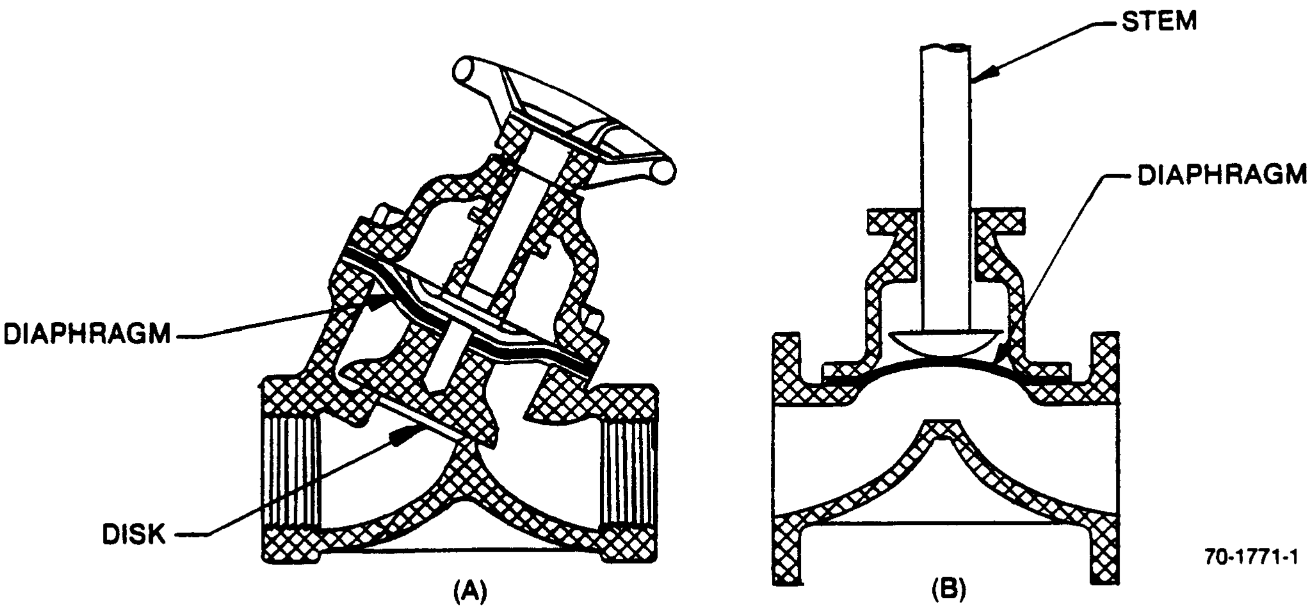


FIGURE 2-3. DIAGRAMS OF VALVES WITH DIAPHRAGM SEALS

Since a mechanical seal will leak (unless routinely replaced), the ultimate potential for leakage can be reduced through redundancy of sealing mechanisms. For instance, a single seal may employ a packed seal as an auxiliary sealing mechanism to reduce fugitive emissions. Or the same purpose might be just as easily accomplished with some dual mechanical seal arrangements (either back-to-back or tandem.) As shown in Figure 2-4, the dual mechanical seals in both arrangements form a cavity.

In the back-to-back arrangement, a barrier fluid circulates between the two seals. With the barrier fluid pressure maintained above the pump operating pressure, any leakage is across the inboard seal face into the process fluid and across the outboard seal face to the atmosphere. The tandem arrangement basically has a single seal backed up by another single seal; both seals are mounted facing the same direction. The seal fluid (also referred to as the buffer or barrier fluid) is circulated through the space between the seals. Any process fluids that may leak into the barrier fluid across the inboard seal interface may be removed with the barrier fluid or degassed in a reservoir. The degassed materials could then be treated in a control system.

In general, mechanical seals have the advantage of improved sealing characteristics and auxiliary control for VOC that may leak into the barrier fluid system. However, repair of mechanical seals can be both costly and time consuming. To eliminate a leak from a pump equipped with a mechanical seal, the pump must be taken off-line and dismantled to permit repair or replacement of the seal. Additionally, care must be exercised to minimize emissions resulting from dismantling the pump.

In addition to these pump types and seal designs, there are several types of sealless technology available. Three designs have been applied in the chemical industry where leakage cannot be tolerated. The canned-motor pump is a shaftless design in which the pump bearings run in the process fluid. The motor rotor housing and pump casing are interconnected. Diaphragm pumps eliminate all seals and packing exposed to the process fluid through the use of a flexible diaphragm (constructed of metal, rubber, or plastic material) as the driver for moving the fluid. Magnetic-drive pumps also have no seals in contact with the process fluid; the impeller in the pump casing is driven by

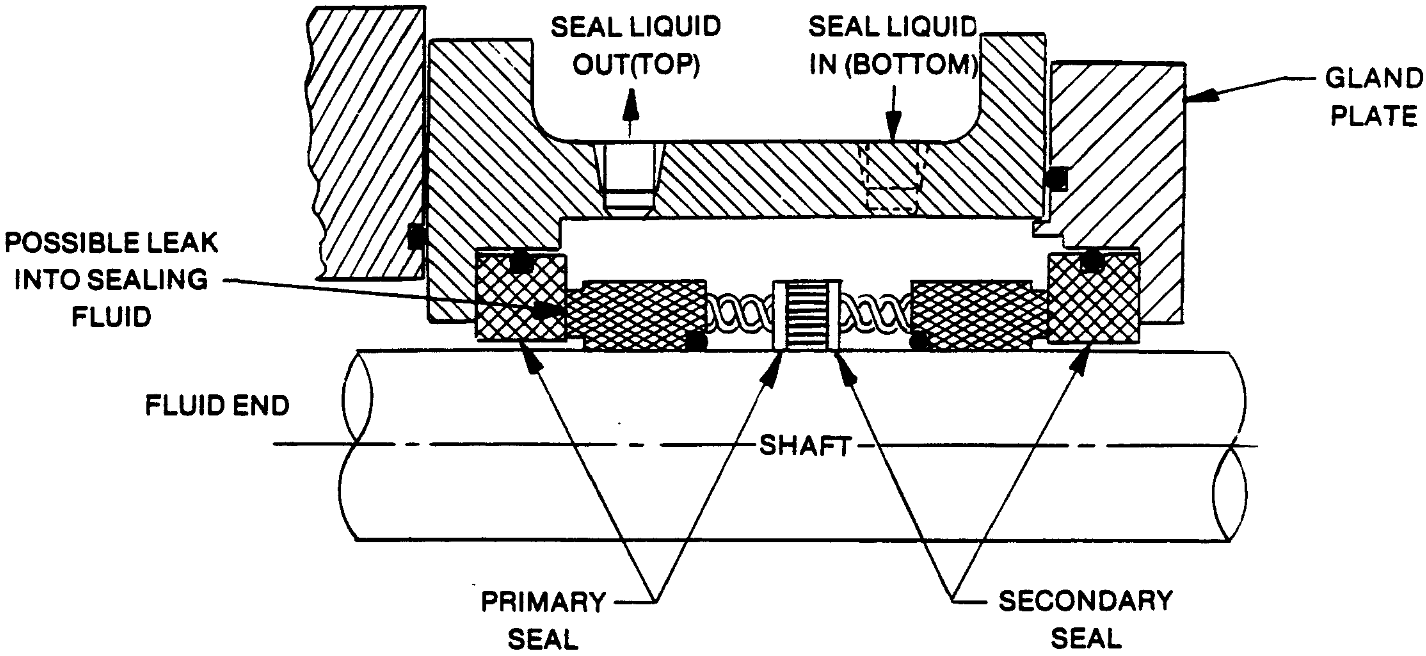


FIGURE 2-4a. DIAGRAM OF A DOUBLE MECHANICAL SEAL (BACK-TO-BACK ARRANGEMENT)

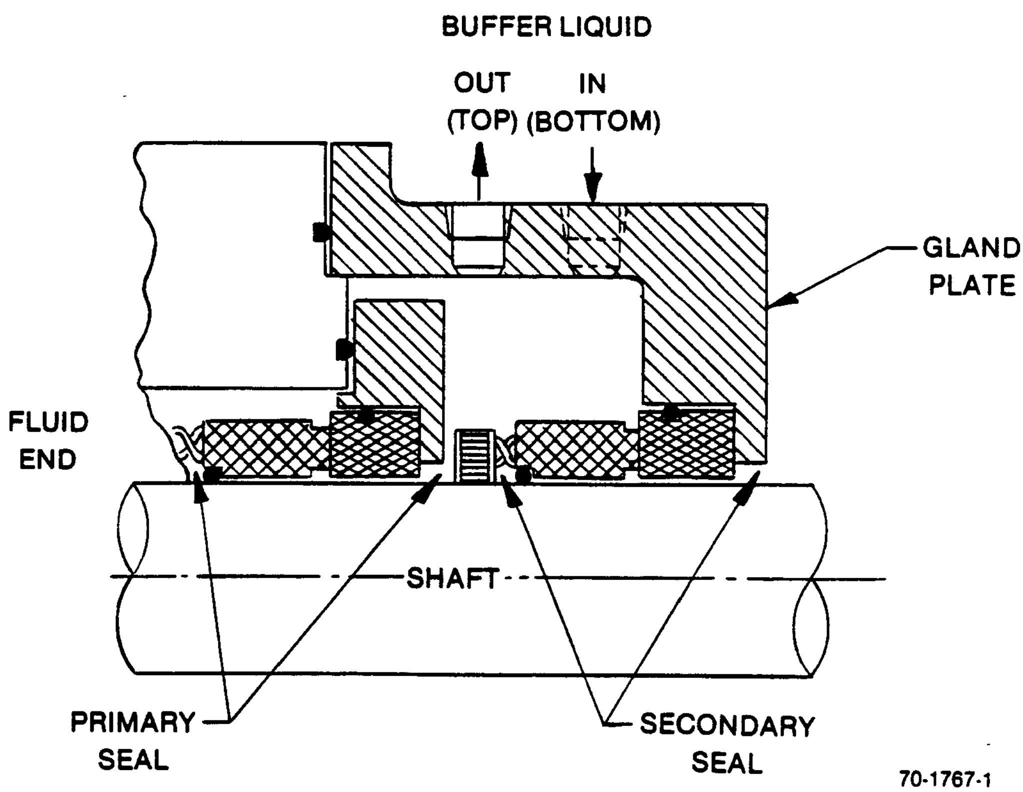


FIGURE 2-4b. DIAGRAM OF A DOUBLE MECHANICAL SEAL (TANDEM ARRANGEMENT)

an externally-mounted magnet coupled to the motor. Examples of uses of sealless technology for pumps include the handling of organic solvents, organic heat transfer liquids, toxic or hazardous materials, and expensive materials.

2.3 COMPRESSORS

Compressors provide motive force for transporting gases throughout a process unit in much the same manner that pumps are used to transport liquids. Compressors are driven with rotating or reciprocating shafts. Thus, the sealing mechanisms for compressors are similar to those for pumps; that is, packed and mechanical seals are the designs primarily used. Again, it is the sealing mechanism that is the potential source of fugitive VOC emissions.

The mechanical seals used on compressors reduce but do not eliminate leakage of the process fluid. The types of seals commonly used on compressors include:

- Labyrinth, comprised of interlocking teeth to restrict flow;
- Restrictive carbon rings, comprised of multiple stationary carbon rings;
- Mechanical contact, which is similar to the mechanical seal for pumps; and
- Liquid film, which employs an oil film between the rotating shaft and stationary gland.

