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ANALYSIS OF SOCMI

VOC FUGITIVE

EMISSIONS DATA

Prepared for

Office of Air Quality Planning and Standards

Prepared by

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Research Triangle Park NC 27711

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ANALYSIS OF SOCMI VOC FUGITIVE EMISSIONS DATA

Final Report

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SECTION 1

INTRODUCTION

The contribution of fugitive leaks from process unit components are being investigated as a potential source of Volatile Organic Compound (VOC) emissions in the Synthetic Organic Chemical Manufacturing Industry (SOCMI). The purpose of this study is to provide an in-depth analysis of data on these emissions collected under EPA contracts 68-02-3171-1, 68-02-3173-2 and 11, 68-02-3174-5, and 68-02-3176-1 and 6 and 68-03-2776-4. These data were collected by Radian, PEDCO, TRW and Acurex and are summarized in References 1 and 2. The results of this study will be available for use in evaluating VOC fugitive emissions.

The study design and test procedures for the data analyzed in this report are described in References 1 and 2. The 24 process units studied in the data collection programs were selected to represent a cross-section of the population of the SOCMI. Several factors were considered during process unit selection. These factors included total annual production volume, number of producers, process conditions, corrosivity, volatility, toxicity, and value of the final chemical product. Factors varied widely from unit type to unit type, so that the selected process unit types represented a reasonable sample of the variety of chemical process units encountered in SOCMI.

Evaluating the leak frequency in SOCMI was done by the collection of screening data from 24 process units, where a screening value is the maximum repeatable concentration of total hydrocarbons detected at a source with a portable hydrocarbon detector (Reference 1). Evaluation of maintenance was done by measurement of fugitive emission leak rates (lb./hour) at selected sources before and after maintenance at six process units representing three chemical processes (Reference 2). The results of these two programs provide the background information necessary for the current study:

- source population data
- screening value profiles for each source type
- screening-to-emission rate relationships

The screening procedures began with the definition of the process unit boundaries. All feed streams, reaction/separation facilities, and product and by-product delivery lines were identified on process flow diagrams and in the process unit. Process data, including stream compositions, line temperatures, and line pressures, were obtained for all flow streams.

The Century Systems Models OVA-108 and OVA-128 hydrocarbon detectors were used for screening. The detector probe of the instrument was placed directly on those areas of the sources where leakage would typically occur. For example, gate valves were screened along the circumference of the annular area around the valve stem where the stem exits the packing gland and at the packing gland/valve bonnet interface. The actual leak rate measurements were taken using a flow-through method described in Reference 8 and were analyzed on Byron Total Hydrocarbon Analyzer.

All accessible sources of the following source types were screened:

- process valves,
- pump seals,
- compressor seals,
- agitator seals,
- relief valves,
- process drains, and
- open-ended lines.

Also, a randomly selected subset of flanges was screened. Originally, only five percent of all flanges were screened. The subset was increased to 20 percent of all flanges when initial results indicated a higher frequency of emitting flanges than had been encountered in previous programs. The important variables available from this study are: screening value, source category, stream service, source type, chemical produced, ambient temperature elevation, line temperature and line pressure. For the purposes of this report, a source is defined as "leaking" if its screening value is greater than or equal to 10,000 ppmv.

This report is actually a presentation of four distinct data analysis tasks. Section 2 is a short summary of the results of all four tasks. In Section 3 a detailed analysis of the SOCMI screening data (from 24 process units) is presented along with summaries of important correlating process parameters (line pressure, etc.). Emission factor development for three specific chemical processes (7 units) is presented in Section 4. The analysis reported in Section 5, an extension of the results in Reference 2, is directed at investigating the increase in mass emissions due to occurrence and recurrence of leaks. In Section 6 the impact on leak frequency from adjusting screening values by chemical response models is investigated. The statistical methods used in Sections 3 through 6 are presented in Section 7. Appendix A is a statistical summary of all the screening data from the 24 untis. Appendix B contains summary statistics and information on the effect of line pressure and line temperature on the percent leaking. Appendix C contains similar descriptions for ambient temperature and elevation. Appendix D is a summary of all corrections made to the original data.

SECTION 2

SUMMARIES AND CONCLUSIONS

This section presents the major findings from the analyses discussed in Sections 3 through 6.

RELATIONSHIP OF LEAK FREQUENCY TO PROCESS PARAMETERS (SECTION 3)

The process parameters that were examined for their effect on leak frequency were: process, service, material in the line, line pressure, line temperature, ambient temperature and source elevation. Data on four source types (valves, pump seals, flanges and open ended lines) were used to examine the effects of these parameters. The sources were grouped into 32 categories (see Figure 3-2) based on source type, process type, stream service and primary chemical in the line. These groupings were for statistical reasons and were not based on engineering reasoning.

Stream service was defined as either gas, light liquid or heavy liquid (Reference 1). Heavy liquids were not included in any analyses, since they leaked so rarely regardless of the other conditions. Gas stream service generally had a higher leak frequency than light liquid service. Proceeding with four source types and two stream service types the data was then categorized by process unit as either ethylene processes, high leaking processes or low leaking processes. The ethylene units were analyzed separately because of the large number of sources in ethylene processes and the high leak frequency. The high leaking group consists of all other units with greater than 1% of all source types leaking. The low leaking group consisted of all units with less than 1% of all source types leaking. Since there were very few sources leaking, the low leaking process units were not considered in further analyses. Within these process unit groups, the data was further subdivided by primary materials in the line. Caution should be used in these evaluations, however, since other chemicals in the line may also have an effect on leak frequency.

Examination of the data within these categories resulted in the following conclusions for this data set:

- Leak frequency was affected not only by the type of chemical process but also by the type of primary material in the line.
- Control valves had a higher leak frequency than block valves.
- For block valves, gate valves had a higher leak frequency than most of the other types, and plug and ball valves have lower leak frequencies.
- On-line pump seals had an overall leak frequency of 13.1 percent versus 4.9 percent for off-line pump seals.
- These data did not show a difference in leak frequency between double mechanical pump seals and single mechanical pump seals, although the type of barrier fluid was unknown and therefore unaccounted for in this analysis.
- Line pressure was seen to have a statistically significant effect in almost every case, with higher levels of pressure associated with higher leak frequencies.
- Line temperature had no consistent effect on leak frequency. The combined effect of line pressure and temperature was important in some cases.

- Ambient temperature had a consistent effect on leak frequency, however, the effect was not statistically significant for a majority of the cases. Higher leak frequencies tended to be associated with the higher ambient temperature category.

- Elevation had no consistent effect on leak frequencies. In the four cases where a statistically significant effect was observed, sources at ground level had a higher leak frequency than sources at higher elevations.

EMISSION FACTOR DEVELOPMENT (SECTION 4)

The sources included in the development of the emissions factors are all valves and pump seals screened in the seven ethylene, cumene, and vinyl acetate process units or 51.2% (16,575) of all valves and pump seals screened in the screening program. Since leak rate screening value models were only developed for these three process types, emission factor estimation was limited to these three processes.

The emission factors developed in this study are reported in Table 2-1. The emission factors for ethylene process are consistently higher than the factors for the cumene and vinyl acetate processes. The vinyl acetate process tends to have the lowest emission factors of the three process types.

Cumulative distributions of screening values and mass emissions as a function of screening values were also developed for each of the three processes. Table 2-2 gives the estimates and confidence intervals from these curves for a 10,000 ppmv screening value.

INCREASE IN MASS EMISSIONS DUE TO OCCURRENCE AND RECURRENCE (SECTION 5)

Further analysis of data collected during the EPA SOCMI maintenance

TABLE 2-1. ESTIMATED EMISSION FACTORS FOR NONMETHANE HYDROCARBONS FROM VALVES AND PUMP SEALS (lbs./hr./source and kgs./hr./source)

Source Type	Emission Factor (95% Confidence Interval) (lbs./hr.)	(kgs./hr.)
Valves		
- Gas Service		
Ethylene processes	0.024(0.008, 0.07)	0.011(0.004, 0.03)
Cumene processes	0.011(0.003, 0.05)	0.0052(0.001, 0.02)
Vinyl Acetate processes	0.0046(0.001, 0.03)	0.0021(0.0004, 0.01)
- Light Liquid		
Ethylene processes	0.020(0.007, 0.06)	0.010(0.003, 0.03)
Cumene processes	0.0056(0.002, 0.02)	0.0025(0.001, 0.01)
Vinyl Acetate processes	0.0003(0.0001, 0.002)	0.0001(0.00003, 0.001)
Pump Seals		
- Light Liquid		
Ethylene processes	0.069(0.006, 0.8)	0.031(0.003, 0.4)
Cumene processes	0.052(0.001, 2.7)	0.023(0.0004, 1.2)
Vinyl Acetate processes	0.0043(0.0001, 0.1)	0.0020(0.00006, 0.06)

TABLE 2-2. SUMMARY OF PERCENT OF SOURCES DISTRIBUTION CURVES AND PERCENT OF MASS EMISSIONS CURVES AT SCREENING VALUE OF 10,000 PPMV

	Percent of Sources Screening ⩾ 10,000 ppmv		Percent of Mass Emissions Attributable to Sources Screening ⩾ 10,000 ppmv	
Source Type	Estimate	95% Confidence Interval	Estimate	95% Confidence Interval
Valves				
Gas				
Ethylene	15	(14, 16)	94	(93, 95)
Cumene	16	(13, 19)	94	(90, 96)
Vinyl Acetate	3.7	(2, 5)	90	(85, 94)
Light Liquid				
Ethylene	26	(24, 27)	89	(87, 90)
Cumene	12	(10, 13)	80	(72, 86)
Vinyl Acetate	0.2	(0, 0.4)	25	(9, 47)
Pump Seals				
Light Liquid				
Ethylene	30	(20, 39)	96	(90, 98)
Cumene	14	(1, 27)	89	(50, 98)
Vinyl Acetate	1.7	(0, 4)	67	(5, 92)

program (Reference 2) was done to estimate the effects of leak occurrence and recurrence on mass emissions. The following conclusions are based on these analyses:

- The increase in emissions for valves for which a leak occurred over a one to six month period was estimated to be 530% (95% confidence interval of 200% to 900%).

- Not enough data was available to accurately quantify the effect on emissions from leak occurrence from pump seals. However, the percent increase estimate was 75% with a 95% confidence interval of -100% to 6000%.

- The percent increase in emissions for valves with a leak recurrence within the six month period was estimated to be 510% (95% confidence interval of -100% to 1700%).

- Further analysis of the effect of valve maintenance on emissions showed a 98% reduction in emissions for valves which were "repaired" (screening valve <10,000 ppmv after maintenance) and a 63% reduction for sources which were "not repaired" (screening valve remained ⩾10,000 ppmv after simple, on-line maintenance).

IMPACT OF RESPONSE ADJUSTMENTS ON LEAK FREQUENCY ESTIMATION (SECTION 6)

Three different techniques were used to adjust the original screening value for each source:

- the original OVA reading adjusted for the associated OVA response relationship of the primary chemical compound in the line,

- weighted logarithmic average of response of primary and secondary chemicals, and

- weighted arithmetic average of response of primary and secondary chemicals.

The percent of leaking valves was calculated for each of the three estimates for both gas and light liquid services. The three estimates were found to be similar in most cases to the leak frequency based on the original screening valves. Table 2-3 presents the overall results.

TABLE 2-3. COMPARABLE ESTIMATES FOR PERCENT LEAKING (VALVES)
(24 SOCMI Process Units)

Process Stream	Number Screened[1]	Percent Leaking Based on OVA Readings	Percent Leaking Based on Method 1 Adjustments[2]	Percent Leaking Based on Method 2 Adjustments[3]	Percent Leaking Based on Method 3 Adjustments[4]
Gas	9374	11.3	10.1	10.2	10.3
Light Liquid	18,133	6.1	5.3	5.6	5.5

[1]119 sources with screening valves = 10,001 ppmv were excluded.

[2]Method 1 is the adjustment to the OVA Reading based on the response of the primary chemical in the line.

[3]Method 2 is the mixed chemical weighted logarithmic average technique.

[4]Method 3 is the mixed chemical weighted average technique.

SECTION 3

DETAILED RESULTS FOR THE EFFECTS OF PROCESS PARAMETERS ON LEAK FREQUENCY

The effects of various process parameters on leak frequency are evaluated in this section. The process variables analyzed are source category, stream service, source type, chemical produced, ambient temperature, elevation, line temperature and line pressure. Each of these variables was examined to determine which of them is associated with high or low leak frequencies. Leak frequency data from four source types are analyzed in detail in this section. They are open-ended lines, valves, pumps, and flanges. Simple summary statistics for all source types are presented in Appendix A. The data were grouped into exclusive categories for statistical reasons (not engineering) as outlined in the following paragraphs.

Data for this analysis come from an EPA study in which all sources in 24 chemical process units were screened (Reference 1). In a data collection study such as this, it is possible to have several of the process parameters confounded. This means it can be difficult to separate the effects of one parameter from that of another. For example, if one process source type does in fact have a high frequency of leaks, but is almost always associated with a certain type of stream service, it may appear that the high leak frequency is associated with the stream service. If the data are grouped by both source type and stream service, the effect of each of these two variables can be seen. To avoid this type of problem, the data have been analyzed in smaller groups whenever a possibility of confounding was suspected.

Another reason the data were grouped into subsets is that the analysis procedure used to statistically evaluate factors affecting the leak frequency is very sensitive to frequencies of zero. That is, if there were no sources leaking (or very few) in a particular category (e.g., heavy liquid) the analysis procedure is not appropriate. To avoid this problem, the data to be analyzed for statistical significance were first categorized to include only groupings that displayed at least a moderate percentage of leaking sources. Summary statistics for the groupings not statistically analyzed (heavy liquids and process units with less than 1 percent of the sources leaking) are presented separately in the appendices.

OVERVIEW OF SCREENING DATA FROM 24 CHEMICAL UNITS

Table 3-1 gives information on the number of sources screened, the number that were leaking and the percentage that were leaking in the 24 chemical units screened. This information is given for each source type and each stream service within each source category. (The stream service classifications are described in Reference 1.) It can be seen from this table that sources in the heavy liquid service category have a fairly low leak frequency. There are also fewer heavy liquid service sources than gas or light liquid in each source type. However, even in a group such as valves, where there were 3,632 valves in heavy liquid service, the leak rate is very low (0.4 percent, or 13 leaking sources). Table 3-1 shows that valves in gas service have both a large number and high percentage of leaking sources. It also appears that the percent leaking varies with both source type and stream service.

Valves as a source type had the largest number of screening values. Flanges and open-ended lines also had a large number (although only 5 to 20 percent of the flanges were screened). For further analysis, these three categories plus pump seals were investigated. It was felt that the sample sizes of the other categories were too small to allow meaningful subcategorization of the source type.

Since only 17 sources in heavy liquid stream service in the source types to be further analyzed were found to be leaking, sources in this service were not included in further anlaysis of factors affecting the leak frequency. However, summary statistics for this stream service are included in the later sections, where appropriate.

TABLE 3-1. PERCENT OF SOURCES LEAKING[1] BY SOURCE
(24 Process Units)

Source	Service	Number Screened	Sources with Screening Values ≥10,000: Number	Percent	95% Confidence Interval for Percent ≥10,000
Valves	Gas[3]	9669	1103	11.4	(10.8, 12.0)
	Light Liquid[3]	18299	1183	6.5	(6.1, 6.9)
	Heavy Liquid	3632	13	0.4	(0.2, 0.7)
Pump Seals	Light Liquid[3]	646	57	8.8	(6.4, 11.0)
	Heavy Liquid	97	2	2.1	(0.3, 7.3)
Flanges	Gas[3]	1450	66	4.6	(3.7, 5.7)
	Light Liquid[3]	2833	36	1.3	(0.9, 1.7)
	Heavy Liquid	607	0	0	(0, 0.6)
Open Ended Lines	Gas	923	54	5.9	(4.4,7.9)
	Light Liquid[3]	3605	141	3.9	(3.4, 4.7)
	Heavy Liquid	477	2	1.3	(0.5, 2.8)
Process Drains	Gas	83	2	2.4	(0.3, 8.4)
	Light Liquid[3]	496	19	3.8	(2.3, 5.9)
	Heavy Liquid	28	2	7.1	(0.9, 23.5)
Agitator Seals	Gas	7	1	14.3	(0.4, 57.9)
	Light Liquid	8	0	0	(0, 36.9)
	Heavy Liquid	1	0	0	(0, 100)
Relief Valves	Gas[3]	84	3	3.6	(0.7, 10.1)
	Light Liquid[3]	68	2	2.9	(0.4, 10.2)
	Heavy Liquid	3	0	0	(0, 70.8)
Compressors	Gas[3]	22	2	9.1	(1.1, 26.2)
Other[2]	Gas	19	3	15.8	(3.4, 39.6)
	Light Liquid[3]	34	2	5.9	(0.7, 19.7)
	Heavy Liquid	2	0	0	(0, 84.2)

[1]A leaking source is defined as one with a screening value ≥10,000 ppmv.

[2]Includes filters, vacuum breakers, expansion joints, rupture disks, sight glass seals, etc.

[3]The numbers in each column may be different from that found in Reference 1 because of corrections to the original data (See Appendix D).

EFFECT OF CHEMICAL PRODUCED ON LEAK FREQUENCIES

Table 3-2 describes the screening data in terms of chemical produced by the source types and service categories outlined earlier. Some differences between the chemical processes are apparent. The production of ethylene appears to be associated with a leak frequency that is higher than that found with the production of any of the other chemicals. Leak frequencies from the Cumene and MEK units are also high. Other processes had very low leak frequencies for all four of the source types. The formaldehyde unit screened only had two leaks and the two adipic acid units had no leaks from the four source types. Figure 3-1 graphically presents the estimated percent leaking along with 95 percent confidence intervals for valves in gas and light liquid service by process type.

It is clear from looking at Figure 3-1 and examining Table 3-2 that the breakdown by process type, in addition to source type and stream service, results in some subsets with few or no leaking sources. To avoid the problem of analyzing such small groups, a method of grouping the chemicals produced was devised. Three chemical process groups based on overall leak frequency were formed. The groups are Low Leaking Process, High Leaking Process, and Ethylene Process. Each category, and the processes and unit identification numbers that are associated with it, is given in Table 3-3. The Low Leaking group contains data on chemicals whose leak frequency was less than one percent for all source types and stream services. The overall leak frequencies for the High Leaking group range from one percent to six percent.

Table 3-4 summarizes the data available for further analysis for the subcategories formed by the source type, service category, and chemical process groups. In the analysis of the effect of other process parameters on leak frequency, only the High Leaking and Ethylene groups were used. The Low Leaking group had too few leaks to adequately determine any types of effects on leak frequency of the other variables.