These mechanical seals can be vented in various manners to a control device for elimination of VOC which may leak from the process. The use of packed seals is generally restricted to reciprocating compressors where mechanical seal designs cannot be used.

Leakage of VOC to the atmosphere from compressor seals can be detected by instrument monitoring at the seal. Repair of mechanical seals requires removing the compressor from service. Since compressors in the SOCMI do not typically have spares, immediate repair may not be practical or possible without a process unit shutdown. There are optional control techniques that are considered effective means of controlling emissions from mechanical seals on compressors. One example is venting the barrier fluid system or the seal to a control system (for example, a closed vent system connected to a control device).

Leakage from packed seals may be reduced by tightening the packing gland. Figure 2-5 shows a typical arrangement of a single stage reciprocating compressor. On some reciprocating designs (particularly newer compressors), the distance piece between the compressor cylinder and the drive crankcase can be vented to a control device to treat any leakage through the packing. On the older designs, however, this practice may not be possible without replacing (or possibly recasting) the distance piece to accommodate the vent line or completely replacing the older compressor with a newer design incorporating a vent line connection.

2.4 RELIEF DEVICES

Relief devices are safety devices commonly used to prevent operating pressures from exceeding the maximum allowable working pressures of process equipment. The most common pressure relief device is a spring-loaded valve (as shown in Figure 2-6) designed to open when the operating pressure exceeds a set pressure. The pressure relief valve (PRV) is constructed so that it will reseat after the operating pressure has decreased to a level below the set pressure.

Leaks of VOC from relief devices occur through the valve seat. Basically two mechanisms are cited for relief device leaks: (1) leakage resulting from improper reseating of the valve after a release and (2) leakage resulting from process operation at or near the valve set pressure. The latter condition is often referred to as "simmering" or "popping."

Rupture disks (RDs) are pressure relief devices that allow no fugitive emissions, if the integrity of the disk is maintained. Upon pressure relief, however, the disk bursts and the process vents directly to the atmosphere

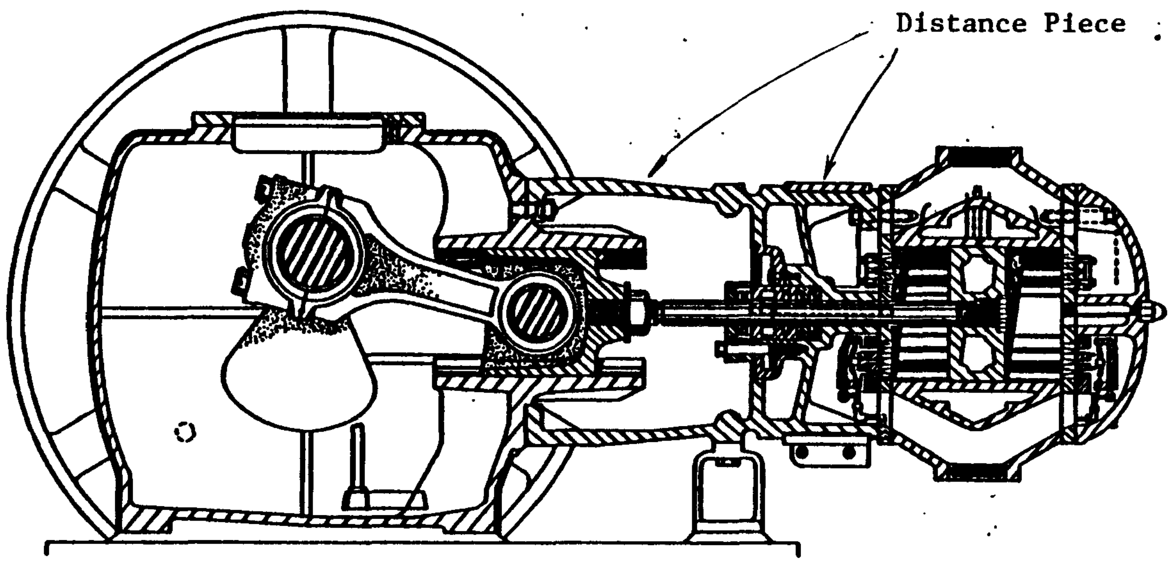


Figure 2-5. Simple Single-stage Reciprocating Compressor

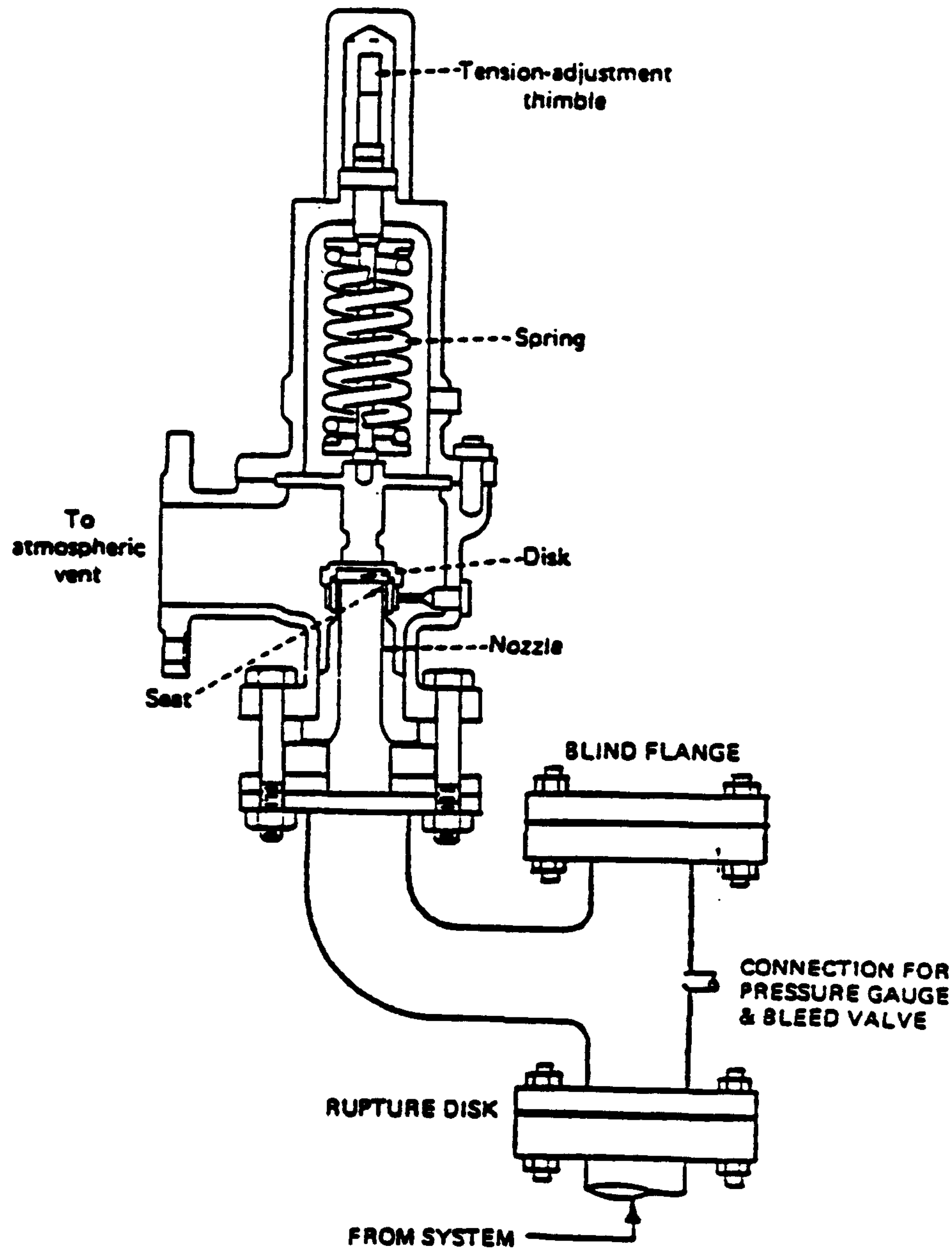


Figure 2-6. Pressure Relief Valve in a Basic RD/PRV Combination

until the process pressure has normalized with the atmosphere. Replacement of the rupture disk restores the process to a condition of no fugitive emissions.

Rupture disks should be used in conjunction with relief valves to eliminate potential fugitive emissions from relief valves. When mounted upstream of a relief valve, fugitive emissions are blocked prior to the potential leak source, the valve seat. (Leakage may occur if the integrity of the disk is not maintained.) A typical arrangement of an RD/PRV combination is shown in Figure 2-6; such systems have been specified by ASME Codes which establish the design constraints and criteria to avoid potential safety hazards from the practice. For instance, to meet ASME requirements, the space between the RD and the PRV must be equipped with a bleed valve and pressure gauge that would indicate any pressure build-up resulting from a leaking disk.[4]

To ensure no fugitive emissions to the atmosphere, the rupture disk must be replaced after an overpressure relief. One option that accommodates this procedure consists of block valves mounted upstream of the relief devices. This option is only possible where safety rules permit the use of a block valve in relief line service. (Even where permitted, this practice generally includes provisions for locking the block valve in the open position during normal operation.) The other options are dual relief valve systems equipped with 3-way valves. By using a 3-way valve, a relief system will always remain in service, even when replacing a rupture disk on the other relief combination. A number of possible configurations are possible for this option. For instance, the "primary" side (which would be used normally) could employ the RD/PRV combination, while the "secondary" side (which would be for back-up service only) could consist of a rupture disk, a pressure relief valve, or another RD/PRV combination.

Soft-seat technology for relief valves consists of using an elastomeric O-ring to provide an improved seal when the valve reseats after an overpressure release. The applicability of soft-seat technology is limited by materials compatibility and operating conditions. Furthermore, soft-seat technology has no impact on emissions from "simmering."

Fugitive emissions from all mechanisms can be stringently controlled by routing the discharge of the pressure relief device to an appropriate control device via a closed vent system. The most prevalent example of this procedure is the use of a flare header.

2.5 OPEN-ENDED VALVES AND LINES

Open-ended valves and lines are found throughout chemical plants; they are generally drain valves, purge valves, and vent valves. Process fluids may be emitted to the atmosphere through the valve seat as a result of faulty seats or incompletely closed valves. To prevent any atmospheric emissions from valve seat leakage, a pipe plug, cap, or blind flange can be installed on the open end. Another option is the use of a second valve, in something like a "block-and-bleed" arrangement. Using this arrangement, after the valves have been opened to allow flow of process fluid, it is best to close the upstream valve first. In this manner, no process fluid can be trapped between the two valves.

2.6 SAMPLING SYSTEMS

Routine periodic checks of process unit operation are often made by sampling process streams to evaluate the performance of reactors, distillation units and other operations, and to verify purity and composition of feedstocks, intermediates, and products. Process fluids contained in sample lines must be purged prior to sampling to obtain a representative sample for analysis. The purged fluid is often merely drained onto the ground or into the sewer drains, where VOC may be released to the atmosphere.

Sampling emissions can be reduced by using a closed purge sampling system, designed to return the purged VOC to the process or to send the VOC to a closed disposal system (e.g., a closed vent system connected to a control device). Examples of closed purge sampling systems are shown schematically in Figure 2-7. In one case, the sample is collected as a side-cut stream from the purge stream, which flows around a flow-restricting device (e.g., an orifice or valve) in the main process line. In the second example, the purge is directed through the sample container. These two examples are not the only

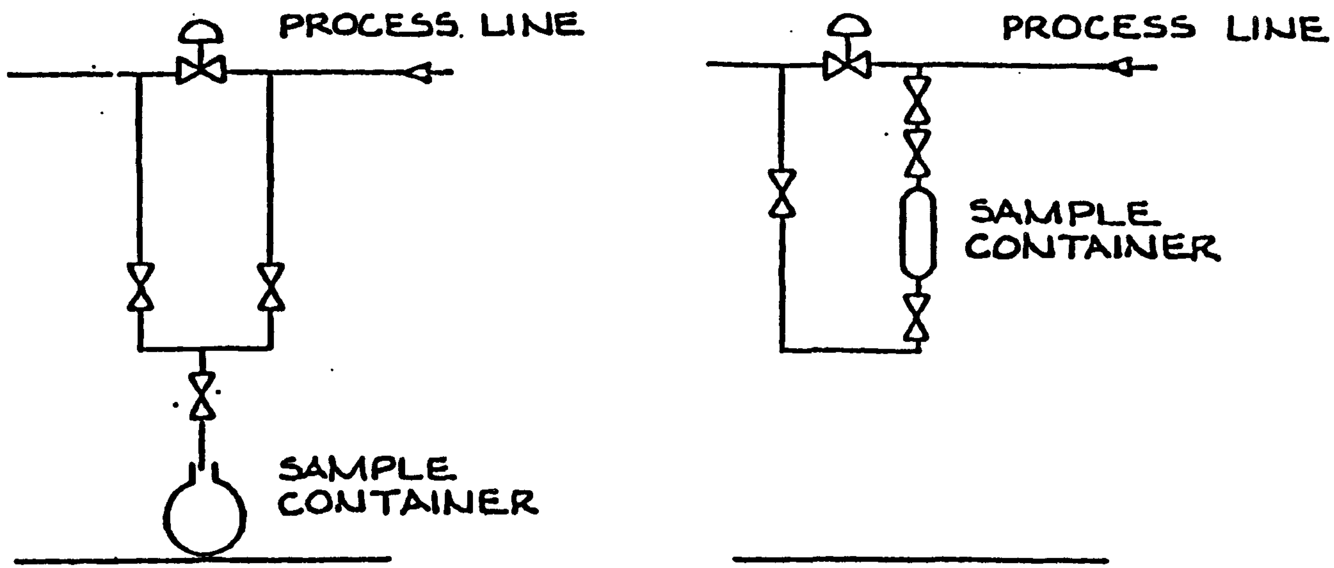


Figure 2-7. Schematics of Closed Purge Sampling Systems

closed purge sampling systems possible. For instance, closed purge sampling may also be done with partially-evacuated sample containers.

2.7 FLANGES AND OTHER CONNECTORS

Flanges and other connectors comprise the single largest class of fugitive emission sources in a process unit, in terms of total numbers. Flanges are gasket-sealed junctions used to mate pipe and other equipment such as valves, vessels, and pumps. Flanges may be used in pipe sizes 50 mm (2 inches) or greater in diameter. Other connectors, such as threaded connections and nut-and-ferrule connections, perform the same function as flanges, but they are used primarily on line sizes less than 50 mm in diameter.

Flanges and other connectors may leak VOC as a result of:

- improperly selected gaskets;
- poorly assembled flanges;
- poorly assembled nut-and-ferrule combinations; or
- cross-threaded pipe connections.

The major cause of VOC leakage from flanges and other connectors is deformation of sealing surfaces as a result of thermal stress. VOC leaks from flanges and other connectors can be determined using instrument monitoring techniques; potential leaks may be evidenced through other means such as visual, auditory, or olfactory means. Tightening bolts on flanges is one method of effectively sealing VOC leaks from some flanges. Generally, however, flange gasket replacement or correction of a leaking connector requires partial or complete process unit shutdown. And emissions from the shutdown or repair procedure could even exceed the long-term emissions from the leak itself.

3.0 EMISSION FACTORS

In evaluating standards of performance or even the effectiveness of individual programs of emissions reduction, the estimation of emissions from a given source is a key element. Source testing for process emission sources, such as reactor vents, etc., is a relatively straightforward procedure. Estimating emissions from widely dispersed fugitive emission sources can be somewhat more difficult.

One of the first published studies of fugitive emissions was conducted in several petroleum refineries in the Los Angeles County Air Pollution Control District. The estimates of this 1950's joint study showed that potentially a large quantity of hydrocarbons could be lost to the atmosphere from various sources such as valves, pump and compressor seals, cooling towers, flanges, and pressure relief valves.[5]

It was the middle 1970's before another comprehensive assessment of emissions from petroleum refineries was made.[6] In this newer study, emissions measurements were made at 13 refineries located throughout the United States. Emission factors, screening relationships, and correlations were generated from data collected on valves, flanges, pump seals, compressor seals, drains, and pressure relief valves. The focus of this study was the assessment of atmospheric emissions in petroleum refineries, and it was surprising to many people to find that fugitive emissions were a major contributor to the total air emissions from a refinery.

The Refining Assessment Study was subsequently used as a primary reference in standards development activities by EPA. The Refining Assessment Study was then augmented with other information available in the literature and additional studies of fugitive emissions conducted in chemical process units.

3.1 STUDIES CONSIDERED IN SOCMI EMISSION FACTOR DEVELOPMENT

Since the initial fugitive emissions work done in the 1950's LA County studies, numerous research efforts have focused on understanding fugitive emissions of VOC. Studies have considered leak frequency, leak rate, emission factors, methods of leak prevention, and the effectiveness of leak prevention techniques on reducing the number of leaks and mass emissions associated with them. The studies listed in Table 3-1 are briefly described below. Each study is summarized with respect to method and results. Actual numerical results have been summarized in the Additional Information Document (AID) for Fugitive Emission Sources of Organic Compounds.[7]

3.1.1 Petroleum Refining Assessment Study[6]

The Refining Assessment Study was designed to provide comprehensive emissions data from a representative number of fugitive emission sources in each refinery tested. In each of the 13 refineries tested, equipment in several process units were sampled. A total of 500 to 600 emission sources in each refinery were screened or sampled. To eliminate potential bias from source selection, all individual sources were preselected from piping and instrumentation drawings before entering the refinery.

Unlike previous studies, data were gathered on screening value (i.e., portable organic vapor detector instrument reading) and mass emissions. These data permitted the development of average emission factors and the correlation of the maximum observed screening value and the measured non-methane leak rate of VOC. The leak frequencies determined from field measurements and the average emission factors computed are shown in Table 3-2. These results served as the principal data against which other fugitive emissions work by EPA would be compared.

The Refining Assessment Study also provided some other very important results. The only equipment or process variable found to correlate with fugitive emission rates was the volatility of the stream components. This result led to the separation of equipment component emissions by service: gas/vapor, hydrogen, light liquid and heavy liquid. These classifications have been used in most fugitive emissions standards to direct effectively the major effort toward equipment most likely to leak.

Table 3-1. FUGITIVE EMISSIONS STUDIES IN THE AID

Reference No.	
6	Petroleum Refining Assessment Study
8	Four Unit EPA Study
9	EPA 6-Unit Study
10	Du Pont Study
11	Exxon Cyclohexane Study
12	EPA 24-Unit Study
13	Evaluation of Maintenance for Fugitive VOC Emissions Control
14	Analysis of Fugitive Emissions Data
15	Revision of Emission Factors/SOCMI Processes
16	German Studies
17	Union Carbide Study
18	Evaluation of Allied HDPE Study
19,20	Coke Oven By-Product Recovery and Gas Plants Studies

TABLE 3-2. LEAK FREQUENCIES AND EMISSION FACTORS: REFINING ASSESSMENT STUDY

Equipment	Service	Emission Factor[a] kg/hr/source	Percent of Sources >10,000 ppm[a]
Valves	Gas	0.0268	10
	LL[b]	0.0109	11
	HL[c]	0.00023	0.2
Pump Seals	LL	0.114	24
	HL	0.021	2
Compressor Seals	Gas	0.636	36
Pressure Relief Valves	Gas	0.16	7
Flanges	All	0.00025	0.5
Open-Ended Lines	All	0.0023	7.7

[a] From Appendix B of the Refining Assessment report (EPA-600/2-80-075c). Reference 21.

[b] LL - light liquid service; i.e., compounds with vapor pressure greater than kerosene.

[c] HL - heavy liquid service; i.e., compounds with vapor pressure of kerosene and lower.

3.1.2 Four Unit EPA Study[8]

Although designed along the same lines as the Refining Assessment Study, this study conducted by EPA-IERL (RTP) was too limited in scope to yield results with reasonable confidence intervals for most source types. The most important result of the Four Unit Study was that of illustrating the need for more intensive sampling and screening.

3.1.3 EPA 6-Unit Study[9]

The 6-Unit Study was the next level in testing of fugitive emissions conducted by EPA. For this study, leak frequencies (as determined using a portable organic analyzer and considering a 10,000 ppmv leak definition) were evaluated for all potential sources on an individual component basis. Plant personnel identified those equipment believed to handle organics. And no attempt was made to segregate equipment by service (e.g., in gas/vapor service, in light liquid service, etc.). No emission rate measurements were made, so no emission factors were determined.

3.1.4 Du Pont Study[10]

E. I. duPont de Nemours conducted an independent survey of two of their process units to evaluate the leak frequencies of pumps and valves and the leak rates of valves. A portable organic analyzer (calibrated to hexane) was used to identify leaks of 10 ppm or greater. Du Pont evaluated actual leak rates on only 6-8 valves. The study had a limited data base for pumps and valves and was restricted to two older process units. Du Pont's leak definition was inconsistent with EPA work. And finally, there was no determination of an average emission factor.

3.1.5 Exxon Cyclohexane Study[11]

Exxon Chemical Company conducted a study of fugitive emissions sources at its Baytown cyclohexane unit. Valves were screened using a soap solution (soaping); pump seals, compressor seals and safety valves were instrument screened using an undefined leak definition. Valve leaks were classified as small, medium, or large for selection for mass emissions sampling. The percentage of leaks and emission factors determined from the study could not be related to EPA's work due to the inconsistencies in leak definitions between the two studies.

3.1.6 EPA 24-Unit Study[12]

In 1980, EPA coordinated a study of 24 individual chemical process units. The process units were selected to represent a cross-section of the population across SOCMI. Among the chemical compounds included in the survey were acrylonitrile, ethylene dichloride, formaldehyde, perchloroethylene, and vinyl chloride. Selections of equipment to be screened were made prior to screening activities; screening was conducted by two-person teams using portable organic analyzers. Calibration was done daily at a minimum. A large number of the following types of equipment were screened in the 24 units for determination of leak frequency: flanges, process drains, open-ended lines, agitator seals, relief valves, valves, pump seals, and compressor seals. These sources were further grouped by the chemical phase of the material being handled: in gas/vapor service, in light liquid service, and in heavy liquid service.

3.1.7 Maintenance Study[13]

A study of the effects of maintenance on emissions was performed concurrently at six of the units screened in the 24-Unit Study. This work yielded quantitative estimates of leak occurrence and recurrence rates and of the effects of maintenance on fugitive emissions. Coincident with these estimates, correlations of screening values and leak rates were made.

The Maintenance Study focused on gas valves, light liquid valves, and light liquid pumps in three types of process units: ethylene, cumene, and vinyl acetate. The units selected were considered to be representative of the level of control existing in the chemical industry.