TABLE 3-2. PERCENT LEAKING FOR EACH CHEMICAL PRODUCED AS A FUNCTION OF SOURCE TYPE AND STREAM SERVICE

Source/Chemical (units)[1]	GAS			LIGHT LIQUID			HEAVY LIQUID		
	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking
Valves									
Vinyl Acetate (1,3)	949	35	3.7	2137	8	0.4	124	0	0
Ethylene (2,4,11)	6294	934	14.8	4176	969	23.2	1237	13	1.1
Cumene (5,6)	448	63	14.1	799	84	10.5	198	0	0
Acetone/Phenol (12)	8	0	0	1818	6	0.3	488	0	0
Ethylene Dichloride (21,29)	403	4	1.0	2256	24	1.1	----	----	----
Vinyl Chloride Monomer (20,28)	412	30	7.3	1209	12	1.0	----	----	----
Formaldehyde (22)	41	1	2.4	121	0	0	----	----	----
Methyl Ethyl Ketone (31,32)	207	19	9.2	671	34	5.1	----	----	----
Acetaldehyde (33)	178	8	4.5	551	3	0.5	----	----	----
Methyl Methacrylate (34)	190	0	0	1058	1	0.1	----	----	----
Adipic Acid (35,64)	95	0	0	17	0	0	1478	0	0
Chlorinated Ethanes (60, 62)	48	0	0	1620	10	0.6	12	0	0
Acrylonitrile (65,66)	396	9	2.3	1494	28	0.9	95	0	0
1,1,1-Trichloroethane (61)	----	----	----	373	4	1.1	----	----	----
Pump Seals									
Vinyl Acetate (1,3)	----	----	----	89	4	4.5	5	0	0
Ethylene (2,4,11)	----	----	----	76	20	26.3	15	0	0
Cumene (5,6)	----	----	----	25	4	16.0	3	0	0
Acetone/Phenol (12)	----	----	----	86	2	2.3	36	0	0
Ethylene Dichloride (21,29)	----	----	----	58	3	5.2	----	----	----
Vinyl Chloride Monomer (20,28)	----	----	----	65	7	10.8	----	----	----
Formaldehyde (22)	----	----	----	8	0	0	----	----	----
Methyl Ethyl Ketone (31,32)	----	----	----	31	1	3.2	----	----	----
Acetaldehyde (33)	----	----	----	32	3	9.4	----	----	----
Methyl Methacrylate (34)	----	----	----	45	2	4.4	----	----	----
Adipic Acid (35,64)	----	----	----	----	----	----	30	0	0
Chlorinated Ethanes (60, 62)	----	----	----	60	5	8.3	----	----	----
Acrylonitrile (65,66)	----	----	----	61	5	8.2	8	2	25.0
1,1,1-Trichloroethane (61)	----	----	----	10	1	10.0	----	----	----

(Continued)

TABLE 3-2. (continued)

Source/Chemical (units)[1]	GAS Number Screened	GAS Number Leaking	GAS Percent Leaking	LIGHT LIQUID Number Screened	LIGHT LIQUID Number Leaking	LIGHT LIQUID Percent Leaking	HEAVY LIQUID Number Screened	HEAVY LIQUID Number Leaking	HEAVY LIQUID Percent Leaking
Flanges									
Vinyl Acetate (1,3)	107	3	2.8	173	0	0	8	0	0
Ethylene (2,4,11)	634	39	6.2	407	25	6.1	89	0	0
Cumene (5,6)	367	19	5.2	468	9	1.6	130	0	0
Acetone/Phenol (12)	----	----	----	82	0	0	30	0	0
Ethylene Dichloride (21,29)	25	1	4.0	163	1	0.6	----	----	----
Vinyl Chloride Monomer (20,28)	16	2	12.5	47	0	0	----	----	----
Formaldehyde (22)	2	0	0	8	1	12.5	----	----	----
Methyl Ethyl Ketone (31,32)	22	0	0	76	0	0	----	----	----
Acetaldehyde (33)	32	0	0	144	0	0	----	----	----
Methyl Methacrylate (34)	38	0	0	247	0	0	----	----	----
Adipic Acid (35,64)	49	0	0	2	0	0	320	0	0
Chlorinated Ethanes (60, 62)	16	0	0	461	0	0	2	0	0
Acrylonitrile (65,66)	142	2	1.4	382	0	0	28	0	0
1,1,1-Trichloroethane (61)	----	----	----	73	0	0	----	----	----
Open Ended Lines									
Vinyl Acetate (1,3)	145	8	5.5	318	8	2.5	22	2	9.1
Ethylene (2,4,11)	305	37	12.1	214	41	19.2	91	0	0
Cumene (5,6)	6	0	0	15	2	13.3	1	0	0
Acetone/Phenol (12)	2	0	0	518	8	1.5	107	0	0
Ethylene Dichloride (21,29)	100	0	0	475	16	3.4	----	----	----
Vinyl Chloride Monomer (20,28)	55	2	3.6	340	18	5.3	----	----	----
Formaldehyde (22)	14	0	0	36	0	0	----	----	----
Methyl Ethyl Ketone (31,32)	37	3	8.1	186	19	10.2	----	----	----
Acetaldehyde (33)	34	3	8.8	158	8	5.1	----	----	----
Methyl Methacrylate (34)	63	0	0	335	1	0.3	----	----	----
Adipic Acid (35,64)	19	0	0	1	0	0	214	0	0
Chlorinated Ethanes (60,62)	27	0	0	412	6	1.5	4	0	0
Acrylonitrile (65,66)	116	1	0.9	486	12	2.5	38	4	10.5
1,1,1-Trichloroethane (61)	----	----	----	111	2	1.8	----	----	----

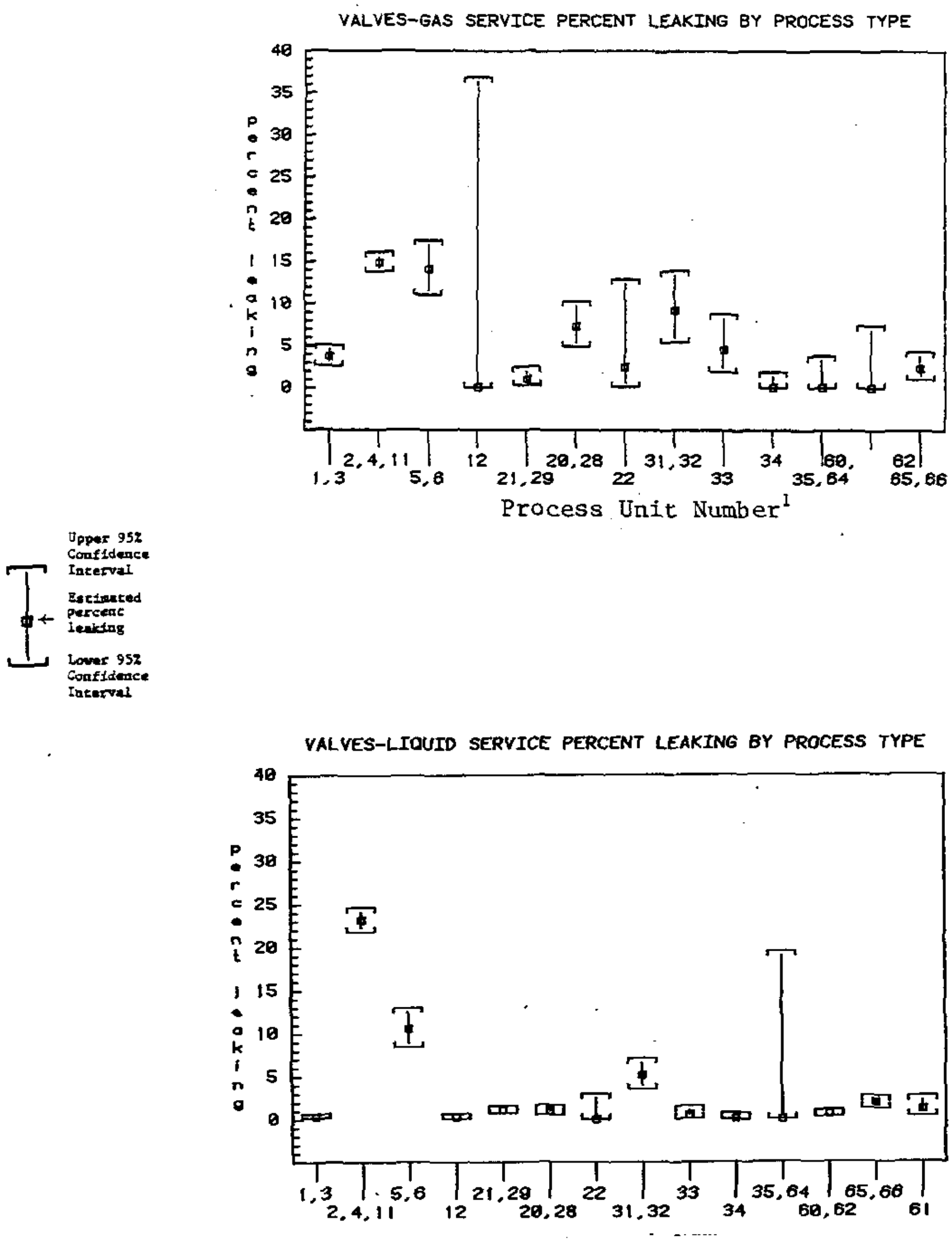


Figure 3-1. Effect of Process Type on Percent of Valves Leaking

[1] See Table 3-3 for definition of process type identification numbers

TABLE 3-3. DEFINITION OF CHEMICAL PROCESS GROUPS

Process Group	Chemical Process	Unit Numbers	Percent Leaking*
"Low Leaking" <1% of all source types leaking	Adipic Acid	35, 64	0.0
	Acetone	12	0.5
	Formaldehyde	22	0.8
	Methyl Methacrylate	34	0.3
	Trichloroethylene/ Perchloroethylene	60	0.8
	Vinyl/Ethylene Dichloride	62	0.0
"High Leaking" >1% of all source types leaking	Acetaldehyde	33	2.3
	Acrylonitrile	65, 66	1.7
	Vinyl Acetate	1, 3	1.4
	Vinyl Chloride Monomer	20, 28	2.8
	Ethylene Dichloride	21, 29	1.2
	1,1,1-Trichloroethane	61	1.2
	Cumene	5, 6	6.3
	Methyl Ethyl Ketone (MEK)	31, 32	5.9
"Ethylene"	Ethylene	2, 4, 11	12.9

*For all source types and stream services

TABLE 3-4. LEAK FREQUENCIES BY PROCESS UNIT GROUP, SOURCE TYPE AND STREAM SERVICE

		Ethylene Process Units			
Source Type	Stream Service	Number Screened	Number Leaking	Percent Leaking	95% Confidence Interval for Percent Leaking
Valves	gas	6294	934	14.8	(13.8, 15.8)
	light liquid	4176	969	23.2	(21.8, 24.6)
Pump Seals	light liquid	76	20	26.3	(16.9, 37.7)
Flanges	gas	634	39	6.2	(4.4, 8.4)
	light liquid	407	25	6.1	(4.0, 8.9)
Open Ended Lines	gas	305	37	12.1	(8.6, 16.3)
	light liquid	214	41	19.2	(14.0, 25.3)

		High Leaking Process Units			
Source Type	Stream Service	Number Screened	Number Leaking	Percent Leaking	95% Confidence Interval for Percent Leaking
Valves	gas	2993	168	5.6	(4.7, 6.5)
	light liquid	9490	197	2.1	(1.8, 2.4)
Pump Seals	light liquid	371	28	7.5	(5.1, 10.5)
Flanges	gas	711	27	3.8	(2.5, 5.5)
	light liquid	1626	10	0.6	(0.3, 1.1)
Open Ended Lines	gas	493	17	3.4	(2.0, 5.4)
	light liquids	2089	85	4.1	(3.3, 5.0)

		Low Leaking Process Units			
Source Type	Stream Service	Number Screened	Number Leaking	Percent Leaking	95% Confidence Interval for Percent Leaking
Valves	gas	382	1	0.3	(0.01, 1.5)
	light liquid	4626	16	0.4	(0.2, 0.6)
Pump Seals	light liquid	199	9	4.5	(2.1, 8.4)
Flanges	gas	105	0	0.0	(0.0, 3.4)
	light liquid	798	1	0.1	(0.0, 0.7)
Open Ended Lines	gas	125	0	0.0	(0.0, 2.9)
	light liquid	1300	15	1.2	(0.7, 1.9)

EFFECT ON LEAK FREQUENCY OF PRIMARY CHEMICAL IN THE PROCESS LINE

The effect on leak frequency of the primary chemicals in the process lines is investigated in this section. The definition of primary chemical is described in Reference 1. Only the primary chemical is investigated here; the influence of the other chemicals in the line is not evaluated. The results of this section should be considered with this in mind.

Tables 3-5a and 3-5b display the percent of leaking sources by their primary chemical in the line for valves - gas service and liquid service, respectively. Large differences in leak frequency between primary chemicals can be seen in these tables. Because of these differences it was decided to further categorize the sources by the primary chemical in the line, depending on the leak frequency associated with that chemical.

To do this categorization, the percent leaking data for valves associated with primary chemicals were analyzed for the categories previously established (source type, stream service, and process groups). Tables 3-6a and 3-6b display this data for valves. It can be seen that chemicals associated with high percent leaking in the ethylene group were also seen to be associated with high percent leaking in the high leaking process unit grouping. For example, ethylene as a primary chemical in ethylene process units has a high percent leaking and, it also was found to have a high percent leaking in other process units.

Using the data from Table 3-6, the primary chemicals were grouped into two categories. If the percent of leaking (from Tables 3-6a and 3-6b) was above 5% the chemical was put into the high leaking chemical group. Otherwise it was put into the low leaking group. The resulting final groupings of the screening data for further analyses are shown in Figure 3-2.

TABLE 3-5a. PERCENT OF LEAKING VALVES BY PRIMARY MATERIAL IN LINE
(All Process Units)

Chemical	Valves - Gas Service: Number Screened[1]	Valves - Gas Service: Percent of Total Gas Service Valves	Number Leaking[1]	Percent Leaking
Ethylene	3134	33.3	498	15.8
Methane	1849	19.6	232	12.5
Propylene	1128	12.0	207	18.3
1,2-Ethylene Dichloride	525	5.6	4	0.8
Ethane	379	4.0	35	9.2
Benzene	332	3.5	53	16.0
Acrylonitrile	287	3.0	0	0.0
Vinyl Acetate	272	2.9	0	0.0
Acetaldehyde	179	1.9	4	2.2
Propane	145	1.5	18	12.4
Acetic Acid	125	1.3	1	0.8
Methyl Ethyl Ketone	116	1.2	7	6.0
Vinyl Chloride	96	1.0	0	0.0
Other Chemicals	851	9.0	42	4.9
Total	9418	100%	1101	11.7

[1]Numbers displayed in this table may not add up to totals in previous sections due to missing information on primary chemicals.

TABLE 3-5b. PERCENT OF LEAKING VALVES BY PRIMARY MATERIAL IN LINE

(All process units)

Chemical	Valves - Light Liquid Service: Number[1] Screened	Percent of Total Light Liquid Service Valves	Number[1] Leaking	Percent Leaking
1,2-Ethylene Dichloride	2809	15.4	32	1.1
Propylene	1604	8.8	488	30.4
Ethylene	1230	6.8	321	26.1
Acetic Acid	1162	6.4	6	0.5
Acrylonitrile	1126	6.2	6	0.5
Vinyl Acetate	973	5.3	3	0.3
1,1,2-Trichloroethane	914	5.0	4	0.4
Cumene	773	4.2	4	0.5
Vinyl Chloride	611	3.4	4	0.6
Perchloroethylene	601	3.3	3	0.5
Phenol	594	3.3	0	0.0
Benzene	536	2.9	49	9.1
Acetaldehyde	456	2.5	2	0.4
Methyl Ethyl Ketone	425	2.3	23	5.4
Methyl Methacrylate	393	2.2	1	0.2
Methanol	373	2.0	4	1.1
Ethane	328	1.8	92	28.0
α-Methyl Styrene	326	1.8	0	0.0
Hydrocarbons-C_5^+	323	1.8	8	2.5
Trichloroethylene	272	1.5	6	2.2
Acetone	209	1.1	5	2.4
Methane	205	1.1	36	17.6
Sec Butyl Alcohol	202	1.1	10	5.0
Acetone Cyanohydrin	191	1.0	0	0.0
Other Chemicals	1572	8.6	69	4.4
Total	18208	100%	1176	6.5

[1]Numbers displayed in this table may not add up to totals in previous sections due to missing information on primary chemicals.

TABLE 3-6a. PERCENT LEAKING BY PRIMARY MATERIAL FOR VALVES - GAS SERVICE

	High Leaking Process Units				Ethylene Process Units			
	Number[1] Screened	Percent of Total Screened	Number[1] Leaking	Percent Leaking	Number[1] Screened	Percent of Total Screened	Number[1] Leaking	Percent Leaking
Ethylene	680	22.8	62	9.1	2454	40.6	436	17.8
Methane	-	-	-	-	1849	30.6	232	12.6
Propylene	69	2.3	15	21.7	1059	17.5	192	18.1
1,2-Ethylene Dichloride	505	16.9	4	0.8	-	-	-	-
Ethane	-	-	-	-	379	6.3	35	9.2
Benzene	282	9.4	50	17.7	50	0.8	3	6.0
Acrylonitrile	287	9.6	0	0.0	-	-	-	-
Vinyl Acetate	272	9.1	0	0.0	-	-	-	-
Acetaldehyde	179	6.0	4	2.2	-	-	-	-
Propane	81	2.7	12	14.8	64	1.1	6	9.4
Acetic Acid	125	4.2	1	0.8	-	-		
Methyl Ethyl Ketone	116	3.8	7	6.0	-	-	-	-
Vinyl Chloride	96	3.2	0	0.0	-	-	-	-
Other Chemicals	294	9.9	13	4.4	195	3.2	28	14.4
TOTAL	2986	100.0	168	5.6	6050	100.0	932	15.4

[1]Numbers displayed in this table may not add up to totals in previous sections due to missing information on primary chemicals.

TABLE 3-6b. PERCENT LEAKING BY PRIMARY MATERIAL FOR VALVES - LIGHT LIQUID SERVICE

Primary Chemical in the Line	High Leaking Process Units				Ethylene Process Units			
	Number[1] Screened	Percent of Total Screened	Number[1] Leaking	Percent Leaking	Number[1] Screened	Percent of Total Screened	Number[1] Leaking	Percent Leaking
1,2 Ethylene Dichloride	2809	29.7	32	1.1	-	-	-	-
Propylene	253	2.7	44	17.4	1351	32.8	444	32.9
Ethylene	9	0.1	0	0.0	1221	29.6	321	26.3
Acetic Acid	1162	12.3	6	0.5	-	-	-	-
Acrylonitrile	1126	11.9	6	0.5	-	-	-	-
Vinyl Acetate	973	10.3	3	0.3	-	-	-	-
1,1,2 Trichlorethane	-	-	-	-	-	-	-	-
Vinyl Chloride	611	6.5	4	0.7	-	-	-	-
Perchloroethylene	-	-	-	-	-	-	-	-
Phenol	-	-	-	-	-	-	-	-
Benzene	432	4.6	48	11.1	104	2.5	1	1.0
Acetaldehyde	456	4.8	2	0.4	-	-	-	-
Methyl Ethyl Ketone	425	4.5	23	5.4	-	-	-	-
Methyl Methacrylate	-	-	-	-	-	-	-	-
Methanol	-	-	-	-	68	1.6	4	5.9
Ethane	-	-	-	-	328	8.0	92	28.1
Hydrocarbons C_5^+	-	-	-	-	-	-	-	-
α-Methyl Styrene	-	-	-	-	-	-	-	-
Trichloroethylene	-	-	-	-	-	-	-	-
Acetone	-	-	-	-	-	-	-	-
Methane	-	-	-	-	205	5.0	36	17.6
Sec Butyl Alcohol	202	2.1	10	5.0	-	-	-	-
Acetone Cyanohydrin	-	-	-	-	-	-	-	-
Other Chemicals	827	8.7	12	1.4	844	20.5	68	8.1
TOTAL	9453	100.0	193	2.0	4121	100.0	966	15.4

[1]Numbers displayed in this table may not add up to totals in previous sections due to missing information on primary chemicals.

SOURCE TYPE	Valves Pump Seals Flanges Open Ended Lines							
PROCESS UNITS	Ethylene Unit[2] = 2,4,11				High Leaking Unit=1,3,5,6,20,21 28,29,31,32,33, 61,65,66			
STREAM SERVICE	Gas[1]		Light Liquid		Gas		Light Liquid	
	High Leaking GROUP 1	Low Leaking GROUP 2	High Leaking GROUP 3	Low Leaking GROUP 4	High Leaking GROUP 5	Low Leaking GROUP 6	High Leaking GROUP 7	Low Leaking GROUP 8
PRIMARY CHEMICAL	Ethylene Methane Propylene Ethane Benzene Propane Other	None	Ethylene Propylene Benzene MEK Ethane Methane Butylene C6+ Methanol Propane Butanes Butadiene Butylenes, mixed	C4+ C5+ Ethanol N Butane Benzene	Ethylene Propylene Benzene Propane MEK	1,2-Ethylene Dichloride Acrylonitrile Vinyl Acetate Acetaldehyde Acetic Acid Vinyl Chloride Other	Ethylene Propylene Benzene MEK	1,2-Ethylene Dichloride Acetic Acid Acrylonitrile Vinyl Acetate Cumene Vinyl Chloride Acetaldehyde Sec Butyl Alcohol Other

[1] There were <4% of the sources in ethylene process units-gas streams associated with a low leaking primary chemical.

[2] See Table 3-2 for definition of process unit type identification numbers

Figure 3-2. Categories of Sources for Further Analysis

The major reason for grouping the sources into these eight categories was to aggregate the sources into groups that have similar leak frequencies. Note that this categorization was done for the data analysis and not for engineering or physical reasons. The final 25 groups used for further analyses are internally similar in:

- source type
- stream service
- leak frequency by process type, and
- leak frequency by primary chemical in the line.

With these groupings, any differences that the analysis detects in the other parameters of interest (line pressure, line temperature, etc.) will not be confounded with these grouping parameters.

The division into categories was done separately for each combination of stream service and process unit category. For this reason, a particular chemical may be grouped in the high leaking group in one subset and the low leaking group in another. Also the influence of other chemicals in the line was not investigated here. As a result, it is difficult to quantify the effect of a specific chemical.

Two additional comments should be made. First, the chemical groupings were made according to valve data only, so the high-low primary chemical breakdown for pump seals, flanges, and open-ended lines (see Tables 3-7a and 3-7b) may not reflect a strict high versus low leaking classification in all cases. Secondly, the numbers displayed in the tables in this section may not add up to totals from other tables in previous sections due to missing information on primary chemicals for some sources.

TABLE 3-7a. HIGH VERSUS LOW LEAKING PRIMARY CHEMICAL GROUPS FOR HIGH LEAKING PROCESS UNITS

		High Leaking Chemicals (Group 5 and Group 7[1])				Low Leaking Chemicals (Group 6 and Group 8[1])			
Source Type	Stream Service	Number Screened	Number Leaking	Percent Leaking	95% Confidence Intervals for Percent Leaking	Number Screened	Number Leaking	Percent Leaking	95% Confidence Intervals for Percent Leaking
Valves	Gas	1228	146	11.9	(10.2, 14.1)	1758	22	1.2	(0.7, 1.7)
	Light Liquid	3299	147	4.5	(3.7, 5.3)	6154	46	0.8	(0.6, 1.0)
Pump Seals	Light Liquid	126	14	11.1	(6.2, 18.1)	243	14	5.8	(3.3, 9.4)
Flanges	Gas	391	18	4.6	(2.7, 7.1)	316	9	2.8	(1.2, 5.3)
	Light Liquid	578	10	1.7	(0.7, 3.6)	1010	0	0.0	(0, 0.4)
Open Ended Lines	Gas	146	13	8.9	(4.9, 14.6)	347	4	1.2	(0.4, 3.1)
	Light Liquid	798	47	6.0	(4.5, 7.9)	1291	38	2.9	(2.0, 4.1)

[1]See Figure 3-2 for explanation of groups.

Note: Chemical groupings were made according to valve data only, so other sources may not reflect a strict high versus low leaking classification.

TABLE 3-7b. HIGH VERSUS LOW LEAKING PRIMARY CHEMICAL GROUPS FOR ETHYLENE PROCESS UNITS

Source Type	Stream Service	High Leaking Chemicals (Group 1 and Group 3[1]) Number Screened	Number Leaking	Percent Leaking	95% Confidence Intervals for Percent Leaking	Low Leaking Chemicals (Group 4[1]) Number Screened	Number Leaking	Percent Leaking	95% Confidence Intervals for Percent Leaking
Valves	Gas	6050	932	15.4	(14, 16)				
	Light Liquid	3514	957	27.2	(26, 29)	607	9	1.5	(0.67, 2.8)
Pump Seals	Light Liquid	61	18	29.5	(19, 43)	15	2	13.3	(1.7, 40)
Flanges	Gas	566	39	6.9	(4.9, 9.2)				
	Light Liquid	32.7	25	7.6	(5.0, 12)	70	0	0.0	(0.0, 5.1)
Open Ended Lines	Gas	284	37	13.0	(9.4, 17)				
	Light Liquid	151	39	25.8	(19, 34)	63	2	3.2	(.39, 11)

[1]See Figure 3-2 for explanation of groups.

Note: Chemical groupings were made according to valve data only so other sources may not reflect a strict high versus low leaking classification.

EFFECT OF TYPE OF VALVE ON LEAK FREQUENCY

The first breakdown for studying the effect of valve type is block valves versus control valves. Within these two categories, there are six types of valves evaluated: gate, globe, plug, ball and butterfly, plus one group called "other" which includes any valve type that does not fit into the first five categories.

Tables 3-8 and 3-9 show the valve leak frequency data for gas and light liquid stream service, respectively. Confidence intervals for percent leaking are included to help distinguish those cases with a high percent leaking but a small sample size.

Since some of the specific types of valves, particularly for control valves, had very small sample sizes when the data is categorized, an overall tabulation of valve types is given in Table 3-10. The smaller confidence limits make differences by type more easily seen. Figures 3-3a and 3-3b show this information graphically. For block valves, gate valves have the highest leak frequency while plug and ball valves have the lowest leak frequency.

The totals for block and control valves over all individual types were tested to evaluate the influence of both process unit and chemical in the line. Categorical statistical analyses were performed on these data to determine the significance of these classifications and their combined effects. (This method of analysis is described in Section 7.) Separate analyses were performed for gas and light liquid stream service. A summary of these analyses are given in Table 3-11.

The analysis of gas stream service does not include a variable to distinguish primary material groups since no such group was defined for ethylene process units with gas stream service. The analysis shows a significant effect of chemical produced, block/control and their combined

TABLE 3-8. PERCENT LEAKING FOR ALL TYPES OF VALVES IN GAS SERVICE AS A FUNCTION OF PROCESS GROUP AND PRIMARY MATERIAL GROUP

		High Leaking Process Units								Ethylene Process Units			
		Group 5[1] Primary Chemicals				Group 6[1] Primary Chemicals				Group 1[1] Primary Chemicals			
Valve Function	Type	Number Screened	Number Leaking	Percent Leaking	95% Confidence Interval	Number Screened	Number Leaking	Percent Leaking	95% Confidence Interval	Number Screened	Number Leaking	Percent Leaking	95% Confidence Interval
Block	gate	978	107	10.9	(9.1, 13)	1124	20	1.8	(1.1, 2.8)	4495	823	18.3	(17, 19)
	globe	9	4	44.4	(14, 79)	34	1	2.9	(0.1, 15)	73	10	13.7	(6.7, 24)
	plug	34	0	0.0	(0, 10)	245	0	0.0	(0, 1.5)	39	0	0.0	(0, 9.0)
	ball	102	4	3.9	(1.1, 9.6)	273	0	0.0	(0, 1.3)	834	14	1.7	(0.9, 2.9)
	butterfly	17	1	5.9	(0.2, 29)	21	0	0.0	(0, 16)	102	8	7.8	(3.3, 15)
	other	1	0	0.0	(0, 100)	9	0	0.0	(0, 34)	261	16	6.1	(3.7, 10)
	Total	1141	116	10.2	(8.7, 13)	1706	21	1.2	(0.8, 1.9)	5804	871	15.0	(14, 16)
Control	gate	19	8	42.1	(20, 66)	15	0	0.0	(0, 22)	24	7	29.2	(13, 51)
	globe	39	11	28.1	(15, 45)	21	1	4.8	(0.1, 24)	137	24	17.5	(11, 24)
	plug	3	0	0.0	(0, 71)	2	0	0.0	(0, 84)	5	0	0	(0, 52)
	ball	5	1	20.0	(0.5, 72)	1	0	0.0	(0, 100)	8	2	25.0	(3.2, 65)
	butterfly	20	9	45.0	(23, 68)	13	0	0.0	(0, 25)	56	26	46.4	(34, 62)
	other	1	0	0.0	(0, 100)	0	-	-	-	16	2	12.5	(1.6, 38)
	TOTAL	87	29	33.3	(24,44)	52	1	1.9	(0.1, 10)	246	61	24.8	(19, 30)

[1]See Figure 3-2 for explanation of groups.

TABLE 3-9. PERCENT LEAKING FOR ALL TYPES OF VALVES WITH LIGHT LIQUID STREAM SERVICE BY PROCESS GROUP AND PRIMARY MATERIAL GROUP

	High Leaking Process Units							
	Group 7 Primary Chemicals				Group 8 Primary Chemicals			
Valve Type	Number Screened	Number Leaking	% Leaking	95% Confidence Interval	Number Screened	Number Leaking	% Leaking	95% Confidence Interval
Block								
Gate	2330	122	5.2	(4.3, 6.2)	3322	38	1.4	(0.8, 1.6)
Globe	37	4	10.8	(3.0, 25)	187	1	0.5	(0.01,2.9)
Plug	470	2	0.4	(0.1, 1.5)	1030	0	0.0	(0, .36)
Ball	255	0	0.0	(0, 1.5)	1263	0	0.0	(0, .29)
Butterfly	63	0	0.0	(0, 5.7)	33	0	0.0	(0, 11)
Other	5	0	0.0	(0, 52)	38	0	0.0	(0, 9.25)
TOTAL	3160	128	4.1	(3.4, 4.9)	5873	39	0.66	(0.5, .91)
Control								
Gate	58	11	19.0	(9.9, 31)	65	2	3.1	(0.4, 11)
Globe	40	6	15.0	(5.7, 30)	121	5	4.1	(1.3, 9.5)
Plug	26	1	3.8	(0.1, 20)	53	0	0.0	(0, 6.7)
Ball	2	0	0.0	(0, 85)	25	0	0.0	(0, 14)
Butterfly	11	1	9.1	(0.2, 41)	12	0	0.0	(0, 26)
Other	2	0	0.0	(0, 85)	5	0	0.0	(0, 52)
TOTAL	138	19	13.8	(8.4, 20)	281	7	2.5	(1.0, 5.0)

TABLE 3-9. (continued)

	Ethylene Process Units							
	Group 3 Primary Chemicals				Group 4 Primary Chemicals			
Valve Type	Number Screened	Number Leaking	% Leaking	95% Confidence Interval	Number Screened	Number Leaking	% Leaking	95% Confidence Interval
Block								
Gate	3125	877	28.1	(26, 30)	529	7	1.3	(0.5, 2.7)
Globe	45	2	4.4	(0.5, 15)	15	0	0.0	(0, 22)
Plug	3	0	0.0	(0, 71)	2	0	0.0	(0, 84)
Ball	49	4	18.2	(2.3, 20)	8	0	0.0	(0, 37)
Butterfly	4	2	50.0	(6.8, 93)	1	0	0.0	(0, 100)
Other	94	15	16.0	(9.2, 25)	20	0	0.0	(0, 17)
TOTAL	3320	900	27.1	(25, 29)	575	7	1.2	(0.5, 2.5)
Control								
Gate	20	9	45.0	(23, 68)	7	0	0.0	(0, 41)
Globe	162	46	28.4	(22, 36)	20	2	10.0	(1.2, 32)
Plug	2	0	0.0	(0, 84)	5	0	0.0	(0, 52)
Ball	3	0	0.0	(0, 71)	0	0	---	---
Butterfly	7	2	28.6	(3.7, 71)	0	---	---	---
Other	0	---	---	---	0	---	---	---
TOTAL	194	55	28.4	(23, 35)	32	2	6.2	(0.8, 21)

[1]See Figure 3-2 for explanation of groups.

TABLE 3-10. LEAK FREQUENCIES FOR ALL TYPES OF VALVES FOR GAS AND LIGHT LIQUID STREAM SERVICE

Type	Gas Service				Light Liquid Service			
	Number Screened	Number Leaking	Percent Leaking	95% Confidence Limits	Number Screened	Number Leaking	Percent Leaking	95% Confidence Limits
Block								
Gate	6976	952	13.7	(13, 15)	11017	1059	9.6	(8.6, 9.8)
Globe	145	15	10.3	(5.9, 17)	755	8	1.1	(0.5, 2.1)
Plug	440	0	0.0	(0, 0.8)	2479	2	0.1	(0.01, 0.3)
Ball	1272	18	1.4	(0.7, 2.5)	2732	4	0.2	(0.04, 0.4)
Butterfly	160	9	5.6	(2.6, 10)	157	2	1.3	(0.15, 4.4)
Other	275	16	5.8	(3.5, 9.2)	378	17	4.5	(2.7, 7.8)
TOTAL	9268	1010	10.9	(10, 11)	17518	1092	6.2	(5.9, 6.6)
Control								
Gate	61	15	24.6	(14, 37)	182	22	12.1	(7.8, 18)
Globe	207	36	17.4	(13, 24)	417	61	14.6	(12, 19)
Plug	10	0	0.0	(0, 31)	91	3	3.3	(0.7, 9.3)
Ball	15	4	26.7	(7.8, 55)	33	1	3.0	(0.1, 16)
Butterfly	91	35	38.5	(28, 49)	34	3	8.8	(0.7, 20)
Other	17	3	17.6	(3.8, 43)	25	1	4.0	(0, 20)
TOTAL	401	93	23.2	(19, 28)	782	91	11.6	(10, 15)

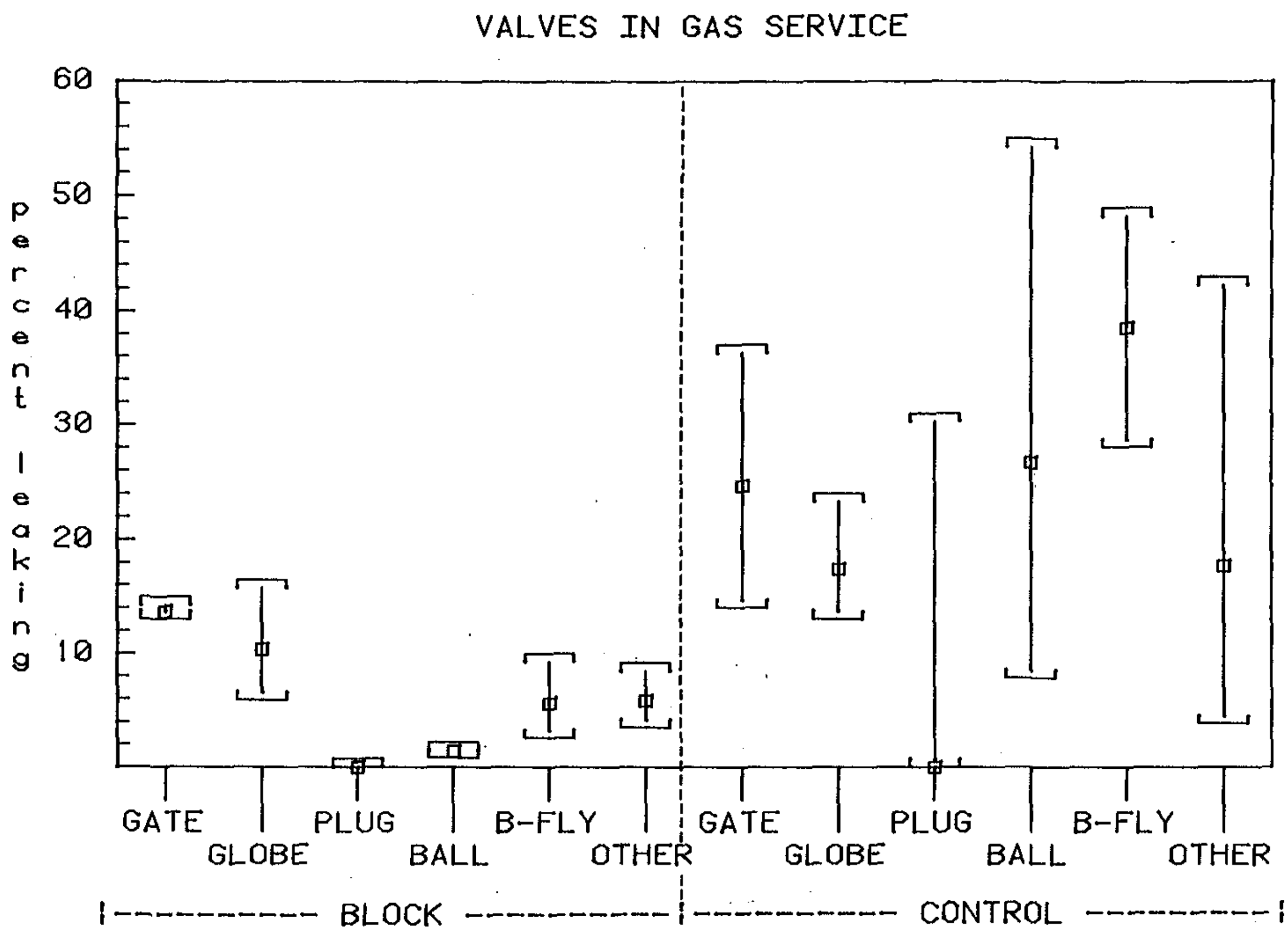


Figure 3-3a. Percent Leaking with 95 Percent Confidence Intervals for Each Valve Type with Gas Service