3.1.8 Analysis Report[14] and Revision of SOCMI Emission Factors[15]

Data gathered during the 24-Unit Study and the Maintenance Study were subjected to a more in-depth analysis. The data analysis tasks included in the report were generation of average emission factors, analysis of leak frequency as a function of process parameters and equipment design, analysis of the impact of instrument response factors on leak frequency, and analysis of the impact on mass emissions of leak occurrence and recurrence rates. Leak frequencies for the various source types varied among the 15 process units and among source types. Higher leak frequencies were found to be associated with higher line pressures, while line temperature appeared to have no consistent effect.

Average emission factors were developed for gas valves, light liquid valves, and light liquid pumps in the three process unit types examined in the Maintenance Study. In this case, emission factors were generated only for these processes since the leak rate/screening value correlations developed depend on process type. These emission factors were later revised to account for data biasing due to off-scale instrument readings and maintenance effects. The values determined were generally found to be lower than the average emission factors determined for petroleum refineries.

3.1.9 German Studies on Fugitive Emissions[16]

Four studies conducted by industry and government groups in West Germany investigated fugitive emissions and methods of prevention in chemical and petrochemical plants. The sources studied included flanges, threaded connections, compressor seals, pump seals, agitator seals and valves. Four different methods of leak rate determination or estimation were employed.

The studies were inconclusive in giving the quantitative dependence of leakages on chemical, physical, and design parameters of sealing elements. Insufficient data were cited as the reason. Leak rates found for the sources investigated were in general about 1/10 of the values previously published in the literature.[5] It is important to note that the low values represent leakage rates for well-maintained facilities. In addition, the studies noted that prior to any directed maintenance activity, the leak rate for valves was 200 percent of the published value. Most of these emissions were reduced by repair of a single large leak prior to additional measurements.

3.1.10 Union Carbide Study[17]

Union Carbide conducted a study of a single process unit to 1) find all leaking points in the unit, 2) quantify the leak rates for these points, and 3) develop a statistical fugitive emission sampling plan for future work. Leaks were determined using a portable organic analyzer calibrated with hexane for a 1,000 ppmv leak definition. An overall leak frequency of 6.7 percent was found for the 1,569 points screened. Pump seals and open-ended lines demonstrated the highest leak frequencies at over 30 percent.

Point leak rates were determined by various means for all sources determined to be leaking (i.e., screening at or above 1,000 ppmv). The method of determining the leak rate depended upon the rate of leakage (high; medium; low) and temperatures. The leak rates were not classified by source type (eg., pump seal, valve, etc.). Rather, they were reported by the degree or extent of leakage: (1) small leak (0.001 - 0.02 lb/day); (2) wet surface (0.1 - 0.5 lb/day); (3) dripping or strong unbearable odor (1 - 20 lb/day); and (4) continuous flow (50 - 150 lb/day). No leak rates were established for sources screening less than 1,000 ppmv. The leak rates were not used in developing EPA's factors since they could not be compared to data gathered by EPA.

In its recommendations, Union Carbide cited development of a leak rate/screening value correlation as an improvement in estimating emissions. In addition, the work done by Union Carbide recognized that, in order to establish leak rates for 13 equipment types, some 23,000 sources would have to be screened and 1,000 leak measurements made to obtain data within the 90 percent levels of confidence desired.

3.1.11 Analysis of Allied HDPE Unit Data[18]

Kemron Environmental Corporation, in conjunction with Allied Chemical, conducted a 10-month study of flanges and valves in a new high density polyethylene (HDPE) unit. Basically focusing on maintenance effects, six screening and emissions measurement tests were performed on valves and flanges over the course of the study. Screening was done using a portable organic analyzer calibrated to 1,000 ppmv hexane. (Unlike the EPA studies, a high concentration calibration standard was not used, nor was calibration verified at the completion of daily screening. While leak rates were determined for sources screening at 10,000 ppmv or greater, these rates are not comparable to average emission factors. (Average emission factors consider emissions from all valves across an entire distribution of screening values, not just values higher than 10,000 ppmv.) Further, some of the valves sampled for leak rate had been subjected to a directed maintenance program prior to sampling. This action resulted in lower emissions than would be expected in the absence of any maintenance efforts.

3.1.12 SCAQMD Study[22]

To evaluate the effectiveness of fugitive emission control regulations, EPA conducted a survey of two refineries in the South Coast Air Quality Management District (SCAQMD) in California. Accessible valves, pumps, agitators, open-ended lines, drains, and relief valves in 8 process units were screened using EPA Reference Method 21. No flanges were surveyed during this study. Since this was a maintenance-oriented study, no mass emission rate measurements were made.

3.1.13 Coke Oven By-Product Recovery[19] and Gas Plant Studies[20]

Three coke oven by-product recovery plants were tested for fugitive benzene emissions. Source screening was done with two different types of portable organic analyzers. Emissions data gathered were categorized according to source type and stream benzene content, but no distinction of service was made. Non-methane hydrocarbon emission factors were generated for valves, pump seals, and exhausters (i.e., compressors mainly in hydrogen service).

A total of six natural gas processing plants were tested by EPA and the American Petroleum Institute (API).[23] Screening was done by both soaping and portable organic analyzers. Leak rate data collected during the combined study were used to estimate leak rates for emitting sources. These results were then applied to the population to estimate the average emission factors for connections and flanges, open-ended lines, pressure relief devices, valves, pump seals, and compressor seals.

3.2 EPA'S CHOICE OF DATA FOR SOCMI EMISSION FACTORS

EPA used three major criteria in evaluating data to use to estimate fugitive VOC emissions: 1) relevance to fugitive emissions, 2) validity of the testing and analytical procedures, and 3) comparability to other studies to allow validation of results.

The studies of fugitive emissions summarized above were evaluated in the AID with respect to their relevance to estimating fugitive emission factors. For example, the emission factors generated in the Maintenance Study were not considered the highest quality, best available data on mass emissions; estimation of emission factors was not the principal purpose of the Maintenance Study. The factors were used, however, to evaluate the results of the emission factor estimates made.

The second criterion was used to eliminate from consideration data that were not collected by clear, consistent, acceptable test procedures. For example, the result of studies under scrutiny would need to be evaluated with respect to 1) how the samples were collected, 2) how the measurements were made (field or laboratory), and 3) what type of equipment was represented by the reported data (only leaking equipment, complete distribution of equipment, etc.). This same sort of evaluation was needed to consider differences in leak definition, method of determining leaks (soaping, instrument screening), and monitoring instruments.

The final criterion was comparability of the studies. Data from both the Refining Assessment Study and the combined SOCMI studies were gathered in the same manner using comparable instrumentation and leak detection criteria. Statistically, the data were handled in a similar manner in studying emissions and the various effects of various parameters on emissions. It was only because the data from the Refining Assessment Study and the combined SOCMI studies were comparable that the two studies could be evaluated against one another. Mass emissions data from the Refining Assessment Study and leak frequency data from the SOCMI work were then combined to form a single set of emission factors.

As detailed in the AID, EPA determined that the best data available for estimating emission factors for fugitive VOC emissions from SOCMI was from the Petroleum Refining Assessment Study and from the SOCMI 24-Unit Study. These studies satisfied the three major criteria for emissions estimate data. EPA compared the two data sets and acknowledged there were differences that could not be explained conclusively. The Petroleum Refining Assessment data were considered the best data on mass emissions from fugitive emissions sources. The Refining Assessment Study was planned with estimation of VOC fugitive emissions as one of its objectives. VOC emissions data were gathered according to equipment type and service (i.e., gas/vapor, light liquid, heavy liquid). These data are considered applicable to VOC fugitive emissions, regardless of industry. The 24-Unit Study best represented the leak frequencies that might be expected across SOCMI. Therefore, fugitive source emission factors for SOCMI were based on the Refining Assessment and SOCMI emissions data, adjusted using the results of the 24-Unit Study. This procedure is detailed in Section 3.4.

Several approaches to estimating the emission factors were considered. The estimation procedure presented in the AID maintained consistency with the mathematical procedure followed in developing the emission factors presented in the Refining Assessment Study and SOCMI Maintenance Study. Before detailing the estimation procedure presented in the AID, the methods followed in the Refining Assessment and SOCMI Maintainance Studies are presented.

3.3 EMISSION FACTOR DEVELOPMENT

3.3.1 Detailed Procedural Method

The development of average emission factors for individual fugitive emission sources was laid out in the Petroleum Refining Assessment Study.[21] Since then, embellishments have been added to this procedure to account for censoring of data (i.e., sources screened at the maximum instrument reading) and other sampling effects (eg., pre-maintenance screening, post-maintenance screening, etc.). The average emission factor is not merely the average of the mass emissions measurements made on any given type of equipment. The process is somewhat more involved than a simple average.

Two types of fugitive emissions data were gathered for the development and analysis of emission factors. First, screening data (i.e., concentration measurements) were collected for a set of sources. Using these raw screening data, empirical cumulative distribution functions were generated. The empirical distribution function would be a key element in estimating an average emission factor. It was found that the cumulative distribution functions were adequately described by a log-normal distribution. This led to the generation of modeled cumulative distribution functions for source screening. These functions relate the screening value of a source to a leak frequency. An example of a modeled cumulative distribution function is found in Figure 3-1. From such a figure, the percentage of sources "leaking" (based upon a selected leak definition) can be established.

The second type of fugitive emissions data gathered for average emission factor development was mass emissions data. Individual sources were "bagged" and measured for mass emission rate (leak rate) and screening value. The mass emissions rate data pairs were regressed to yield leak rate/screening value correlations for the various source types. As with any experimental program, there will be some degree of variability in the data gathered, especially as it is applied to estimate other emissions from sources not tested. Confidence intervals give an indication of the range

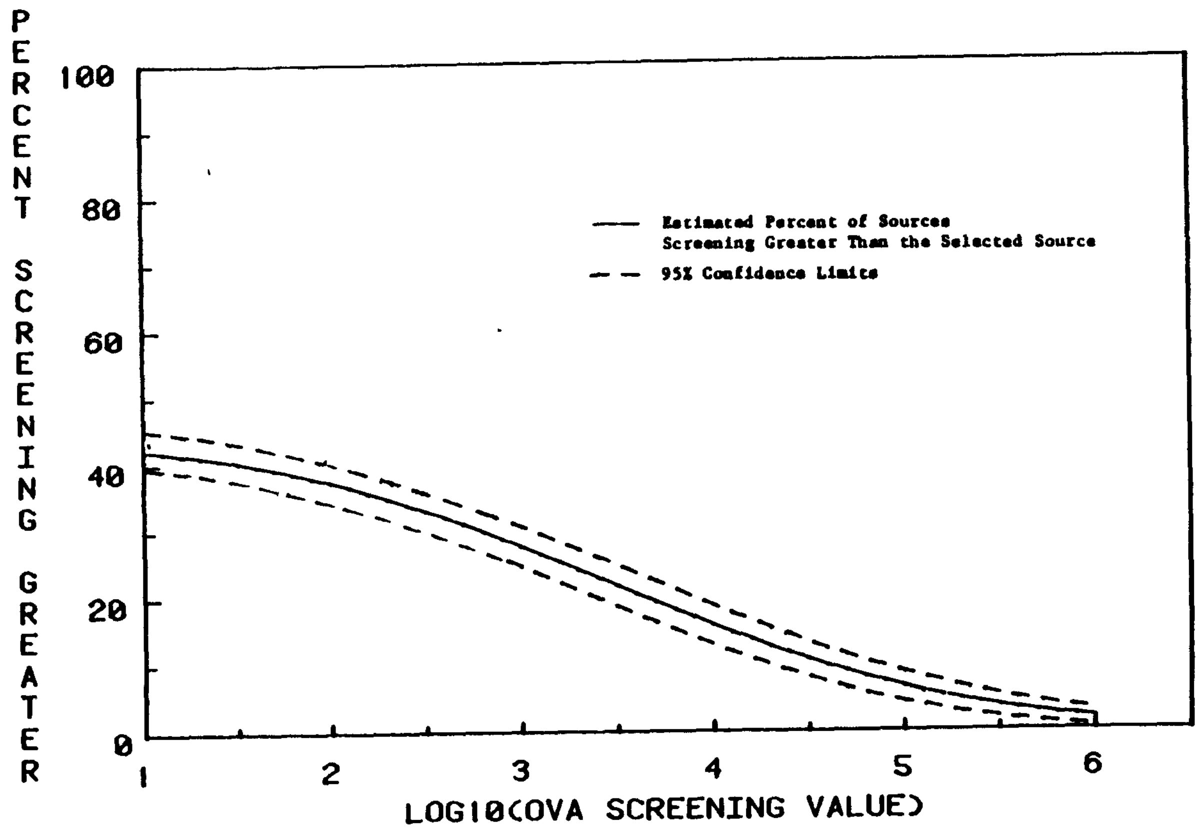


Figure 3-1. Cumulative Distribution: Cumene Gas Valves.

and the degree over which the results are applicable. The number of data pairs necessary to develop this correlation depends upon the confidence intervals desired in the final value. For example, for the 95 percent confidence level currently used in fugitive emissions work, 76 data pairs distributed over the range of screening values found are needed to generate the screening value/mass emissions rate correlation for valves.[24]

By combining these two data sets, cumulative mass emissions distributions were established. The leak rate/screening value correlation (from mass emissions data) was applied to the cumulative distribution function (from screening data) to result in a cumulative mass emissions distribution function for each source type. Figure 3-2 shows an example of this distribution for cumene gas valves. The cumulative mass emissions distribution yields the percentage of mass emissions (of a source type) associated with a selected leak definition. This value is important in generating the leaking and non-leaking emission factors discussed in Section 3.3.3.

The generation of the average emission factor made use of the empirical screening distribution data and the leak rate/screening value correlation. Using the correlation (developed from mass emissions data), leak rates were estimated for all sources that had been screened. The sum of the individual leak rates represented the total mass emissions leak rate for the class of sources being considered. The average emission factor was derived by averaging the sum over the total number of sources that were screened. The resultant average emission factor, therefore, considered the entire distribution of sources (and screening values). It was not merely the average of measured leak rates determined for some sources out of the population. Because the result of the procedure is an average emission factor, it should only be applied to populations of sources, and not to an individual component.

3.3.2 Statistical Considerations

Of course, in generating emission factors and in evaluating their quality, statistical considerations must be made. For example, there is a

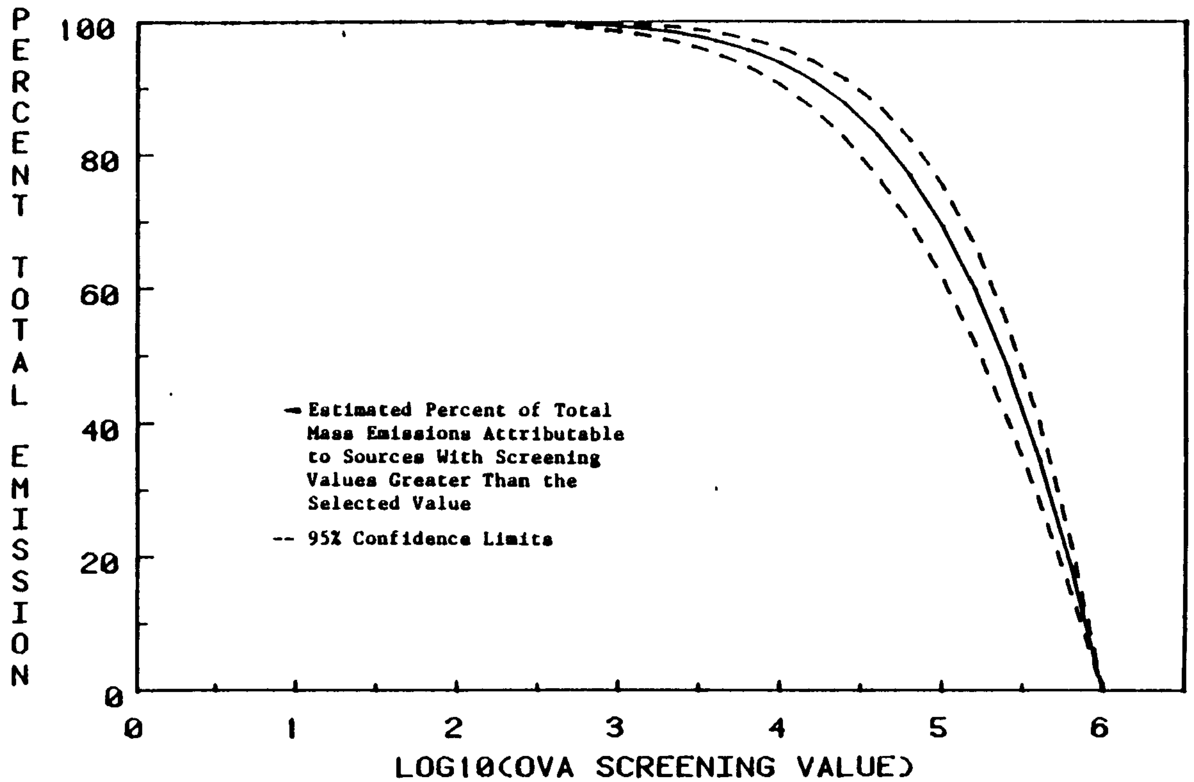


Figure 3-2. Cumulative Mass Emissions Distribution: Cumene Gas Valves.

minimum number of data pairs (screening value and mass emission measurement) required to generate a statistically valid screening value/leak rate correlation. And the number of data collected in the screening survey of any population of sources will have a direct impact on the confidence intervals associated with the modeled results.

From the previous discussion on the emission factor development procedure used in the Refining Assessment and the SOCMI Maintenance Studies, three models are necessary to generate average emission factors. The screening value distribution is first modeled to a log-normal distribution for sources screening at more than 10 ppmv. The confidence intervals for the cumulative function are evaluated using the published values for the Binominal Distribution. At the 95 percent confidence level, the estimated cumulative percent leaking ($\hat{p}$) is given as:

$$\hat{p} \pm 1.96 \left[\hat{p}\,(1 - \hat{p})/n\right]^{1/2}$$

where n is the number of screening values for the particular source type under consideration. From this equation, it is evident that, since the width of the confidence interval varies with the inverse square root of the number of sources screened, a larger population of screened sources yields a smaller confidence interval.

Next, the screening value/leak rate correlations should be considered, again with respect to the confidence interval. Leak rates are modeled in a log-log relationship assuming a binomial distribution, according to:

$$\text{Log (leak rate)} = \alpha + \beta\ (\log(\text{screening value})) + Z\ (\text{standard error})$$

where: α , β = model parameters;
Z = standard normal random number; and standard error is associated with the individual predictor equation.

Again, published Binomial Confidence Interval tables are used to generate the confidence intervals around the average of the log (leak rate) estimates, ($\bar{y}$). For example, the value at the lower confidence interval is:

$$C_1 = \bar{y} - 2.24\,[s^2/(n-r)]^{1/2}$$

where: s^2 = variance of the estimate; and

$(n-r)$ = number of leaking sources.

The equation shows the effect of the number of data points in the survey on the size of the confidence interval. During studies of fugitive emissions in On-Shore Gas Production units, a minimum of 76 data pairs were necessary to develop the screening value/leak rate correlation within the 95 percent confidence interval required of the final emission factor.[24]

The final confidence interval values for the emission factor are actually the product of the value for the (bias-corrected) leak rate estimate (shown above) and the value for the percent of sources leaking. The confidence intervals for percent of sources leaking are obtained by iterative solution of summation series equations. For example, the lower confidence limit, P_L, should be determined from:

$$\sum_{i=k}^{n} \binom{n}{i} P_L^{\,i} (1 - P_L)^{n-i} = \frac{\alpha}{2}$$

where: $(1-\alpha)$ represents the confidence level, n is the number of sources screened, and k is the number of leaking sources. As the number of sources screened increases, the confidence level increases and the confidence interval narrows. This is vividly illustrated in Figure 3-3 which shows 95 percent confidence intervals for a cumulative distribution function, assuming 100 and 1,000 components.

3.3.3 Leak/No-Leak Approach

The leak/no-leak approach to estimating emission factors, as presented in the AID, is an extension of the complicated process described above. The expanded process considers a leak rate/screening value correlation integrated over a continuous distribution function; the leak/no-leak approach instead assumes only two emission rates and two populations: sources that "leak" (with screening values greater than or equal to

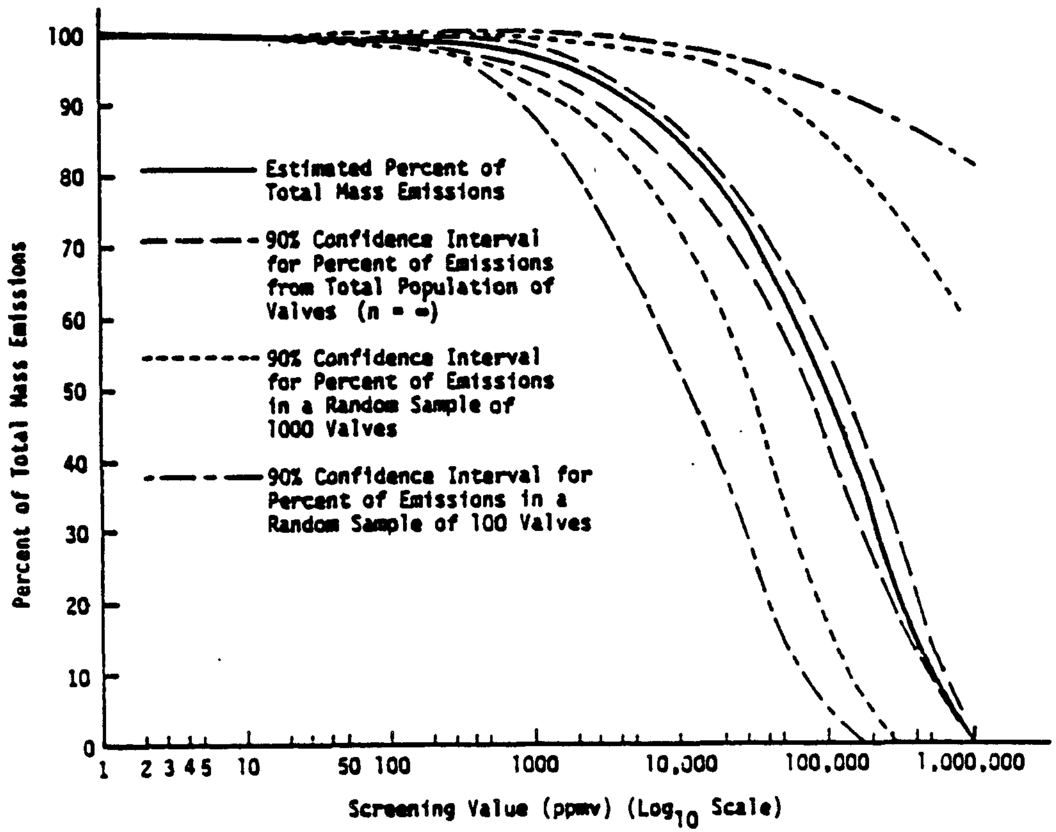


Figure 3-3. Cumulative Distribution of Total Emissions by Screening Values - Comparison of Confidence Intervals.