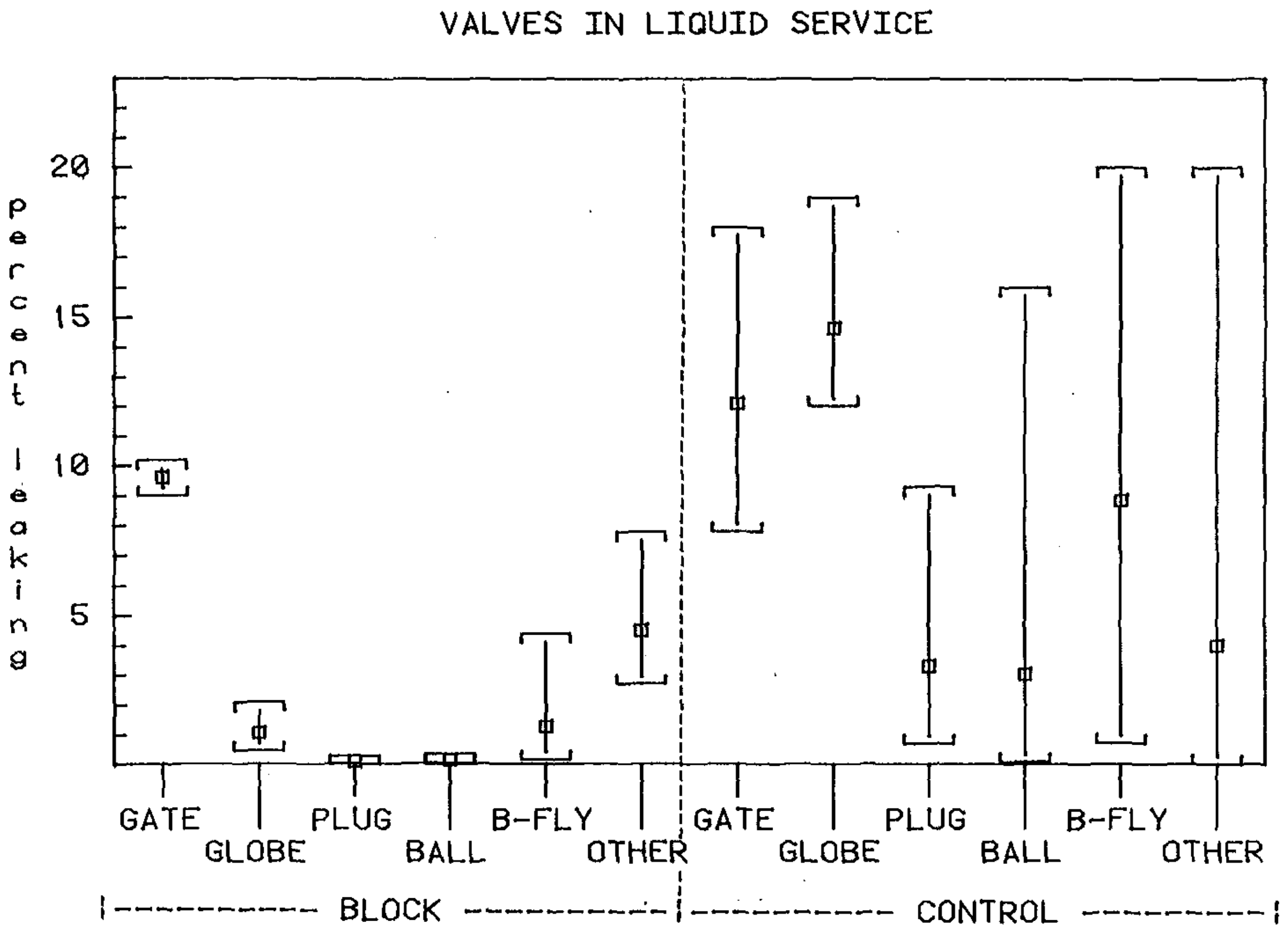


Figure 3-3b. Percent Leaking with 95 Percent Confidence Intervals for Each Type of Valve with Light Liquid Service

effect on the leak frequency. For valves in gas stream service, Table 3-8 shows control valves with a higher percent leaking than block valves for each group. The significant combined effect indicates that the difference between block and control valves is significantly greater in the high leaking process units than in the ethylene process units.

The second analysis summarized in Table 3-11 is for light liquid service. The variables used here are the same as for gas service with the addition of a category by primary material in the line and all of the two-way combined effects. All of the main effects and two of the combined effects are highly significant. The combined effect of primary material in the line and block/control is also statistically significant. Table 3-9 shows the direction of these differences. It can be seen from this table that the percentage of sources leaking for control valves from high leaking process units with high leaking primary materials is about three times that of block valves in the same group. For the low leaking primary material group, it was about four times. Ethylene process units with high leaking primary materials in the line had similar leak frequencies between block and control groups.

Figure 3-4a and Figure 3-4b provide a graphical display of the differences in leak frequency between the block and control valves for each process and primary material category.

Since the analysis found a significant different in leak frequency between block and control valves, the comparison by specific type of valve was done for each of these valve classifications. Figures 3-3a and 3-3b show leak frequencies for each valve type with 95 percent confidence intervals for the leak frequencies. The larger number of block valves tested makes this group the easier one to examine for differences by valve type. For both gas and light liquid service, gate valves have the highest leak frequency, and plug and ball valves have the lowest leak frequency. Globe and butterfly valves in light liquid service also have low leak frequencies. These last two types of valves have comparatively wide confidence intervals for gas service because of the small number of valves of those types found.

TABLE 3-11. RESULTS OF CATEGORICAL ANALYSIS ON VALVES[1]

Source	Chi-Square Statistic	Probability of No Effect
Gas Stream Service		
Chemical Process	655.40	<0.01
Block/Control	19.44	<0.01
Combined Effects	13.81	<0.01
Light Liquid Stream Service		
Chemical Process	207.1	<0.01
Primary Material	60.1	<0.01
Block/Control	25.4	<0.01
Combined Effects		
Process by Material	64.9	<0.01
Process by Block/Control	15.7	<0.01
Material by Block/Control	4.4	<0.05

[1]See Section 7 for explanation of this analysis.

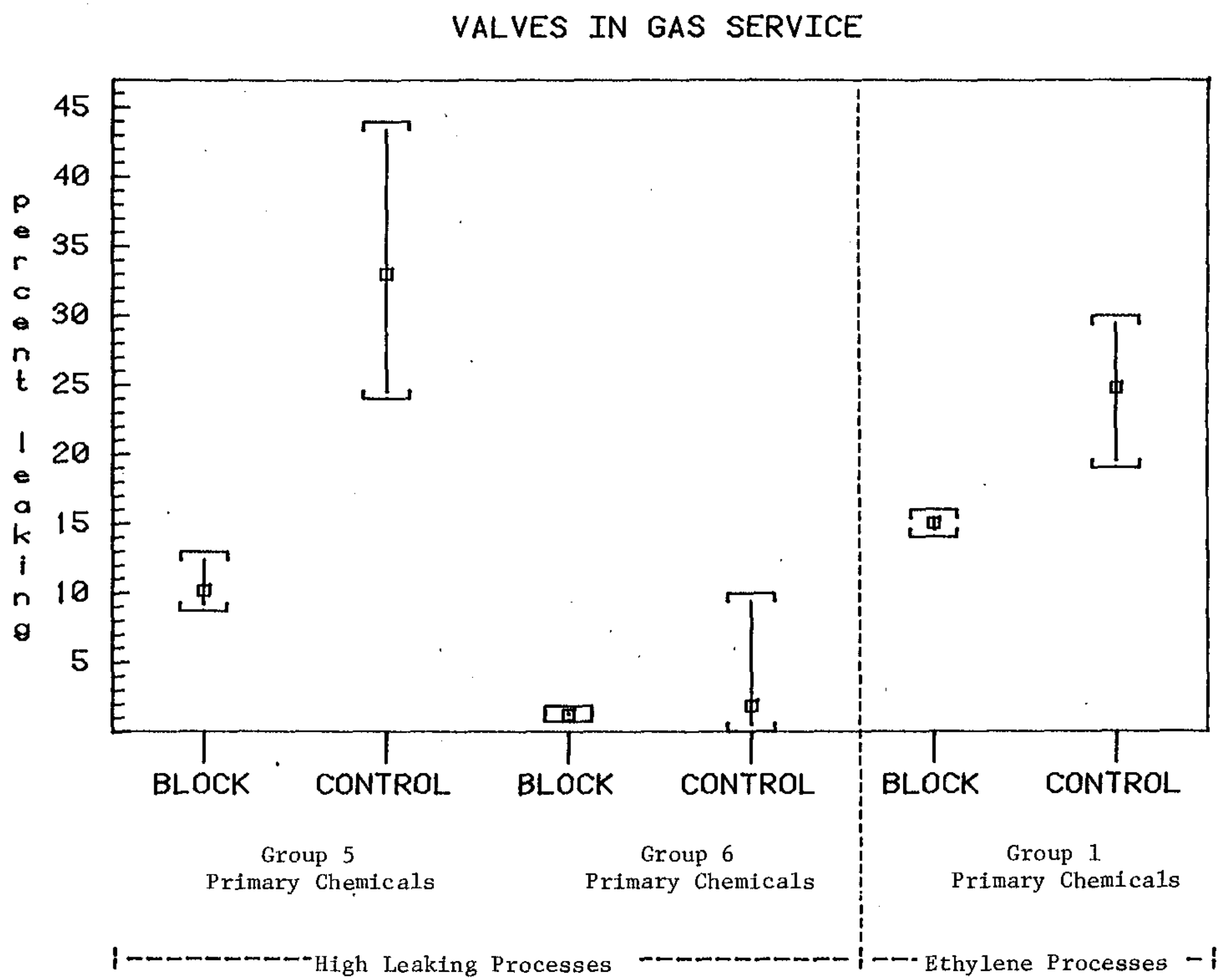


Figure 3-4a. Percent Leaking for Block Versus Control Valves in Gas Service by Primary Material Group and Process Unit Type

Note: See Figure 3-2 for explanation of primary material groups.

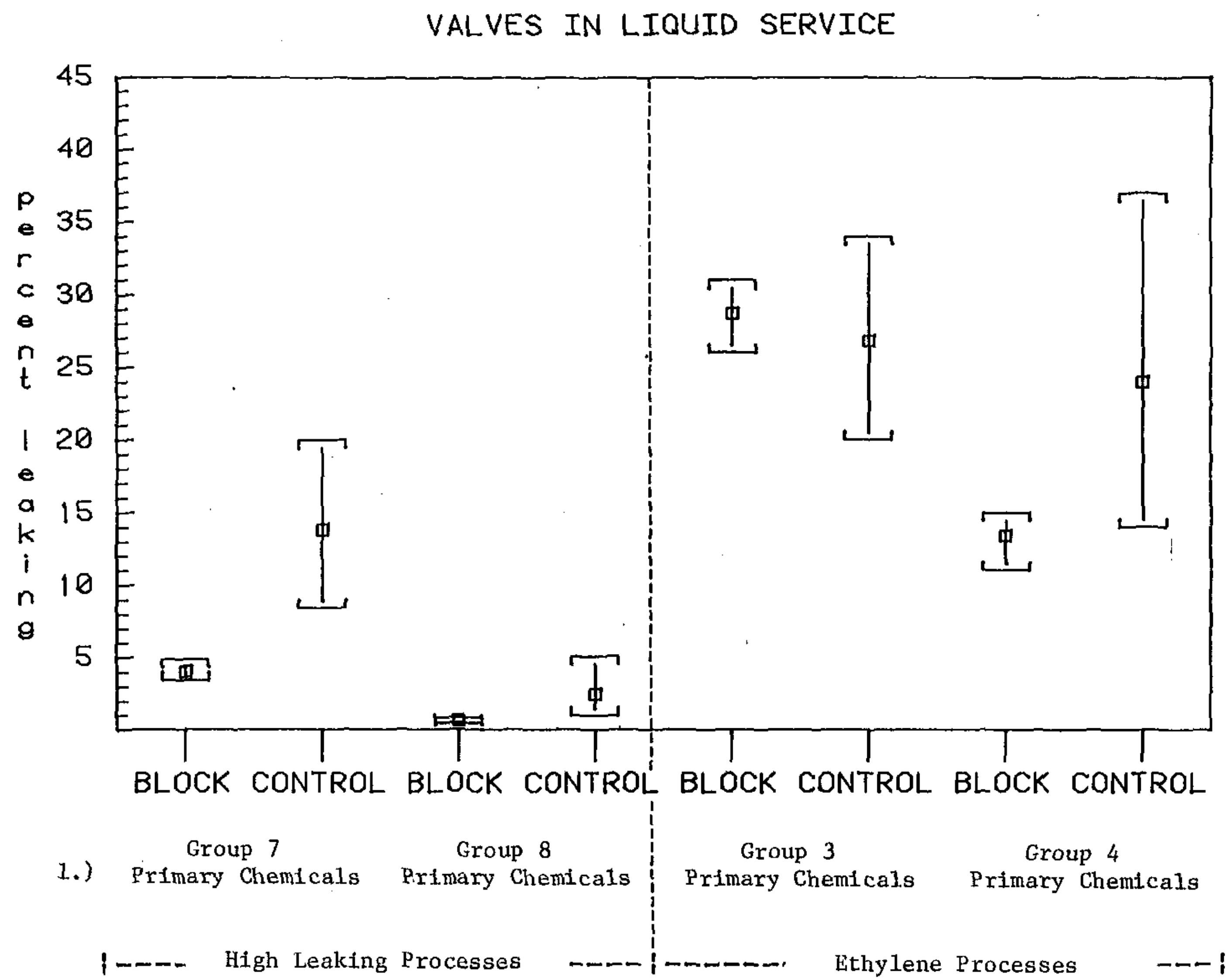


Figure 3-4b. Percent Leaking for Block Versus Control Valves in Light Liquid Service by Primary Material Group and Process Unit Type

Note: See Figure 3-2 for explanation of primary material groups.

For gas service, they appear to fall in the middle range between the high leaking gate valves and low leaking plug and ball valves. A comparison of types of control valves is more difficult because of the small sample sizes. The actual percent leaking for gate valves is higher than that of plug and ball valves, but there are overlapping confidence intervals. In the group of control valves in light liquid service, globe valves show a significantly higher leak rate than plug valves from the same group.

LEAK FREQUENCY FOR PUMP SEAL CLASSIFICATIONS

Pump seals comprise a much smaller group of sources than valves. For this reason, the groupings by process unit type and primary materials in the line are not reported in this section. When these subcategorizations were examined, the small sample size in these categories resulted in such large confidence limits that no statistical differences could be seen. Combining the categories did not effect any of the trends observed.

The primary classifications for pump seals are on-line versus off-line, single versus double seals, mechanical versus packed seals, and location of the emission point. Table 3-12 gives the number of pump seals screened, the number leaking, the percentage leaking and appropriate 95% confidence intervals for these classifications of pump seals. On-line and off-line single mechanical seals with emission point at seal are the two largest groups.

A chi-square test (see Section 7 for details) was performed to determine if there was a statistically significant difference in the leak frequencies between on-line and off-line pump seals when the emission point was at the seal. The outcome is below:

	NO LEAK		LEAK		TOTAL
	Number	%	Number	%	
On-line	271	86.9	41	13.1	312
Off-line	232	95.1	12	4.9	244
Total	503	90.5	53	9.5	556

Chi-Square Statistic = 10.74 , $p < 0.01$

This test indicates that there is a significant difference between on-line and off-line pump seals, with the leak frequency for off-line pumps

TABLE 3-12. LEAK FREQUENCIES FOR PUMP SEALS IN LIGHT LIQUID SERVICE

On Line/ Off Line	Mechanical/ Packed	Single/ Double	Emission Point	Number Screened	Number Leaking	Percent Leaking	95% Confidence Interval
On-Line	Mechanical	Single	Seal	215	28	13.0	(9, 20)
			Vent	24	0	0.0	(0, 14)
			Other	30	2	6.7	(0.8, 22)
	Mechanical	Double	Seal	92	13	14.1	(7.7, 23)
			Vent	3	1	33.3	(0.8, 91)
			Other	3	1	33.3	(0.8, 91)
	Packed	Single	Seal	5	0	0.0	(0, 52)
			Vent	0	-	-	-
			Other	1	0	0.0	(0, 100)
			TOTAL AT THE SEAL	312	41	13.1	(9.0, 17)
Off-Line	Mechanical	Single	Seal	139	9	6.5	(3.0, 12)
			Vent	9	0	0.0	(0, 34)
			Other	17	0	0.0	(0, 20)
	Mechanical	Double	Seal	86	3	3.5	(0.7, 9.9)
			Vent	0	-	-	-
			Other	1	0	0.0	(0, 100)
	Packed	Single	Seal	19	0	0.0	(0, 18)
			Vent	2	0	0.0	(0, 84)
			Other	0	-	-	-
			TOTAL AT THE SEAL	244	12	4.9	(2.6, 8.6)

about one-third that of on-line pumps.

A Chi-square test was also used to compare the leak frequency for the single mechanical pump seals to double mechanical pump seals. Separate tests were performed for on-line and off-line seals. Only data with the emission point at the seal was considered. Single packed pump seals had no leaks in either case and so could not be included in the test. The following table describes this test:

On-Line Pump Seals	NOT LEAKING		LEAK		
	Number	%	Number	%	
Single Mechanical	187	87.0	28	13.0	215
Double Mechanical	79	85.9	13	14.1	98
	266	86.6	41	13.4	307

Chi-Square Statistic = 0.07 $p > 0.10$

Off-Line Pump Seals	NOT LEAKING		LEAKING		
	Number	%	Number	%	
Single Mechanical	130	93.5	9	6.5	139
Double Mechanical	83	96.5	3	3.5	87
	240	94.7	12	5.3	252

Chi-Square Statistic = 0.94 $p > 0.10$

The leak frequency for single mechanical versus double mechanical was not significantly different for either the on-line or the off-line data. Figure 3-5 shows this same information graphically. Note that the presence or type of barrier fluids was generally not recorded for this data. This may have been a factor in the lack of a significant difference between single mechanical and double mechanical pump seals.

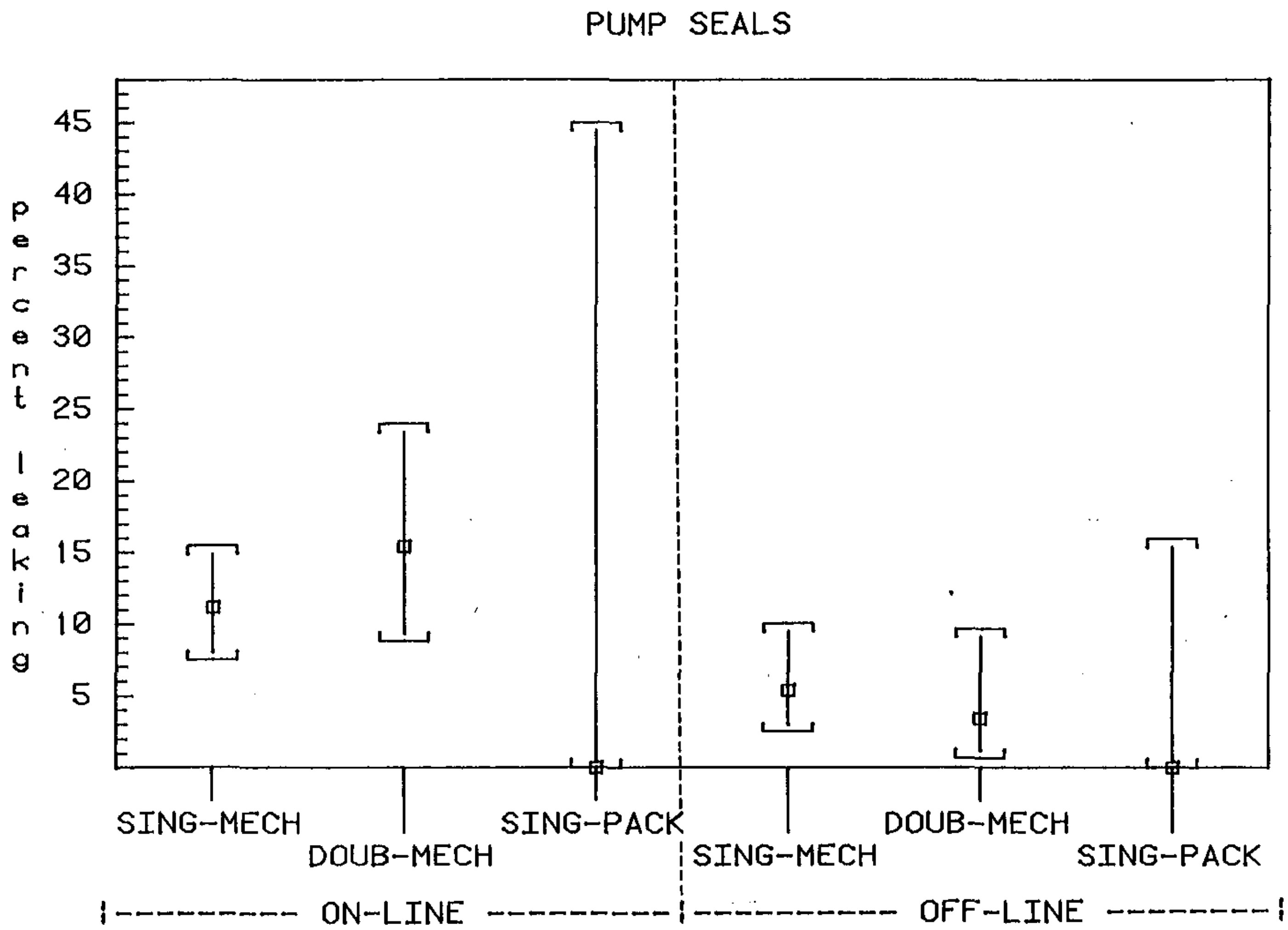


Figure 3-5. Percent Leaking with 95 Percent Confidence Intervals for Each Type of Pump Seal with Light Liquid Service

THE EFFECT OF LINE TEMPERATURE AND LINE PRESSURE

The effects of line temperature and line pressure are examined in parallel in this section. The effects of these two variables are evaluated for the four major source types: flanges, open-ended lines, valves, and pump seals. It was found that different levels of temperature and pressure are present in the 24 units studied depending both on the type of chemical produced and also on the primary material in the line. The data are grouped by these variables as they have been defined earlier in this report. Appendix B contains summary statistics in tabular form for line pressure and line temperature for each of the groups.

Since valves constituted the largest group by source type, the effects of line temperature and line temperature on leak frequency for valves could be studied in the greatest detail. Categorical statistical analysis, described in Section 7, was used to determine the significance on leak frequency of line temperature and line pressure and their combined effects (interaction). This method of analysis is biased by empty cells (any temperature and pressure categories with no leaks). As a result, the only groups to be studied for possible combined effects were valves with high leaking primary chemical groups (see Figure 3-2 for an explanation of groups). The results of this analysis are given in Table 3-13.

The results of the categorical analysis show that for ethylene process units with valves in gas service, both line temperature and line pressure, and also their combined effect, were significant. For the valves in light liquid service, pressure and the combined effect of temperature and pressure were significant. Both of the groups from the high leaking process units showed only pressure to have a significant effect on leak frequency. Tables 3-14 to 3-17 give the data used in this analysis. Figures 3-6 to 3-9 graphically show the results of these analyses. Figure 3-6 provides a good example of significant combined effects (interaction) of line temperature and line pressure. It shows that the effects of increased pressure on the percent leaking is not the same for all temperature groups. If there was no significant combined effect, the lines would be parallel.

Tables 3-18 and 3-19 show the effects of line temperature and line pressure on the valve for primary material groups 4, 6 and 8. The categories of temperature and pressure were chosen to agree with those in Appendix B It appears that pressure may have an effect on each of these three groups (group 4, group 6 and group 8). Temperature appears to have an effect on valves from group 4.

In summary, higher levels of pressure appear to result in higher leak frequency in almost every instance. For example, valves from Primary Material Group 1 have a 4.1 percent leaking in the "less than 25 psig" pressure group and 25.8 percent leaking in the "greater than 200 psig" pressure group. In those cases where this is not seen, it may be due to the smaller sample sizes. Temperature appears to be significant in only a few cases. In those cases, it was the middle range of line temperature rather than the extremes that was associated with higher leak frequency. Valves in gas service from ethylene process units had the greatest percent leaking (16.2%) at temperatures between 0°F and 49°F. The combined effects of line temperature and line pressure could only be studied for valves. It had a significant effect for the ethylene process units only. Higher leak frequencies for high pressure and middle level temperature were found. Figures 3-6 to 3-8 graphically show the effect of the interaction. The significant combined effect is apparent in the fact that the lines for levels of line temperature are not parallel.

TABLE 3-13. RESULTS OF ANALYSIS OF THE EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON LEAK FREQUENCY FOR VALVES

Process Unit Group	Primary Material Group[1]	Stream Service	Source	Degrees of Freedom[2]	Chi-Square	Significance[3]
Ethylene Processes	Group 1	Gas	Temperature	3	9.1	*
			Pressure	3	268.6	**
			Combined effects	9	42.4	**
	Group 3	Light Liquid	Temperature	2	3.4	n.s.
			Pressure	2	67.2	**
			Combined effects	4	25.7	**
High Leaking Processes	Group 5	Gas	Temperature	2	3.2	n.s.
			Pressure	2	7.6	*
			Combined effects	4	3.1	n.s.
	Group 7	Light Liquid	Temperature	2	3.4	n.s.
			Pressure	2	13.9	*
			Combined effects	4	3.1	n.s.

[1]See Figure 3-2 for explanation of groups.

[2]The total degrees of freedom for gas service in the ethylene process units is higher than the total for the other groups because, in this group, four levels of both temperature and pressure could be used without producing any empty cells in the analysis.

[3]*probability of no significant effect is less than 0.05
**probability of no significant effect is less than 0.01
n.s.-no significant effect

TABLE 3-14. LINE TEMPERATURE AND LINE PRESSURE AND THEIR COMBINED EFFECTS ON VALVES IN GAS SERVICE WITHIN ETHYLENE PROCESS UNITS

Temperature (°F)	-267-0			0-49			50-99			100-1570			TOTAL		
Pressure (psig)	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking
-15-25	348	18	5.2	506	29	5.7	542	14	2.6	244	7	2.9	1640	68	4.1
25-99	180	30	16.7	449	54	12.0	881	96	10.9	276	18	6.5	1786	198	11.1
100-199	55	12	21.8	104	8	7.7	332	71	21.4	350	55	15.7	841	146	17.4
200-1050	415	80	19.3	392	144	36.7	491	146	29.7	714	149	20.9	2012	519	25.8
TOTAL	998	140	14.0	1451	235	16.2	2246	327	14.6	1584	229	14.5	6279	931	14.8

TABLE 3-15. LINE TEMPERATURE AND LINE PRESSURE AND THEIR COMBINED EFFECTS ON VALVES FROM GROUP 5*

Temperature (°F)	-267-99			100-149			150-1570			TOTAL		
Pressure (psig)	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking
-15-99	120	8	6.7	141	8	5.7	187	22	11.8	448	38	8.5
100-199	16	4	25.0	83	7	8.4	118	15	12.7	217	26	12.0
200-1050	73	10	13.7	91	14	15.4	236	45	19.1	400	69	17.2
TOTAL	209	22	10.5	315	29	9.2	541	82	15.2	1065	133	12.5

*See Figure 3-2 for explanation of groups. Group 5 is the high leaking primary chemical group from high leaking processes in gas service.

TABLE 3-16. LINE TEMPERATURE AND LINE PRESSURE AND THEIR COMBINED EFFECTS ON VALVES FROM GROUP 3*

Temperature (°F)	-267-49			50-99			100-1570			TOTAL		
Pressure (psig)	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking
-15-99	683	106	15.5	56	1	1.8	104	16	15.4	843	123	14.6
100-199	65	6	9.2	282	90	31.9	108	14	13.0	455	110	24.2
200-1050	1325	360	27.2	490	196	40.0	396	168	42.4	2211	724	32.7
TOTAL	2073	647	31.2	828	287	34.7	608	198	32.6	3509	957	27.3

*See Figure 3-2 for explanation of groups. Group 3 is the high leaking chemical group from light liquid service from ethylene processes.

TABLE 3-17. LINE TEMPERATURE AND LINE PRESSURE AND THEIR COMBINED EFFECTS ON VALVES FROM GROUP 7*

Temperature (°F)	-267-99			100-149			150-1510			TOTAL		
Pressure (psig)	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking	Number Screened	Number Leaking	Percent Leaking
-15-99	795	14	1.8	322	4	1.2	663	24	3.6	1780	42	2.4
100-199	216	12	5.6	234	12	5.1	245	12	4.9	695	36	5.2
200-1050	143	19	13.3	263	20	7.6	390	27	6.9	796	66	8.3
TOTAL	1154	45	3.9	8.9	36	4.4	1298	63	4.8	3271	144	4.4

*See Figure 3-2 for explanation of groups. Group 7 is the high leaking primary chemical group for high leaking processes in light liquid service.

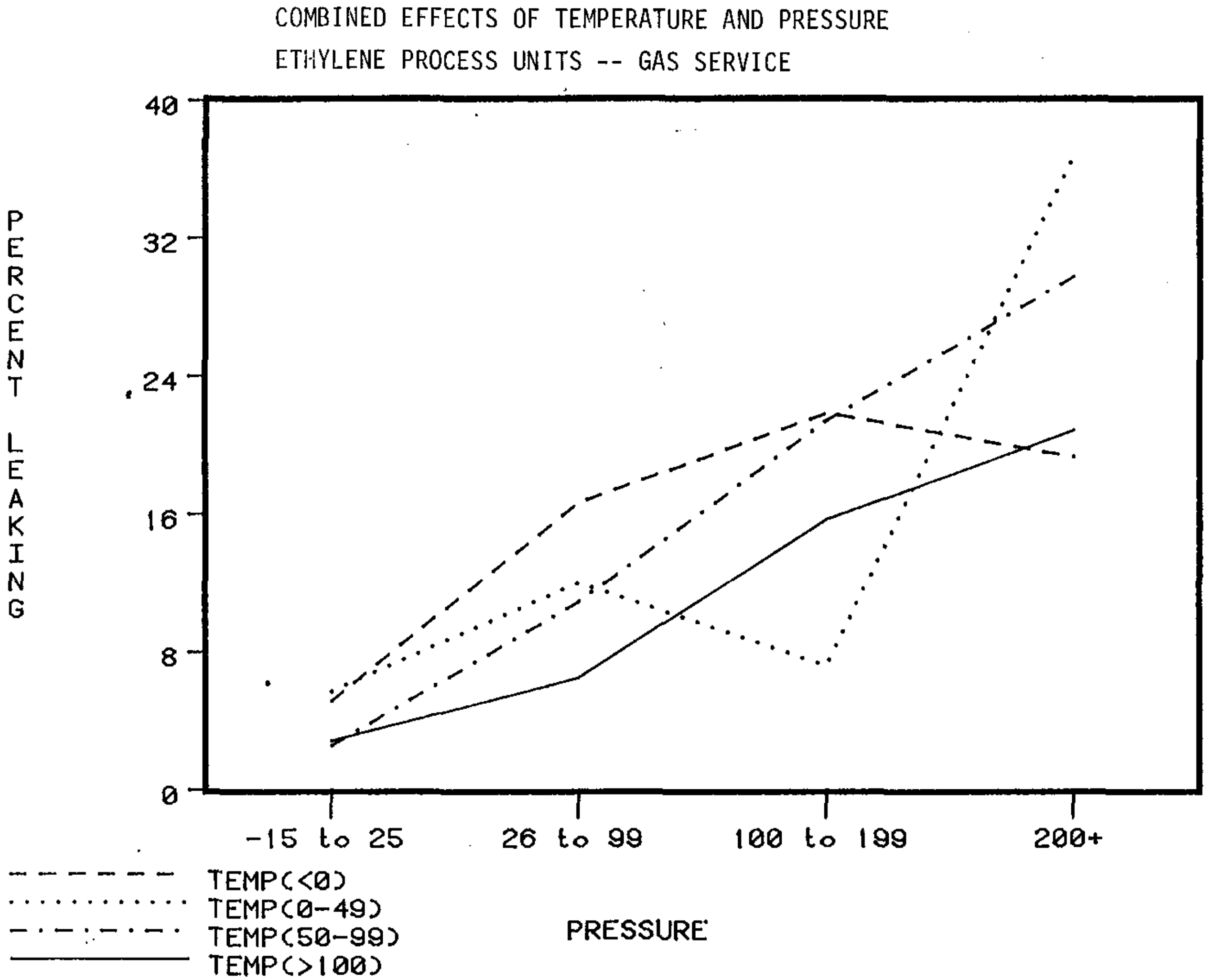


Figure 3-6. Combined Effects of Line Temperature and Line Pressure on Percent Leaking for Valves in Gas Service Within Ethylene Process Units.

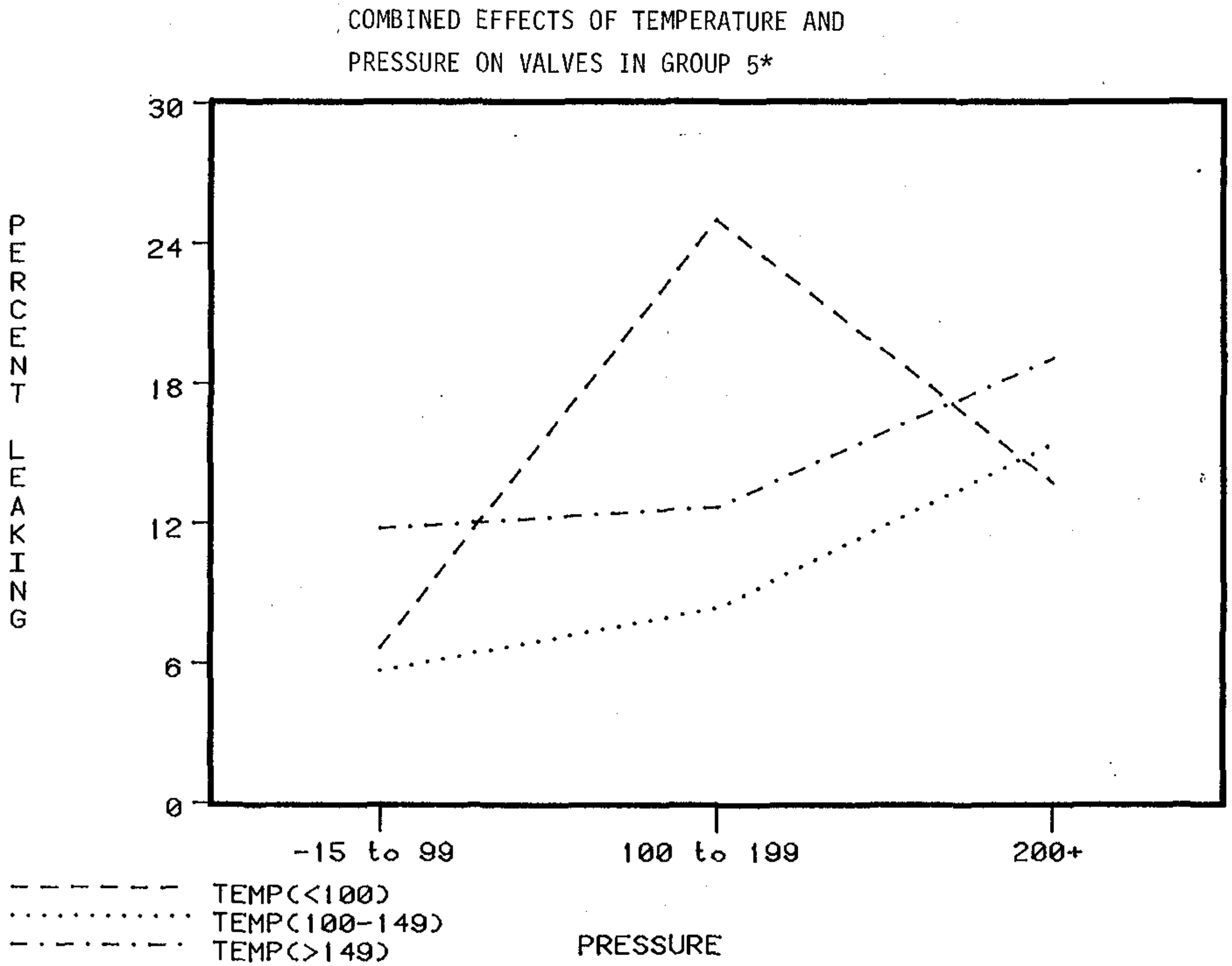


Figure 3-7. Combined Effects of Line Temperature and Line Pressure on Percent Leaking for Valves from Group 5*.