10,000 ppmv) and sources that do not leak (with screening values less than 10,000 ppmv).

The basis of this extension is as follows: when a group of sources "leak" (i.e., have a screening value ≥ 10,000 ppmv), they leak at a certain mass emission rate on the average. Similarly, as a group, sources screened at less than 10,000 ppmv (i.e., non-leaking sources) have on the average a certain mass emission rate associated with them. Thus, the overall average emission factor for a population of emission sources consists of two components: leaking source emissions and non-leaking source emissions.

It is important to remember that fugitive emissions are found distributed over a wide range of screening values. Mass emissions associated with fugitive emission sources are similarly distributed. Therefore, only emission factors generated using distribution data can be used in estimating emissions from equipment leaks. Finally, only those emission factors generated in such a manner can be used in the extended procedure discussed below.

3.3.3.1 Generation of Leaking and Nonleaking Emission Factors. Leaking and non-leaking emission factors are generated using three data: (1) the average emission factor, (2) the leak frequency associated with the average emission factor, and (3) the percent of mass emissions associated with leaking sources. As an example, consider the data for light liquid valves in the Refining Assessment Study:

Average Emission Factor	0.0109 kg/hr/source
Leak Frequency	11%
Percent of Mass Emissions, Leakers	86%

Assuming 1,000 valves, the total mass emissions would be 10.9 kg/hr; and 110 valves of the total 1,000 would account for 86 percent of the mass emissions, or 9.37 kg/hr. Since this amount of emissions would be shared, on the average, by all leaking valves, the individual leaking emission factor would be (9.37 kg/hr)/(110 valves) or 0.0852 kg/hr/source. The non-leaking emission factor is similarly computed. For this example, 890 valves that are "non-leaking" account for only 14 percent of the total emissions, or 1.53 kg/hr. This yields an average nonleaking emission factor of (1.53 kg/hr)/(890 valves) or 0.00171 kg/hr/source.

Put in more general terms, the emission factors for leaking sources (LEF) and the emission factors for nonleaking sources (NLEF) were computed according to the following equations:

$$LEF = \frac{OEF * PCM}{PCL} \quad \text{and} \quad NLEF = \frac{OEF * (100-PCM)}{(100 - PCL)}$$

where: LEF = emission factor for leaking sources
NLEF = emission factor for nonleaking sources
OEF = overall average emission factor
PCM = percent of mass emissions due to leaking sources
PCL = percent of sources found leaking

The leaking and nonleaking emission factors generated by this procedure and presented in the AID are shown in Table 3-3.

3.3.3.2 Computation of Average Emission Factors. Having computed leaking and nonleaking emission factors in the above manner, average emission factors can be determined by merely applying a leak frequency determined from field studies. Continuing with the example from above, the leak frequency for light liquid valves in SOCMI was found to be 6.5 percent on the average (based on the 24-Unit Study). For 1,000 valves in light liquid service, an estimated 65 would leak at a rate, on the average, of 0.0852 kg/hr/valve, or 5.5 kg/hr. The 935 valves predicted to be not leaking would account for an estimated 0.0017 kg/hr/valve, or 1.6 kg/hr. So all 1,000 valves in light liquid service would have a predicted composite leak rate of 7.1 kg/hr, for an average emission factor of 0.0071 kg/hr/source. This procedure, restated below in a more general form, can be applied to a population of sources to determine the average emission factor (AEF), provided the leak frequency of the population has been established.

$$AEF = \frac{LEF * PCL + NLEF * (100 - PCL)}{100}$$

TABLE 3-3. LEAKING AND NON-LEAKING EMISSION FACTORS FOR FUGITIVE EMISSIONS (kg/hr/source)[7]

Equipment	Service	Leaking (≥10,000 ppm) Emission Factor	Non-leaking (<10,000 ppm) Emission Factor
Valves	Gas	0.2626[a]	0.006[a]
	LL[b]	0.0852	0.00171
	HL[c]	0.00023[d]	0.00023
Pump Seals	LL	0.437	0.0120
	HL	0.3885	0.0135
Compressor Seals[e]	Gas	1.608	0.0894
Pressure Relief Valves	Gas	1.691	0.0447
Flanges	All	0.0375	0.00006
Open-Ended Lines	All	0.01195	0.00150

[a]The leaking and non-leaking emission factors for valves in gas/vapor service are based upon the emission factors determined for gas valves in ethylene, cumene, and vinyl acetate units during the SOCMI Maintenance Study. References 15 and 13.

[b]LL - light liquid service.

[c]HL - heavy liquid service.

[d]Leaking emission factor assumed equal to non-leaking emission factor since the computed leaking emission factor (0.00005 kg/hr/source) was less than non-leaking emission factor.

[e]Emission factor reflects existing control level of 60 percent found in the industry.

3.4 EMISSION FACTORS PRESENTED IN THE AID

Table 3-4 presents the results of this estimation process for the leak frequencies determined in the SOCMI 24-Unit Study. As the AID discussed, these leak frequencies were considered to be representative values for a cross-section of the large, diverse industry that is SOCMI. The average emission factors computed based on these leak frequencies were used to estimate emissions for the entire industry. As applied to the entire population of sources in the industry, these "typical" average emission factors were deemed appropriate for standards-setting activities. This was particularly true because they were applied consistently to different regulatory alternatives to arrive at comparisons.

EPA considered the variability of leak frequency in the industry in developing its fugitive emission standards. The extension of the procedure for generating emission factors considers the "typical" average emission factor to be a function of leak frequency considered typical of the industry. Also, in evaluating valve standards for low leak frequency plants, the technical analysis included emission factors that varied with leak frequency for valves. Results of this analysis provided support for the provision in the SOCMI standards allowing annual monitoring for process units with 2 percent or less valves leaking.

The average emission factors given in Table 3-4 were derived in a straightforward manner using the leaking and non-leaking emission factors from the Refining Assessment Study (derived in the manner just discussed) and the leak frequencies from the SOCMI 24-Unit Study. There are two instances where this approach was not used, however. These two cases deserve specific mention.

First, the emission factor for sampling connections is based on the amount of sample purge and not on a field-measured emission factor like other source types. In essence, a sampling connection is considered either "uncontrolled" (that is, the sample purge was assumed drained to the environment) or "controlled" with the sample purge collected and returned to the process line or disposed of properly. The actual value used for the emission factor is based on the quantity of sampling purge reported for

TABLE 3-4. AVERAGE EMISSION FACTORS FOR FUGITIVE EMISSIONS IN SOCMI[7]

Equipment Component	"Average" SOCMI Factors kg/hr/source
Pump Seals	
Light Liquid	0.0494
Heavy Liquid	0.0214
Valves	
Gas	0.0056
Light Liquid	0.0071
Heavy Liquid	0.00023
Compressor Seals	0.228
Safety Relief Valves - Gas	0.104
Flanges	0.00083
Open-Ended Lines	0.0017
Sampling Connections	0.0150

1,000 barrels of refining throughput[25] and the <u>average</u> count of sampling connections reported for every 1,000 barrels of refining throughput capacity.[26] The ratio of these two values yields an emission factor of 0.0150 kg/hr/source. It is important to emphasize that emissions from sampling connections do not include emissions through the seal or stem of the sampling valve. These emissions are considered part of the emissions from the valve and open-ended line categories.

The second case worthy of specific mention is the emission factor for valves in gas service. After computing average emission factors using the Refining Assessment leaking and non-leaking emission factors, a comparison was made with the values determined for the three equipment types in ethylene, cumene, and vinyl acetate process units presented in the SOCMI Maintenance Study. From this comparison, the emission factor for gas valves calculated from the Refining Assessment data appeared different from the SOCMI values. The four emission factors for gas valves determined for petroleum refining, ethylene units, cumene units, and vinyl acetate units were then compared visually as in Figure 3-4. The confidence intervals for the SOCMI gas valve emission factors are much narrower than those for the refining emission factor. Furthermore, there is almost no overlap between the SOCMI confidence intervals and those for petroleum refining. This comparative analysis indicates that (1) the SOCMI gas valve factors are different from the factor for petroleum refining and (2) the SOCMI gas valve factors are better estimators of SOCMI gas valve emissions.

As a result of this comparative analysis, new leaking and non-leaking emission factors for SOCMI gas valves were computed, based on data from the SOCMI Maintenance Program. The final values used in forming the average emission factor for SOCMI gas valves were:

- 0.0451 kg/hr/leaking source and
- 0.00048 kg/hr/nonleaking source.

The factors for valves and pumps in light liquid service, shown in Figure 3-5, were not found to be different. Therefore, the emission factors developed during the Refining Assessment Study (being based upon a more substantial data base) were used as the basis for leaking and non-leaking source emission factors.

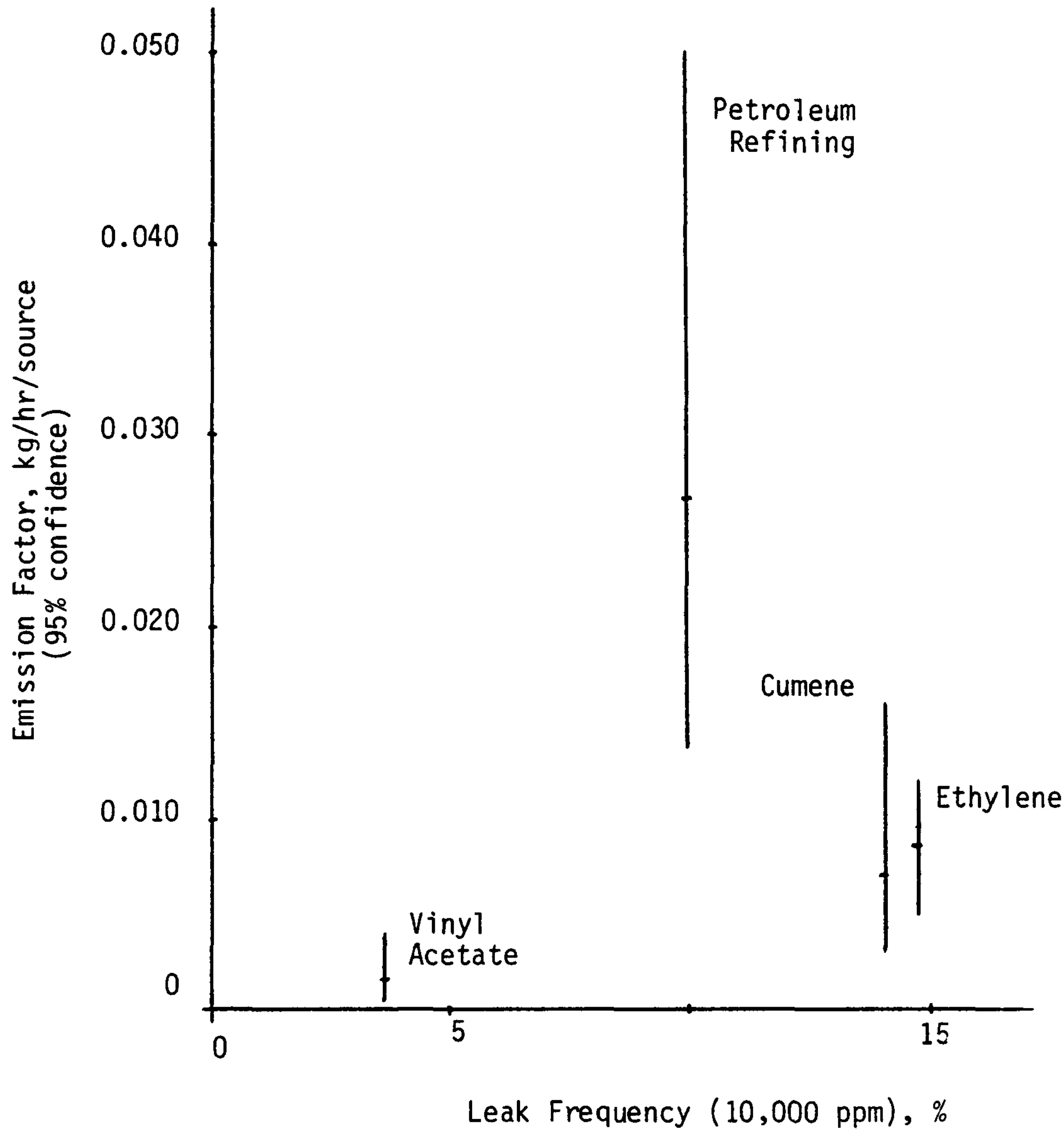


Figure 3-4. Comparison of Emission Factors: Gas Valves.[7]