*See Figure 3-2 for explanation of groups.

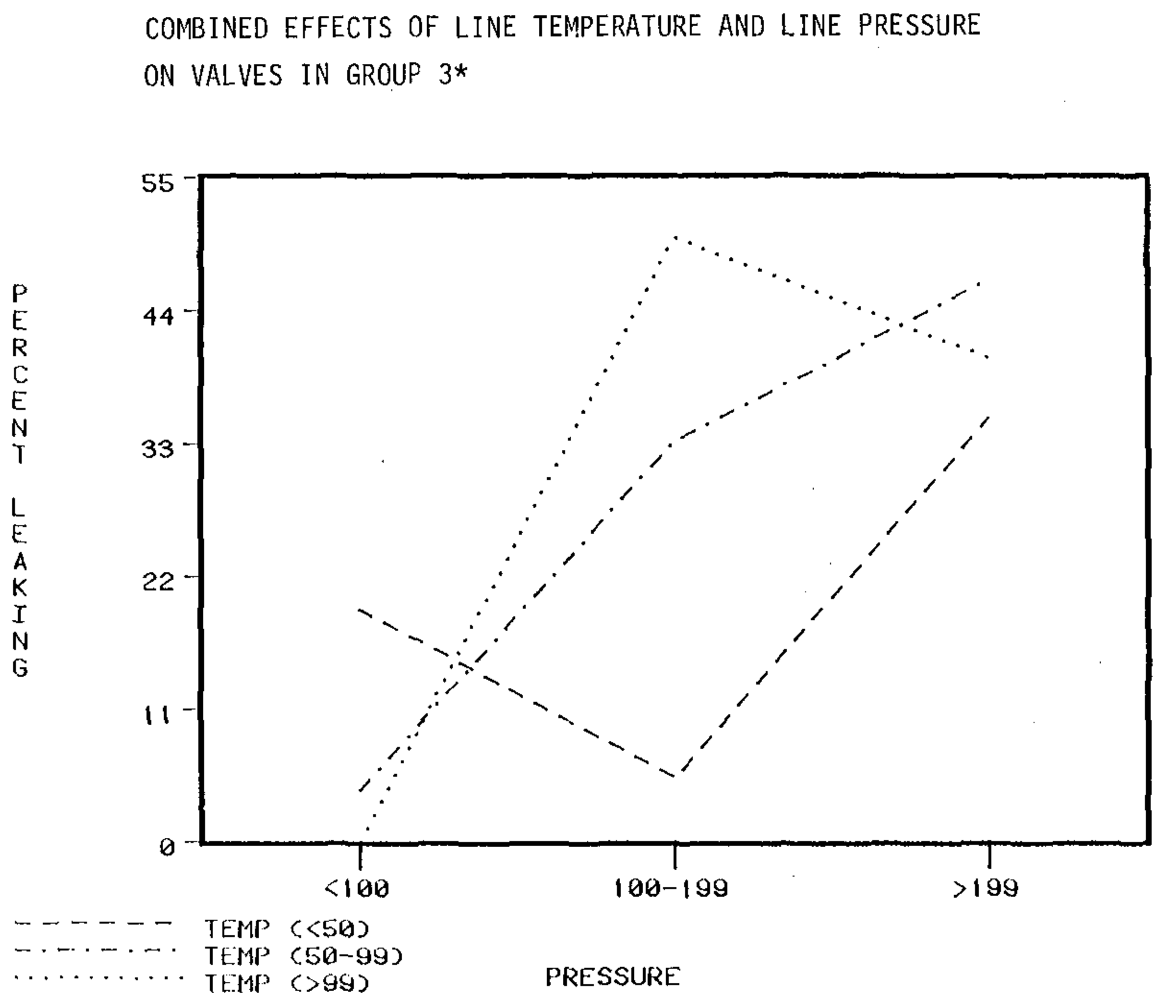


Figure 3-8. Combined Effects of Line Pressure on Percent Leaking for Valves in Group 3.*

*See Figure 3-2 for explanation of groups.

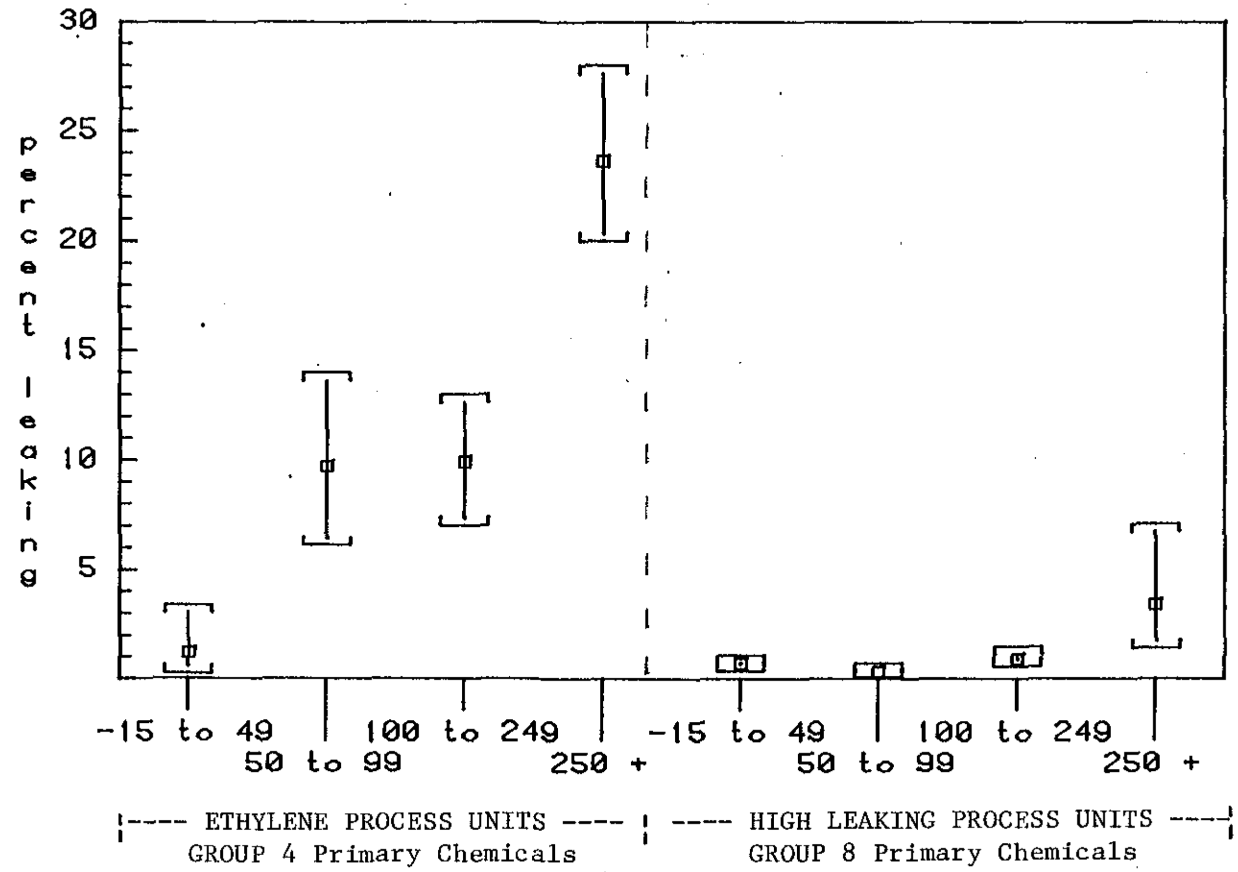


Figure 3-9. The Effect of Line Pressure on Percent Leaking With 95 Percent Confidence Intervals for Valves from Group 4 and Group 8.*

*See figure 3-2 for explanation of groups

TABLE 3-18. EFFECT OF LINE TEMPERATURE AND LINE PRESSURE ON VALVES FROM GROUP 6*

Pressure	Number Screened	Number Leaking	Percent Leaking	95% Confidence Limits
-15-49	1267	7	0.5	(0.2, 1.1)
50-99	141	2	1.4	(0.2, 5.1)
100-249	188	13	6.9	(3.7, 12)
250-1050	162	0	0.0	(0, 2.3)
Total	1758	22	1.2	(0.78, 1.9)
Temperature				
-267-49	45	0	0.0	(0, 7.9)
50-99	335	4	1.2	(0.3, 3.2)
100-199	823	2	0.2	(0.03, 0.9)
200-1570	555	16	2.9	(1.7, 4.7)
Total	1758	22	1.2	(0.8, 1.9)

*See Figure 3-2 for explanation of groups.

TABLE 3-19. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON VALVES FROM GROUP 4 AND GROUP 8 BY PROCESS UNIT GROUP[1]

	Group 4[1] PRIMARY CHEMICALS				Group 8[1] PRIMARY CHEMICALS			
Pressure (psig)	Number Screened	Number Leaking	Number Leaking	95% Confidence Intervals	Number Screened	Number Leaking	Number Leaking	95% Confidence Intervals
-15-49	173	0	0.0	(0, 2.1)	2432	16	0.7	(0.4, 1.1)
50-99	215	4	1.9	(0.5, 4.8)	1567	5	0.3	(0.1, 0.7)
100-249	181	4	2.2	(0.8, 5.6)	1916	18	0.9	(0.6, 1.5)
250-1050	38	1	2.6	(0.1, 14)	205	7	3.4	(1.4, 7.1)
Total	607	9	1.5	(0.7, 2.8)	6120	46	0.8	(0.5, 1.0)
Temperature (°F)								
-267-49	29	0	0.0	(0, 12)	96	2	2.1	(0.3, 7.3)
50-99	127	2	1.6	(0.2, 5.5)	1912	11	0.6	(0.3, 1.0)
100-199	341	6	1.8	(0.6, 3.8)	2583	16	0.6	(0.4, 1.0)
200-1570	110	1	0.9	(0.0, 5.0)	1563	17	1.1	(0.6, 1.7)
Total	607	9	1.5	(0.7, 2.8)	6154	46	0.8	(0.5, 1.0)

[1]See Figure 3-2 for explanation of groups

EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON PUMP SEALS, FLANGES, AND OPEN-ENDED LINES

There was not enough data available to study the possible combined effect of line temperature and line pressure for the remaining source types, and so the effects of these two variables were examined separately. Categories were used that would conform to earlier tables and at the same time provide an approximately even distribution of sources screened.

Table 3-20 shows this information for pump seals for both groups of process units and all primary materials. The 95 percent confidence intervals indicate that no significant effects of temperature or pressure can be seen. If the overall number screened was increased, the size of the confidence intervals would be decreased and it is possible that some significant differences might then be seen. Figure 3-10 shows the percent leaking with 95 percent confidence intervals as a function of pressure for this source type.

Tables 3-21 and 3-22 give the leak frequencies by line temperature and line pressure for flanges in gas and light liquid services, respectively. Increasing levels of line pressure result in increased leak frequency. The effect is most clear for gas service streams. These data are presented by process unit group since for the light liquid service, there appears to be some differences between these two groups.

Tables 3-23 and 3-24 show the leak frequency of open-ended lines by line temperature and line pressure. Ethylene process units services in gas service show a higher leak frequency at the highest level of pressure. Otherwise the gas service show overlapping confidence intervals. Open-ended lines in light liquid service within ethylene process units show an increased leak frequency at higher pressure levels and also a higher frequency at the upper two pressure levels when compared to the high leaking process units. The leak frequency from the high leaking process units does not appear to be affected by line temperature or line pressure. Line temperature does not appear to have an effect on open-ended lines within ethylene process units either.

TABLE 3-20. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON PUMP SEALS WITH LIGHT LIQUID SERVICE

Pressure (psig)	Number Screened	Number Leaking	Percent Leaking	95% Confidence Intervals
-15 - 49	146	10	6.8	(3.3, 12)
50 - 99	115	19	16.5	(10, 25)
100 - 249	116	11	9.5	(4.9, 16)
250 - 1050	65	12	18.5	(9.9, 30)
Total	442	52	11.8	(9.0, 15)
Temperature (°F)				
-267 - 49	53	12	22.6	(12, 36)
50 - 99	148	14	9.5	(5.2, 14)
100 - 199	146	13	8.9	(4.8, 14)
200 - 1570	100	9	0.9	(4.2, 16)
Total	447	48	10.7	(8.0, 14)

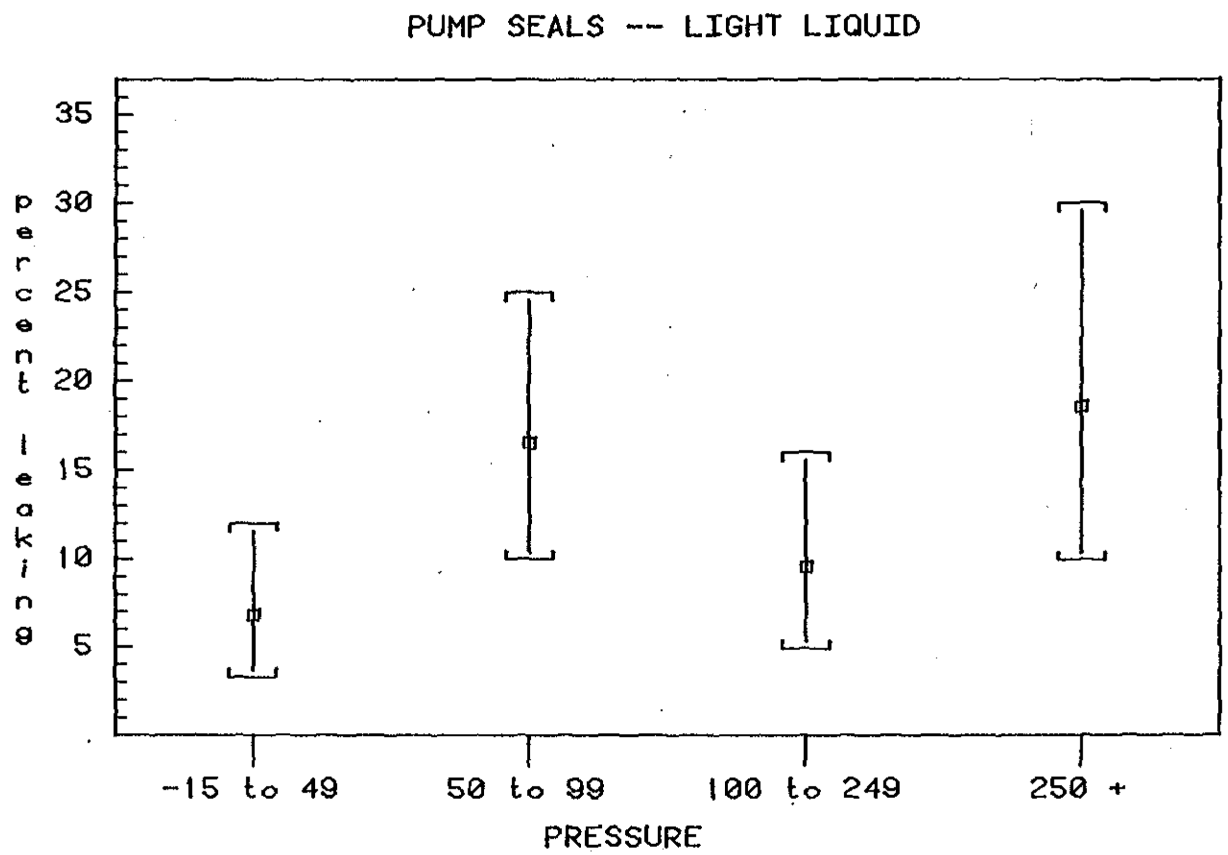


Figure 3-10. The Effect of Line Pressure on Percent Leaking with 95 Percent Confidence Intervals on Pump Seals in Light Liquid Service

TABLE 3-21. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON FLANGES IN GAS SERVICE BY PROCESS UNIT GROUP

	Ethylene Process Units				High Leaking Process Units			
Pressure (psig)	Number Screened	Number Leaking	Percent Leaking	95% Confidence Intervals	Number Screened	Number Leaking	Percent Leaking	95% Confidence Intervals
-15-49	210	3	1.4	(0.3, 4.3)	301	6	2.0	(0.7, 4.3)
50-99	102	4	3.9	(1.1, 9.6)	76	2	2.6	(0.3, 9.2)
100-249	136	8	5.9	(2.5, 11)	117	2	1.7	(0.2, 6.1)
250-1050	182	24	13.2	(8.7, 19)	217	17	7.8	(4.8, 13)
TOTAL	630	39	6.2	(4.4, 8.0)	711	27	3.8	(2.5, 5.5)
Temperature (°F)								
-267-49	129	17	13.2	(7.8, 20)	16	0	0.0	(0, 21)
50-99	335	15	4.5	(2.6, 7.8)	99	1	1.0	(0, 5.5)
100-199	155	5	3.2	(1.0, 7.4)	268	4	1.5	(0.4, 3.7)
200-1570	15	2	13.3	(1.7, 41)	321	22	6.8	(4.4, 10)
TOTAL	634	39	6.2	(4.4, 8.0)	704	27	3.8	(2.5, 5.5)

TABLE 3-22. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON FLANGES IN LIGHT LIQUID SERVICE BY PROCESS UNIT GROUP

	Ethylene Process Units				High Leaking Process Units			
Pressure (psig)	Number Screened	Number Leaking	Percent Leaking	95% Confidence Intervals	Number Screened	Number Leaking	Percent Leaking	95% Confidence Intervals
-15-49	70	1	1.4	(0, 7.7)	581	0	0.0	(0, 0.7)
50-99	52	0	0.0	(0, 6.8)	364	0	0.0	(0, 1.1)
100-249	74	5	6.8	(2.2, 15)	372	2	0.5	(0.1, 2.0)
250-1050	200	19	9.5	(5.8, 14)	279	8	2.9	(1.3, 5.7)
TOTAL	396	25	6.31	(4.1, 9.1)	1596	10	0.6	(0.3, 1.2)
Temperature (°F)								
-267-49	133	13	9.8	(5.3, 16)	26	0	0.0	(0, 13)
50-99	141	10	7.1	(3.5, 13)	491	2	0.4	(0.1, 1.4)
100-199	121	2	1.7	(0.2, 5.8)	638	6	0.9	(0.3, 2.1)
200-1570	9	0	0.0	(0, 34)	452	2	0.4	(0.1, 1.6)
TOTAL	404	25	6.2	(4.1, 9.1)	1607	10	0.6	(0.3, 1.1)