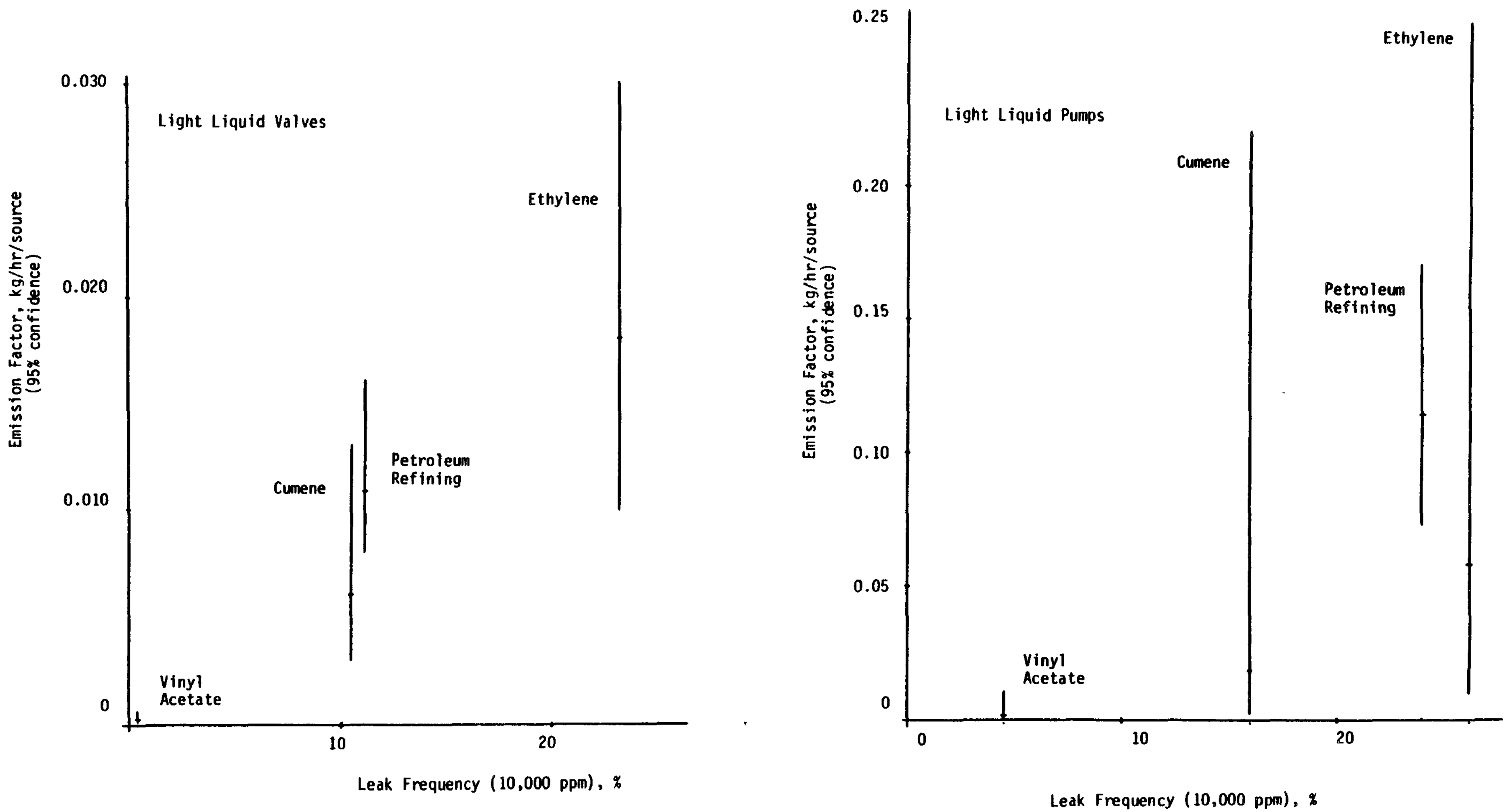


Figure 3-5. Comparison of Emission Factors: Light Liquid Valves and Pumps.[7]

These "typical" average emission factors presented in Table 3-4 would also be appropriate for use in estimating emissions for process units where no additional data are available. Taken on an individual basis, the factors themselves represent a hypothetical "average", not necessarily any specific unit or process. Given data on a specific process unit, average emission factors could be generated using the procedure illustrated above for the average SOCMI factors. For example, assume a process unit has been surveyed for leaks (sources with screening values $\geq$ 10,000 ppmv) and 4 percent of light liquid valves were determined to be leaking. Then an average emission factor for that unit could be computed as follows:

$$\begin{aligned} AEF &= 0.0852 * (0.04) + 0.0017 * (1 - 004) \\ &= 0.0051 \text{ kg/hr/source} \end{aligned}$$

The concept of an emission factor that varies with leak frequency is also consistent with the data gathered during the SOCMI studies. Close examination of Figure 3-14 shows some relationship of leak frequency and average emission factor for gas valves in the three process units studied in the Maintenance Study. Furthermore, there is wide variation in process unit types across SOCMI, as evidenced in Table 3-5 by the variation in leak frequencies for the process units in the 24-Unit Study. The causes of such variation are many, but include chemicals processed, process parameters such as operating temperatures and pressures, and the safety and maintenance practices at a given site.

3.5 EXAMPLE HYPOTHETICAL CASE

In this section, an example of estimating emissions for a hypothetical chemical process unit will be considered. This case assumes that the process unit has been surveyed in accordance with Reference Method 21 and that the leak frequencies have been established.

Table 3-6 shows this hypothetical process unit and a procedure for estimating emissions using data in this report. The first column presents

TABLE 3-5. LEAK FREQUENCIES BY PROCESS FOR EQUIPMENT IN 24 SOCMI UNITS[12]

	Percent of Sources Leaking				
Process	Valves, Gas	Valves, Light Liquid	Pumps, Light Liquid	Flanges	Open-Ended Lines
Vinyl Acetate	3.7	0.4	4.5	1.0	3.7
Ethylene	14.8	23.2	26.3	5.7	12.8
Cumene	14.1	10.5	16.0	2.9	9.1
Acetone/Phenol	0	0.3	2.3	0	1.3
Ethylene Dichloride	1.0	1.1	5.2	1.1	2.8
Vinyl Chloride	7.3	1.0	10.8	3.2	5.1
Formaldehyde	2.4	0	0	10.0	0
Methyl Ethyl Ketone	9.2	5.1	3.2	0	9.9
Acetaldehyde	4.5	0.5	9.4	0	5.7
Methyl Methacrylate	0	0.1	4.4	0	0.3
Adipic Acid	0	0	-	0	0
Chlorinated Ethanes	0	0.6	8.3	0	1.4
Acrylonitrile	2.3	0.9	8.2	0.4	2.7
1,1,1-Trichloroethane	-	1.1	10.0	0	1.8

TABLE 3-6. ESTIMATE OF "UNCONTROLLED" FUGITIVE EMISSIONS FOR A HYPOTHETICAL CASE

Source	Number Screened	Number Leaking	Percent Leaking	Computed Emission Factor[a] kg/hr/source	Annual[b] Emissions Mg/yr
Pump Seals					
Light Liquid	47	3	6.4	0.0256	10.5
Heavy Liquid	3	1	33.3	0.1385	3.6
Valves					
Gas/Vapor	625	19	3.0[c]	0.0018	9.9
Light Liquid	1180	13	1.1[c]	0.0026	26.9
Heavy Liquid	64	0	0	0.00023	0.1
Pressure Relief Valves					
Gas/Vapor	31	1	3.2	0.0978	28.2
Open-Ended Lines	278	9	3.2	0.0018	4.1
Compressor Seals	4	0	0	0.0894	3.1
Sampling Connections	70	-	-	0.0150	9.2
Flanges	2880	20	0.7	0.00032	8.1

[a]Based on values from Table 3-3, using AEF = (LEF * PCL + NLEF * (100-PCL))/100.

[b]Assumes 8,760 hours of operation annually.

[c]Composite percent leaking for valves is 1.8%. NOTE - In this case, valves would only need monitoring annually to ensure less than 2 percent leaking.

the number of sources identified in the process unit for each source type. The second column shows the number of sources with screening values greater than or equal to 10,000 ppmv (i.e., leaking sources). The resulting percentage of sources leaking is shown in the third column. The average emission factors for this hypothetical process unit can then be computed using the leaking and non-leaking emission factors found in Table 3-3. For example, 6.4 percent of pump seals in light liquid service were found to be leaking. Using the leak/no-leak approach, the unit-specific emission factor is estimated as:

$$(0.437 \text{ kg/hr/source})(0.064) + (0.012 \text{ kg/hr/source})(1 - 0.064),$$

or 0.0256 kg/hr/source. The total estimated emissions for pumps in light liquid service would then be computed by multiplying the unit-specific emission factor by the equipment count. The last column in Table 3-6 shows the results of this process for the hypothetical unit.

A further extension of this procedure would be to examine the procedure to estimate the emission factor for a certain specie in the line. For example, consider this same hypothetical case, where the light liquid pumped contained 20 percent of compound A. The compound A emission factor for light liquid pumps is easily computed by applying the weight percent (20 percent in this case) to the emission factor generated above:

$$(0.20)(0.0256 \text{ kg/hr/source}) = 0.0051 \text{ kg/hr/source}.$$

Emission factors calculated in this manner could then be applied to the equipment counts (where the material in the process line contained 20 percent of compound A) to estimate emissions of compound A.

4.0 EMISSION REDUCTION

No single emission reduction technique can be used for all fugitive emission sources. The techniques applicable to fugitive emission sources range from equipment to work practices. The various control techniques considered were described briefly in the earlier section on fugitive emission sources. They are covered in this section in the context of their emissions reduction potential.