TABLE 3-23. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON OPEN ENDED LINES IN GAS SERVICE BY PROCESS UNIT GROUP

	Ethylene Process Units				High Leaking Process Units			
Pressure (psig)	Number Screened	Number Leaking	Percent Leaking	95% Confidence Intervals	Number Screened	Number Leaking	Percent Leaking	95% Confidence Intervals
-15-49	160	6	3.8	(1.4, 8.0)	272	5	1.8	(0.6, 4.3)
50-99	53	7	13.2	(5.5, 25)	59	4	6.8	(1.9, 16)
100-249	35	3	8.6	(1.8, 23)	74	1	1.3	(0, 7.3)
250-1050	55	20	36.4	(24, 50)	51	4	7.8	(2.2, 19)
TOTAL	303	36	11.9	(8.6, 16)	456	14	3.1	(1.7, 5.8)
Temperature (°F)								
-267-49	173	16	9.2	(5.5, 15)	13	0	0.0	(0, 25)
50-99	96	17	17.7	(11,0, 27)	83	8	9.6	(4.2, 18)
100-199	31	4	12.9	(3.6, 30)	225	5	2.2	(0.7, 5.1)
200-1570	5	0	0.0	(0, 52)	134	1	0.8	(0, 4.1)
TOTAL	305	37	12.1	(8.6, 16)	455	14	3.5	(1.7, 5.8)

TABLE 3-24. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON OPEN ENDED LINES IN LIGHT LIQUID SERVICE BY PROCESS UNIT GROUP

	Ethylene Process Units				High Leaking Process Units			
Pressure (psig)	Number Screened	Number Leaking	Percent Leaking	95% Confidence Intervals	Number Screened	Number Leaking	Percent Leaking	95% Confidence Intervals
-15-49	30	0	0.0	(0, 12)	813	27	3.3	(2.2, 4.7)
50-99	48	2	4.2	(0.5, 14)	479	22	4.6	(2.9, 6.8)
100-249	38	7	18.4	(7.7, 34)	474	14	2.9	(1.7, 4.9)
250-1050	98	32	32.6	(24, 43)	125	3	2.4	(0.5, 6.9)
TOTAL	214	41	19.2	(15, 26)	1891	66	3.5	(2.7, 4.4)
Temperature (F)								
-267-49	75	15	20.0	(12, 31)	56	0	0.0	(0, 6.4)
50-99	56	13	23.2	(13, 36)	668	28	4.2	(2.8, 5.9)
100-199	62	11	17.7	(9.2, 30)	685	24	3.5	(2.4, 5.2)
200-1570	21	2	9.5	(1.2, 30)	486	14	2.9	(1.6, 4.8)
TOTAL	214	41	19.2	(15, 26)	1897	66	3.5	(2.7, 4.4)

EFFECT OF AMBIENT TEMPERATURE ON LEAK FREQUENCY

This section evaluates the effects on leak frequency of the ambient temperature. The ambient temperature was measured at the same time that the source was screened. Ambient temperature was measured as a continuous variable, but to evaluate its effect on leak frequency, it was grouped as less than 70°F or greater than or equal to 70°F. Appendix C contains summary statistics for this variable.

Statistical tests were performed for each primary material group to determine if there was a significant difference in leak frequencies between the two classifications of ambient temperature.

Table 3-25 gives a summary of the effects of ambient temperature on leak frequencies of sources. In those cases where the percent leaking was not affected by the primary material in the line or the type of process unit or both, groups were combined. Those groups that did show a significant effect of ambient temperature are noted with asterisks. In one case (open-ended lines in gas service from high leaking process units) a significant difference in leak frequencies was seen when the primary material groups were combined (but the differences were not significant when they were separated).

Overall, ten of the 25 groupings of sources showed a statistically significant effect of ambient temperature on the leak frequency. Four of the seven comparisons for valves were significant. Generally higher leak frequencies were associated with the high ambient temperature classification. Differences in leak frequencies between the two ambient temperature categories range from three percent leaking to 14 percent leaking.

TABLE 3-25. SUMMARY OF THE EFFECTS OF AMBIENT TEMPERATURE ON PERCENT LEAKING

Source Type	Stream Service	Process Group	Primary Material Group[1]	Ambient Temperature	Number Screened	Number Leaking	Percent Leaking	Significant Effect of Temperature	95% Confidence Interval
Valves	Gas	Ethylene	Group 1	<70°	3760	474	12.6	**	(11, 14)
				70°+	2534	460	18.2		(17, 20)
		High Leaking	Group 5 and Group 6	<70°	1591	67	4.2		(3.3, 5.4)
				70°+	1402	101	7.2	**	(5.8, 8.7)
	Light Liquid	Ethylene	Group 3 and Group 4	<70°	1906	448	23.5		(21, 26)
				70°+	2215	518	23.4		(21, 26)
		High Leaking	Group 7	<70°	2435	52	2.1	**	(1.6, 2.8)
				70°+	803	95	11.8		(9.6, 14)
			Group 8	<70°	2861	17	0.6		(0.4, 1.0)
				70°+	3293	29	0.9		(0.6, 1.2)
Pump Seals	Light Liquid	Both	Group 3,4, 7,8	<70°	245	21	9.0		(5.3, 13)
				70°+	202	27	13.0		(9.1, 19)
Flanges	Gas	Both	Group 1,5,6	<70°	288	14	4.7		(2.6, 7.8)
				70°+	1057	52	4.9		(3.7, 4.3)
	Light Liquid	Both	Group 3,4, 7,8	<70°	457	7	1.5		(0.6, 3.2)
				70°+	1576	28	1.8		(1.2, 2.6)
Open Ended Lines	Gas	Ethylene	Group 1	<70°	223	19	8.5		(5.2, 13)
				70°+	82	18	22.0	**	(14, 32)
		High Leaking	Group 5	<70°	71	4	5.6		(1.6, 14)
				70°+	75	9	12.0	2	(5.6, 22)
			Group 6	<70°	204	1	0.5		(0, 2.8)
				70°+	143	3	2.1		(0.5, 6.1)
	Light Liquid	Both	Group 3,4, 7,8	<70°	1288	84	6.5		(5.2, 8.1)
				70°+	1015	42	4.1		(3.0, 5.6)

1-See Figure 3-2 for explanation of groups.

2-Showed significance when groups 5 and 6 were combined.

**Probability of no difference in leak frequency between ambient temperature categories is less than one percent.

EFFECT OF ELEVATION ON LEAK FREQUENCY

This section evaluates the effect of source elevation on leak frequency. The elevation of each screened source was recorded at the time of screening. This elevation was expressed as the process unit landing level closest to the screened source. For analysis in this report, the source elevation was categorized as either ground level or above ground. The data is presented in the same format as that for ambient temperature. Appendix C contains summary statistics for elevation and the results of all statistical tests on the elevation categories.

Table 3-26 gives the same type of summary for the effects of elevation that was given for ambient temperature. Groups of process units and primary materials were combined wherever the effect of elevation was consistent.

Only five of the 25 source type/primary chemical groups evaluated indicated a significant effect of elevation on leak frequency. In all of these cases, the sources at ground level had a higher leak frequency than the sources above ground. The differences between the elevation categories for those groups ranged from 1.7 to 6.0 percent leaking.

TABLE 3-26. SUMMARY OF THE EFFECTS OF ELEVATION ON PERCENT LEAKING

Source Type	Stream Service	Process Group	Primary Material Group	Elevation	Number Screened	Number Leaking	Percent Leaking	Significant Effect of Elevation	95% Confidence Interval
Valves	Gas	Ethylene	Group 1	Ground	3298	475	14.4		(13, 16)
				Above	2977	453	15.2		(14, 17)
		High	Group 5	Ground	479	54	11.3		(8.5, 14)
				Above	749	92	12.3		(10, 14)
			Group 6	Ground	423	12	2.8	**	(1.6, 4.9)
				Above	1333	10	0.7		(0.4, 1.4)
	Light Liquid	Ethylene	Group 3,4	Ground	3123	727	23.3		(22, 25)
				Above	1041	238	22.9		(20, 26)
		High	Group 7	Ground	2494	121	4.8	*	(4.0, 5.8)
				Above	795	25	3.1		(2.0, 4.6)
			Group 8	Ground	4394	35	0.8		(0.6, 1.1)
				Above	1743	10	0.6		(0.3, 1.0)
Pump Seals	Light Liquid	Both	Group 3,4 7,8	Ground	437	48	11.0		(8.3, 14)
				Above	10	0	0.0		(0, 31)
Flanges	Gas	Both	Group 1,5,6	Ground	481	22	4.6		(3.0, 7.8)
				Above	863	44	5.1		(3.7, 7.0)
	Light Liquid	Both	Group 3,4, 7,8	Ground	1414	25	1.8		(1.1, 2.6)
				Above	610	9	1.5		(0.7, 2.8)
Open Ended Lines	Gas	Ethylene	Group 1	Ground	235	25	10.6		(7.1, 16)
				Above	69	12	17.4		(9.3, 28)
		High	Group 5	Ground	59	6	10.2		(3.8, 21)
				Above	87	7	8.0	2	(3.3, 16)
			Group 6	Ground	72	2	2.8		(0.3, 9.7)
				Above	274	2	0.7		(0.1, 2.6)
	Light Liquid	Ethylene	Group 3,4	Ground	163	31	19.0		(13, 26)
				Above	51	10	19.6		(9.8, 33)
		High	Group 7	Ground	623	45	7.2	**	(5.3, 9.4)
				Above	172	2	1.2		(0.1, 4.1)
			Group 8	Ground	949	29	3.1		(2.0, 4.4)
				Above	340	9	2.6		(1.2, 4.9)

1-See Figure 3-2 for explanation of groups.
2-There was a significant difference between elevation categories when chemical groups 5 and 6 were combined.

*Probability of no difference in leak frequency between elevation categories is less than five percent.
**Probability of no difference in leak frequency between elevation categories is less than one percent.

SECTION 4

EMISSION FACTOR DEVELOPMENT FOR THREE PROCESSES

This section presents detailed results of the investigations in the following three areas:

- Distribution of screening values,
- Estimation of emission factors, and
- Mass emission distribution over the range of screening values.

DISTRIBUTION OF SCREENING VALUES

Distributions of OVA screening values were examined for each process, source type (valve or pump seal) and service. From past experience with the refining industry, it was expected that the distributions of the nonzero screening values could be modeled with a lognormal distribution. It was anticipated that censoring above 100,000 ppmv would occur due to the inconsistent use of a secondary OVA dilution probe. Figure 4-1 shows a typical histogram of the logarithms of the nonzero screening values with a pattern that frequently occurred: a large number of observations nominally at 100,000 ppmv with positive skewness (more large values occurring than expected from a normal distribution) and negative kurtosis (flatter peak and shorter tails than a normal distribution). Further examination of the distributions by primary material classification showed similar departures from the lognormal distribution. Two approaches were subsequently taken in modeling the distribution of screening values: fitting an empirical cumulative distribution, which reflects detailed features of the data, and fitting a cumulative lognormal distribution to the nonzero screening values, with adjustment for censoring of the data. Section 7 contains a more detailed discussion of these distribution models. Figures 4-2 through 4-10 compare the lognormal models with the empirical distributions. The departure from lognormality of the screening data does not appear large in magnitude. The lognormal model was therefore used in the development of both screening value distributions and distributions of mass emissions.

EMISSION FACTORS AND CUMULATIVE DISTRIBUTIONS OF TOTAL EMISSIONS BY SCREENING VALUES

This section briefly describes the estimated emission factors and mass emission functions. A more detailed discussion of the statistical methods and assumptions employed is found in Section 7.

Table 4-1 presents estimated emission factors for nonmethane hydrocarbon fugitive emissions from valves and pump seals. Figures 4-11 and 4-12 show graphically how these emission factors compare between the three processes considered in this report.

Comparison of emission factors among the three processes by means of their related confidence intervals shows only one difference that can be considered to be statistically significant: ethylene has a significantly larger emission factor than vinyl acetate for valves with light liquid service. Note, however, that ethylene consistently shows the largest emission factor, followed by cumene and vinyl acetate. For pump seals, ethylene and cumene have about the same emission factor. With the exception of vinyl acetate, pump seals have larger emission factors than do valves. Finally, for comparable sources, gas service has higher emission factors than light liquid service.

Fugitive emissions may also be compared by means of the cumulative distribution of total mass emission by screening value. These curves relate the OVA screening value to the percentage of the total mass emission which can be expected from all sources with screening values greater than any given value. These cumulative functions have been estimated for each process, source type, and service. Figures 4-13 through 4-21 display the cumulative mass emission estimated by an empirical function, with the lognormal model superimposed for comparison. Both the lognormal model and the empirical function are described more fully in Section 7.

Confidence bounds are given to indicate how well the cumulative mass function has been estimated from the data collected in both the screening and maintenance programs. The development of these intervals is discussed in Section 7. In using these estimated functions and confidence intervals, it should be kept in mind that the relationship between screening values and mass emissions is imperfect. Also, the true distribution of screening values is not known precisely: it is estimated from the observed screening value distribution. These two sources of variation contribute to the width of the confidence bands shown in the figures.

Figures 4-22 through 4-30 show the cumulative distribution functions for screening values (Part a) and mass emissions (Part b) based on the lognormal model for the screening values.

Application of Figures 4-22 through 4-30 may be illustrated through the use of Table 4-2, which exhibits point estimated and 95% confidence intervals for both the percentages of sources screening ⩾ 10,000 ppmv and the percentage of total mass emissions attributable to sources screening ⩾ 10,000 ppmv. For example, approximately 15% of ethylene process valves in gas service can be expected to have screening values above 10,000 ppmv (Figure 4-25a). However, these 15% of the valves are responsible for an estimated 94% of the mass emissions (Figure 4-25b). In the same manner, other specific screening values (or percentage of sources) could be chosen and the corresponding percentage of mass emissions found.

NOTE: $\log_e(10) = 2.30$ $\log_e(10{,}000) = 9.21$
$\log_e(100) = 4.61$ $\log_e(100{,}000) = 11.51$
$\log_e(1000) = 6.91$ $\log_e(1{,}000{,}000) = 13.82$

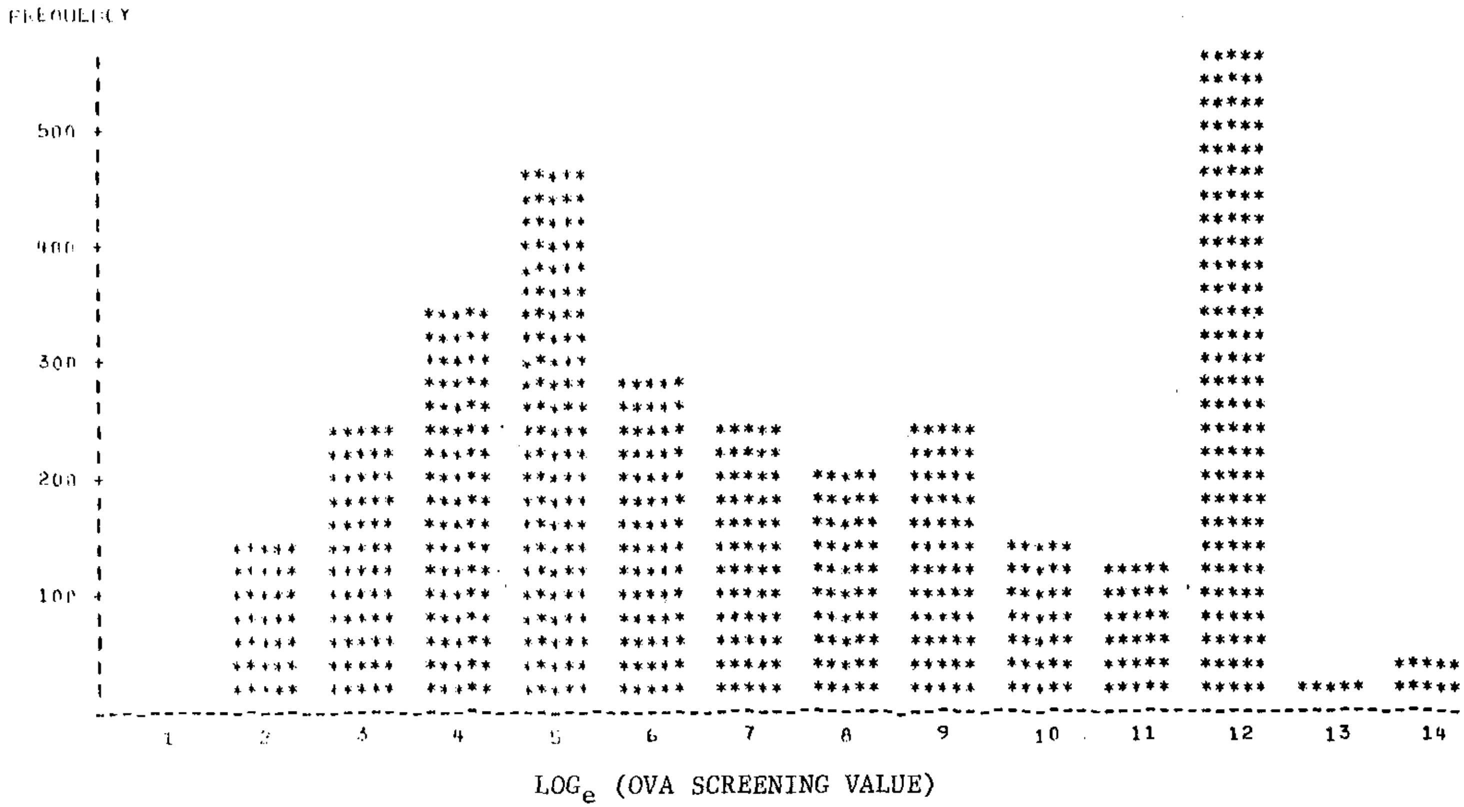


Figure 4-1. Typical Distribution of $\log_e$ (OVA Screening Value) Ethylene Process, Valves in Gas Service