4.1 OVERVIEW OF TECHNIQUES

The techniques used to control emissions from equipment leaks can be classified into two categories: equipment and work practices. An equipment control technique means that some piece of equipment is used to reduce or eliminate emissions. A common example is an add-on control device such as an incinerator that is used to reduce organic emissions from a process vent. For fugitive emission sources, equipment controls include: (1) leakless technology for valves and pumps; (2) plugs, caps, blinds, etc. for open-ended lines; (3) rupture disks and soft-seats (O-rings) for PRVs; (4) dual mechanical seals with non-VOC barrier fluid/degassing vent systems for rotary equipment; (5) closed loop sampling systems; and (6) enclosure of seal area/vent to a combustion control device for dynamic seals. These equipment control techniques can generally attain up to 100 percent reduction of emissions, depending upon the control efficiency of the control device. Mechanical seals and those techniques that rely upon a combustion control technique have been assigned an overall control efficiency of 95 percent, which is consistent with the efficiency assigned to some typically applied recovery techniques.

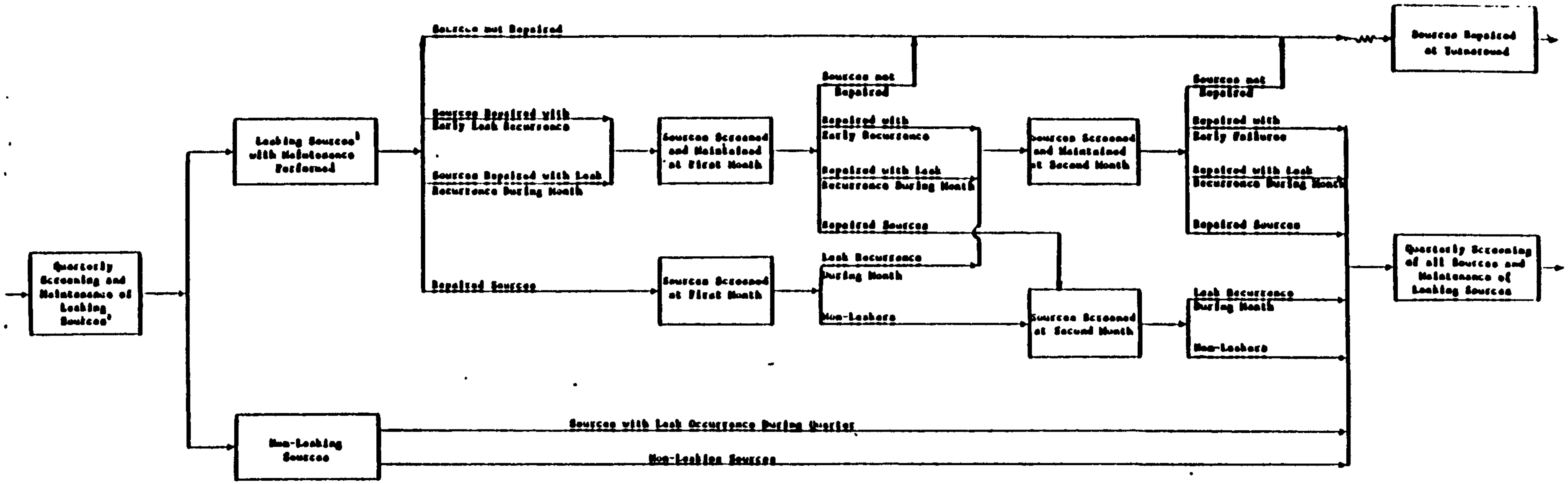
The control techniques used for the largest number of fugitive emission sources are work practices. The primary work practice applied to PRVs, valves, pumps, and other sources is leak detection and repair of sources.

4.2 LEAK DETECTION AND REPAIR (LDAR)

The emissions reduction potential for LDAR as a control technique is highly variable depending upon several factors. The principal element impacting emissions reduction is the frequency of monitoring (surveying) sources for leak detection. For example, a monthly monitoring plan would typically be more effective in reducing emissions than a quarterly monitoring plan since leaks would be found and corrected more quickly. Some characteristics of individual sources also affect emissions reduction: leaking emission factor (as compared to the nonleaking emission factor), leak occurrence rate, leak recurrence rate, and repair effectiveness. Gathering of these data for valves and pumps through extensive field testing was the focus of the SOCMI Maintenance Study.

Using specific source characteristics, an evaluation of control effectiveness can be made for different monitoring plans using the LDAR Model.[27] The model is a set of recursive equations that operates on an overall population of sources that can be segregated into the following subgroups for any given monitoring interval: (1) sources that leak due to the leak occurrence rate; (2) sources that leak and cannot be repaired below the 10,000 ppmv leak definition; (3) sources that leaked, were repaired successfully, but leaked again soon after the repair (i.e., leak recurrence); and (4) sources that do not leak (i.e., those screening below the 10,000 ppmv leak definition). The relative numbers of sources in each subgroup change with each monitoring interval step, based on the characteristics for the sources. Figure 4-1 shows these subgroups and how they may interact according to the individual source characteristics.

The LDAR Model also has the capability to examine complex monitoring plans such as the plan permitted by EPA under its fugitive emissions standard for valves in SOCMI. This plan allows quarterly monitoring of all valves, supplemented with monthly monitoring of those valves that leaked and were repaired.



[1]Leaking sources include all sources which had leak recurrence, had experienced early failures, or had leak occurrence and remained leakers at the end of the preceding quarter.

[2]Except sources for which attempted maintenance was not successful.

Figure 4-1. Schematic Diagram of the LDAR Model.

Perhaps the best way to illustrate the LDAR Model is to present an example. The particular example considered here is the "typical" SOCMI unit presented in the AID. Table 4-1 shows the inputs used in examining a LDAR program for valves and pumps based on monthly monitoring. The input values were derived primarily from the SOCMI Maintenance Study. The selection of each input value is detailed in the AID. The LDAR Model used to estimate emissions reductions gives incremental results as well as results for a program that has been established. For the example, once a monthly monitoring plan is in place, emissions reductions of 73 percent and 59 percent can be expected for valves in gas and light liquid services; likewise a 61 percent reduction in emissions can be achieved for pumps in light liquid service under a monthly LDAR plan.

Table 4-2 presents the results of LDAR modeling published in the AID for valves and pumps in SOCMI. The table presents results for simple monthly, quarterly, semiannual, and annual monitoring of valves and pumps. Additionally, the monthly/quarterly hybrid program allowed by EPA for valves is shown. These results show that, as monitoring frequency is increased, the anticipated emissions reduction increases. Further, the results indicate some instances where there is no positive effect in reducing emissions due to monitoring and repair on too infrequent a schedule. Such results, however, are subject to interpretation for specific cases since they are based on "average" input values for an entire industry.

The ability to model the results of LDAR programs provided the means to examine alternative standards for valves. The LDAR Model was used to consider monthly LDAR programs for process units exhibiting low leak frequencies. With decreasing leak frequency, there is an associated decline in the average emission factor and emissions reduction. Coupling this information with the costs of the LDAR program, an analysis of the resultant cost effectiveness values led to the selection of 2 percent leaking as the performance limit. Thus, process units with low leak rates (and low leak frequencies) were given a special provision in the NSPS for SOCMI fugitive VOC emissions.

TABLE 4-1. LDAR INPUTS AND COMPUTED REDUCTIONS FOR SOCMI/MONTHLY MONITORING

Input	Description	Valves, Gas/Vapor	Valves, Light Liquid	Pumps, Light Liquid
Emission factor, kg/hr/source	Initial average emission factor for all sources	0.0056	0.0071	0.0494
Occurrence rate	Fraction of nonleakers that became leakers over the interval	0.013	0.013	0.034
Initial leak frequency	Fraction of sources leaking at initiation of LDAR program	0.114	0.065	0.088
Fractional emission reduction from unsuccessful repair	Reduction from sources not repaired below 10,000 ppmv	0.63	0.63	0
Fractional emission reduction from successful repair	Reduction from sources repaired below 10,000 ppmv	0.98	0.98	0.972
Fraction of unsuccessful repairs	Sources that leaked but attempted repair below 10,000 ppmv failed	0.10	0.10	0
Fraction of early failures	Sources repaired below 10,000 ppmv but leaked within the next interval	0.14	0.14	0
Turnaround frequency, months	Period between plant shutdowns	24	24	24
EMISSION REDUCTION COMPUTED:		0.73	0.59	0.608

TABLE 4-2. LDAR MODEL RESULTS FOR SOCMI VALVES AND PUMPS

Monitoring Interval	Source Type Valves, Gas	 Valves, Light Liquid	 Pumps, Light Liquid
Monthly	0.73	0.59	0.61
Monthly/Quarterly[a]	0.65	0.46	-
Quarterly	0.64	0.44	0.33
Semi-annual	0.50	0.22	(0.076)
Annual	0.24	(0.19)	(0.80)

[a]Monthly monitoring with quarterly monitoring of "low leak" components.

NOTE: Numbers in parentheses indicate a negative control efficiency. Negative numbers are generated when the occurrence rate for the monitoring interval exceeds the initial leak frequency. Negative results are subject to interpretation and may not be meaningful.

4.3 SUMMARY OF EMISSION REDUCTIONS

Emissions reductions for fugitive emissions control techniques can be extremely variable, particularly for work practices like leak detection and repair programs. In terms of standard-setting activities, criteria for selection of a given control technique or a particular level of control (eg., monitoring interval of a leak detection and repair program) can be quite different. For example, the criterion used in establishing the best demonstrated technology (BDT) for NSPS may not necessarily be equivalent to the choice in setting the reasonably available control technology (RACT) presented in control techniques guidelines (CTG) documents used by States. These two levels of control are compared in Table 4-3 for VOC equipment leaks (fugitive emissions) from SOCMI; the associated control effectiveness values are also presented.

TABLE 4-3. CONTROL LEVELS FOR SOCMI FUGITIVE EMISSIONS: NSPS AND CTG

	CTG		NSPS	
Source	Control Technique	Percent Control	Control Technique	Percent Control
Pumps, Light Liquid	Quarterly leak detection and repair	33	Monthly leak detection and repair	61
			Dual mechanical seal/heavy liquid barrier fluid	100
Valves, Gas	Quarterly leak detection and repair	64	Monthly leak detection and repair	73
Light Liquid		44		59
Pressure Relief Valves, Gas	Quarterly leak detection and repair	44	Rupture disk, soft seats (O-rings), vent to control device	100
Open-Ended Lines	Plugs, caps, blinds, etc.	100	Plugs, caps, blinds, etc.	100
Compressors	Quarterly leak detection and repair	33	Seal enclosed/vented to control device	100
Sampling Connections	--	-	Closed purge sampling	100

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1. REPORT NO. EPA-450/3-86-002	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Emission Factors for Equipment Leaks of VOC and HAP		5. REPORT DATE February 10, 1986
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) John H. E. Stelling III		8. PERFORMING ORGANIZATION REPORT NO. DCN 86-203-024-63-06
9. PERFORMING ORGANIZATION NAME AND ADDRESS Radian Corporation 3200 E. Chapel Hill Road/Nelson Highway Research Triangle Park, N.C. 27709		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-3889, WA 63
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Emission Standards and Engineering Division Research Triangle Park, N.C. 27711		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES Project Officer is Robert E. Rosensteel, Mail Drop 13, (919) 541-5605.		

16. ABSTRACT

The report summarizes the development of emission factors for volatile organic compound (VOC) equipment leaks. The background information used in emission factor development is reviewed. The estimation techniques for generation of VOC emission factors are described and illustrated with an example. The application of the estimation techniques is demonstrated for both VOC and hazardous air pollutants (HAPs).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
	Fugitive Emissions Volatile Organic Compounds Hazardous Air Pollutants	
18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 70
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

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