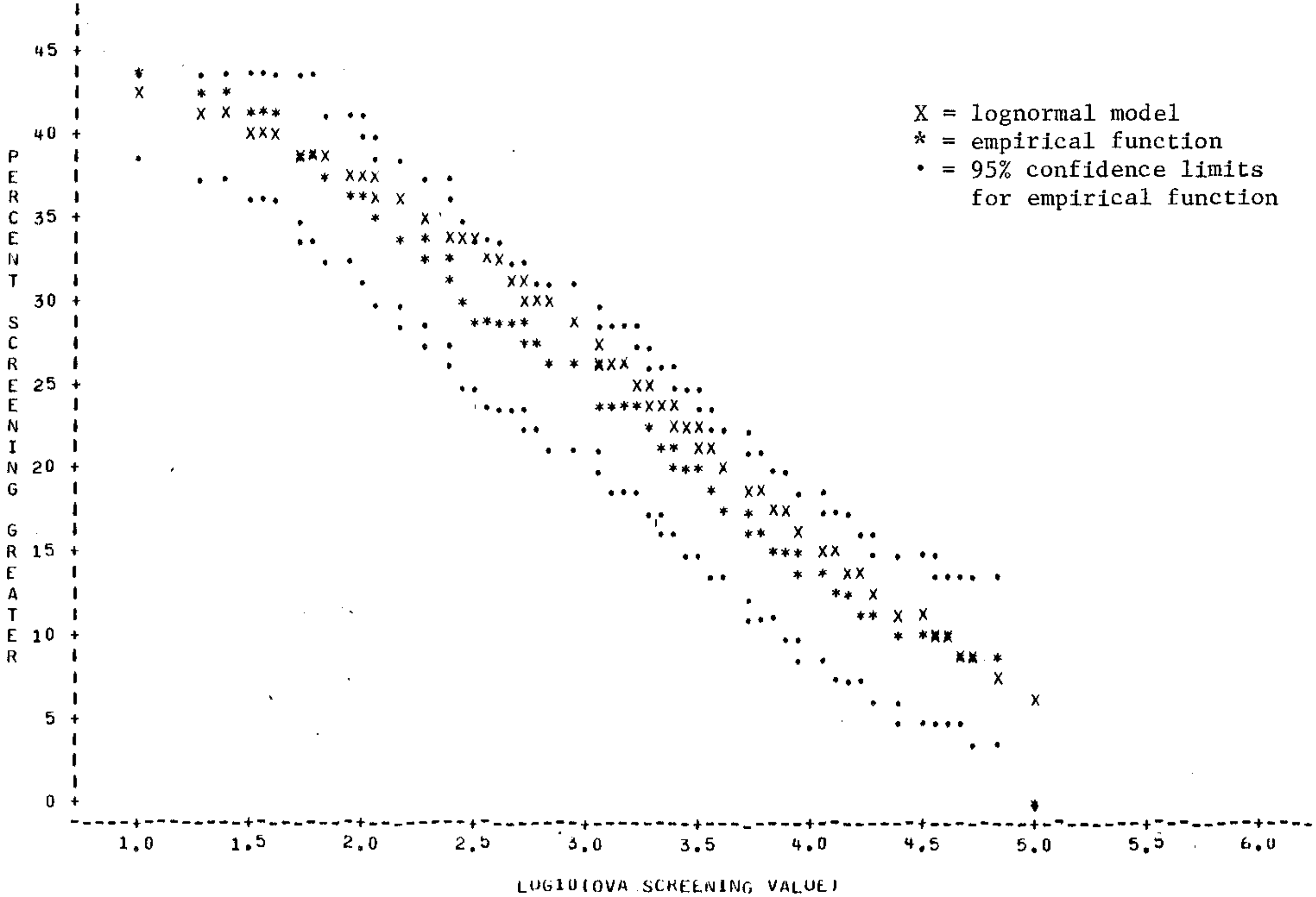


Figure 4-2. Cumulative Distribution of Sources by Screening Values - Cumene Process, Valves in Gas Service

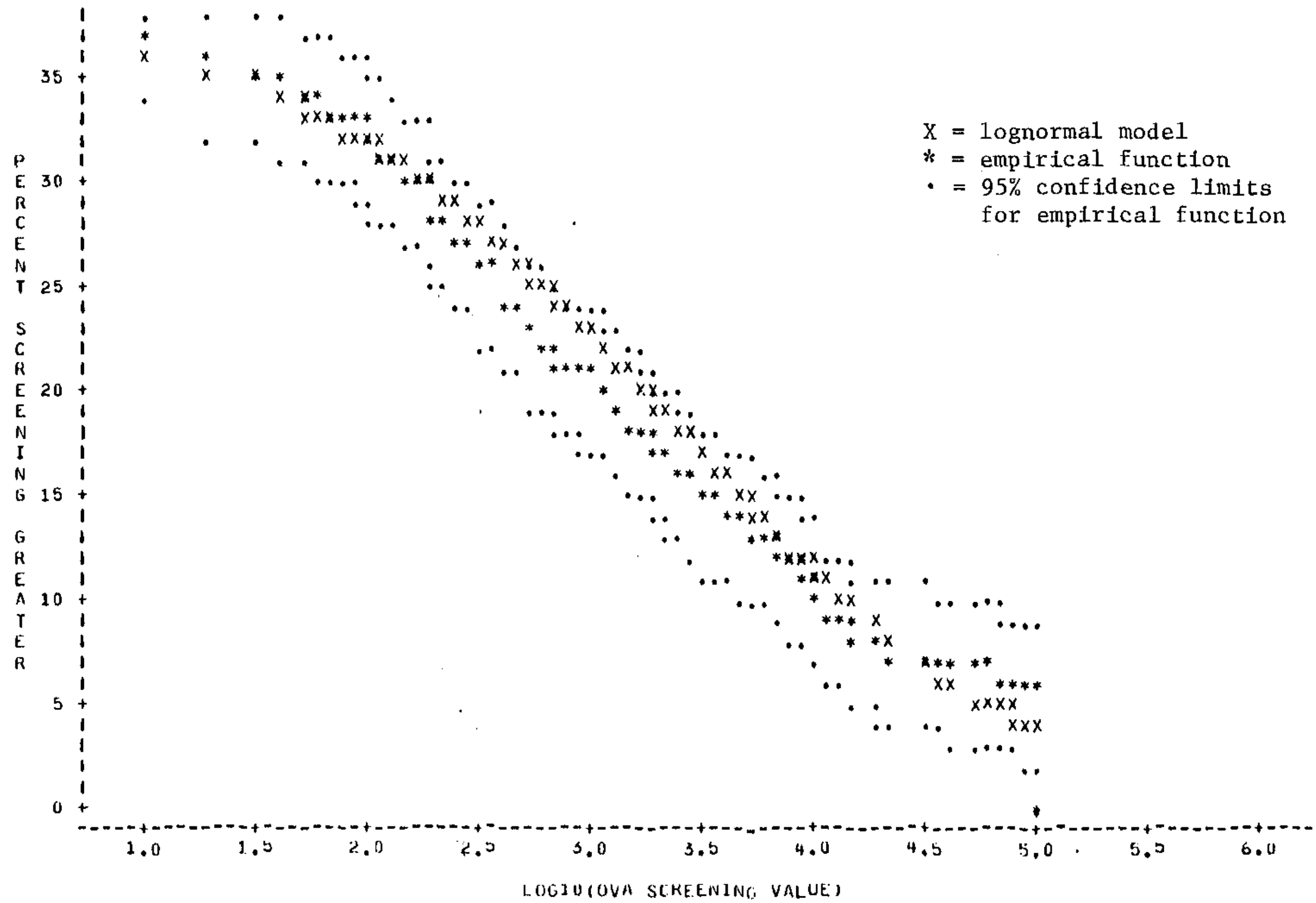


Figure 4-3. Cumulative Distribution of Sources by Screening Values – Cumene Process, Valves in Light Liquid Service

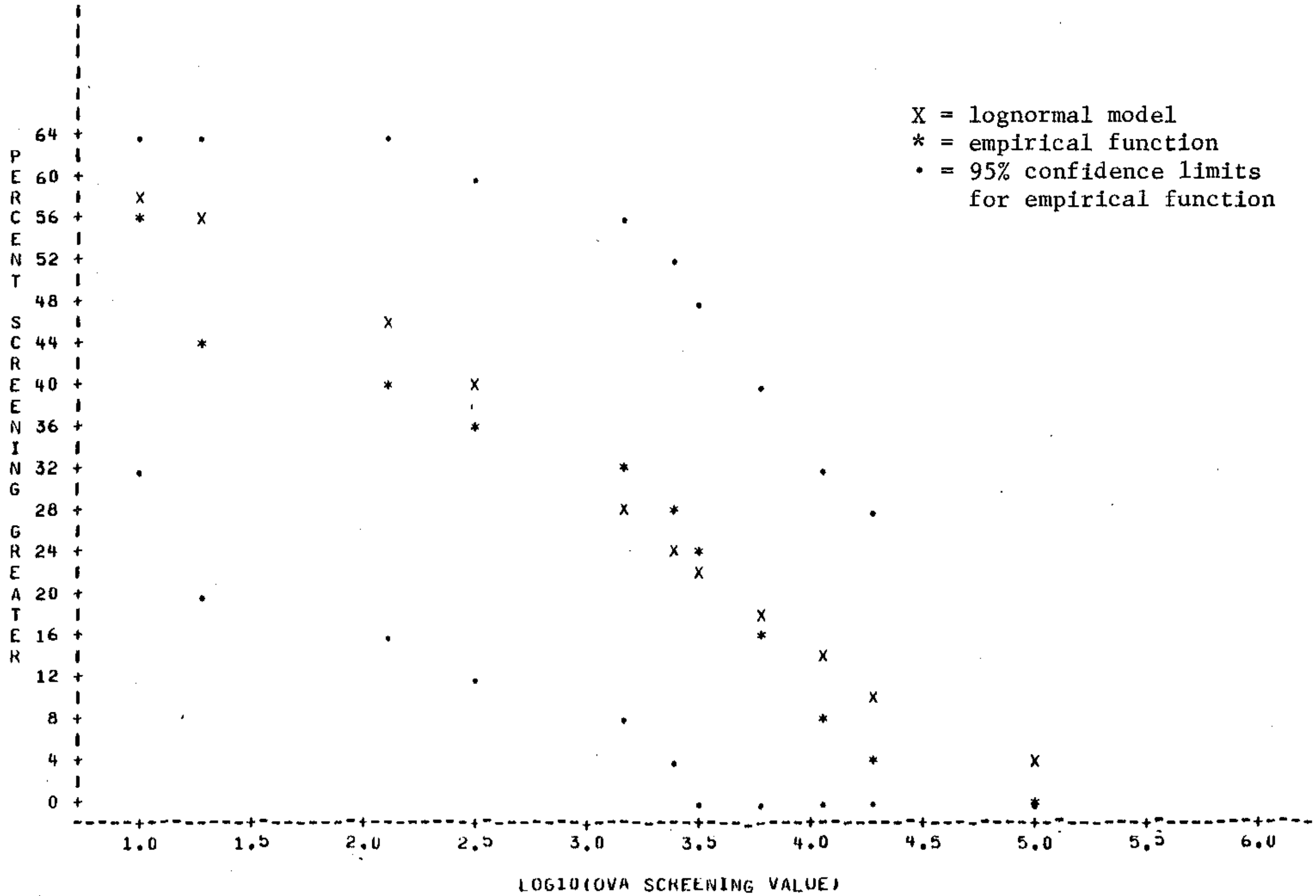


Figure 4-4. Cumulative Distribution of Sources by Screening Values - Cumene Process, Pumps in Light Liquid Service

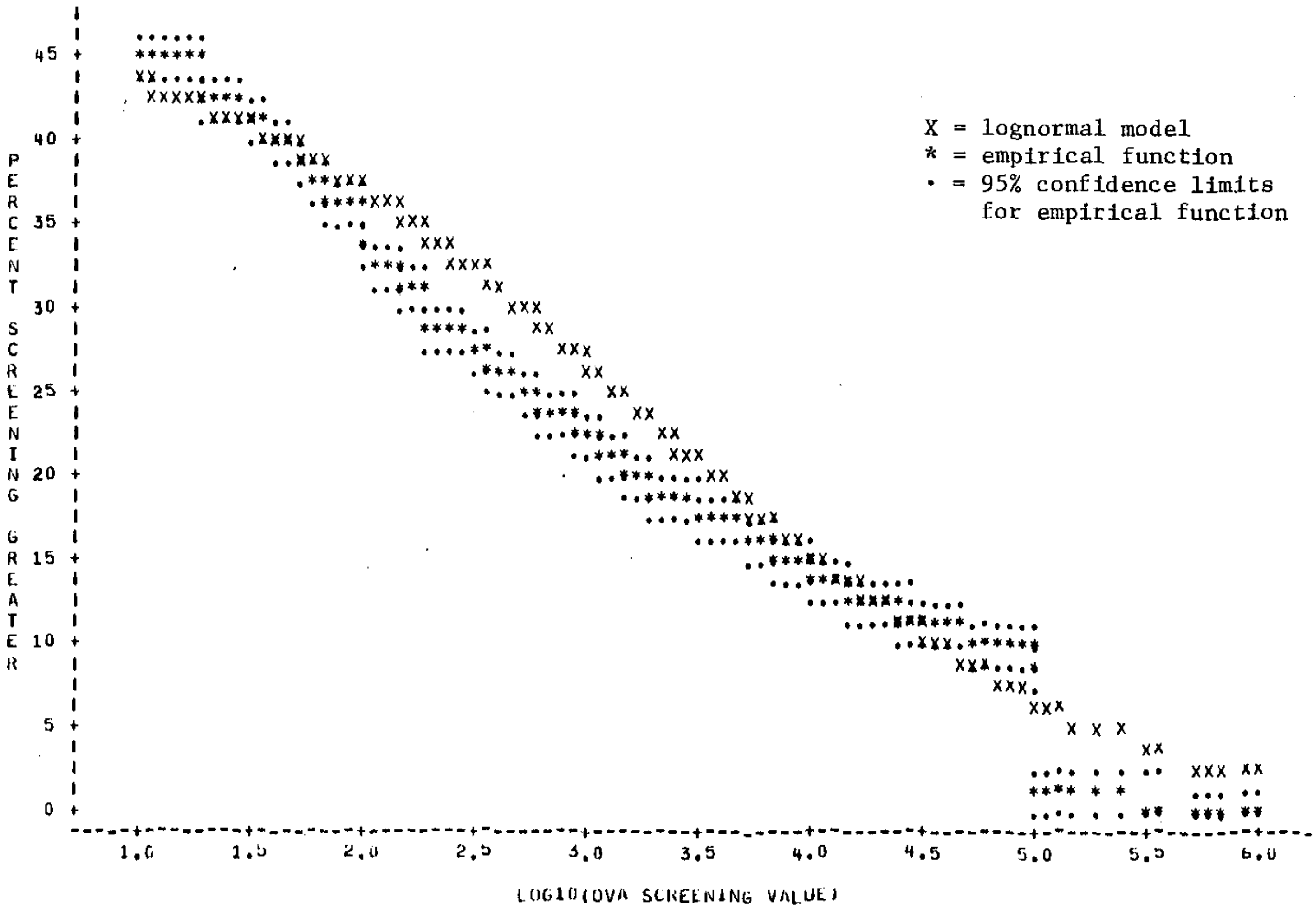


Figure 4-5. Cumulative Distribution of Sources by Screening Values – Ethylene Process, Valves in Gas Service

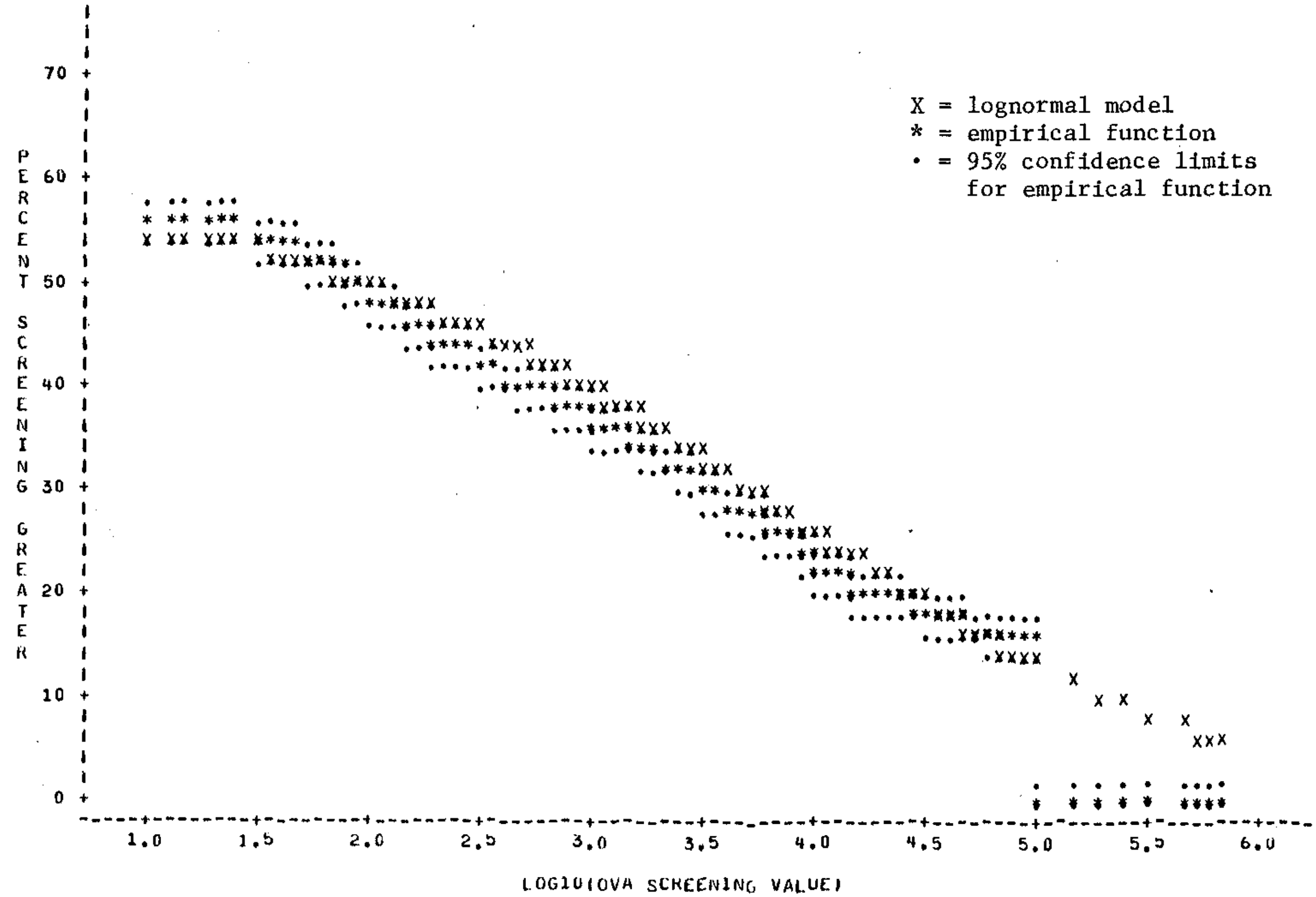


Figure 4-6. Cumulative Distribution of Sources by Screening Values - Ethylene Process, Valves in Light Liquid Service

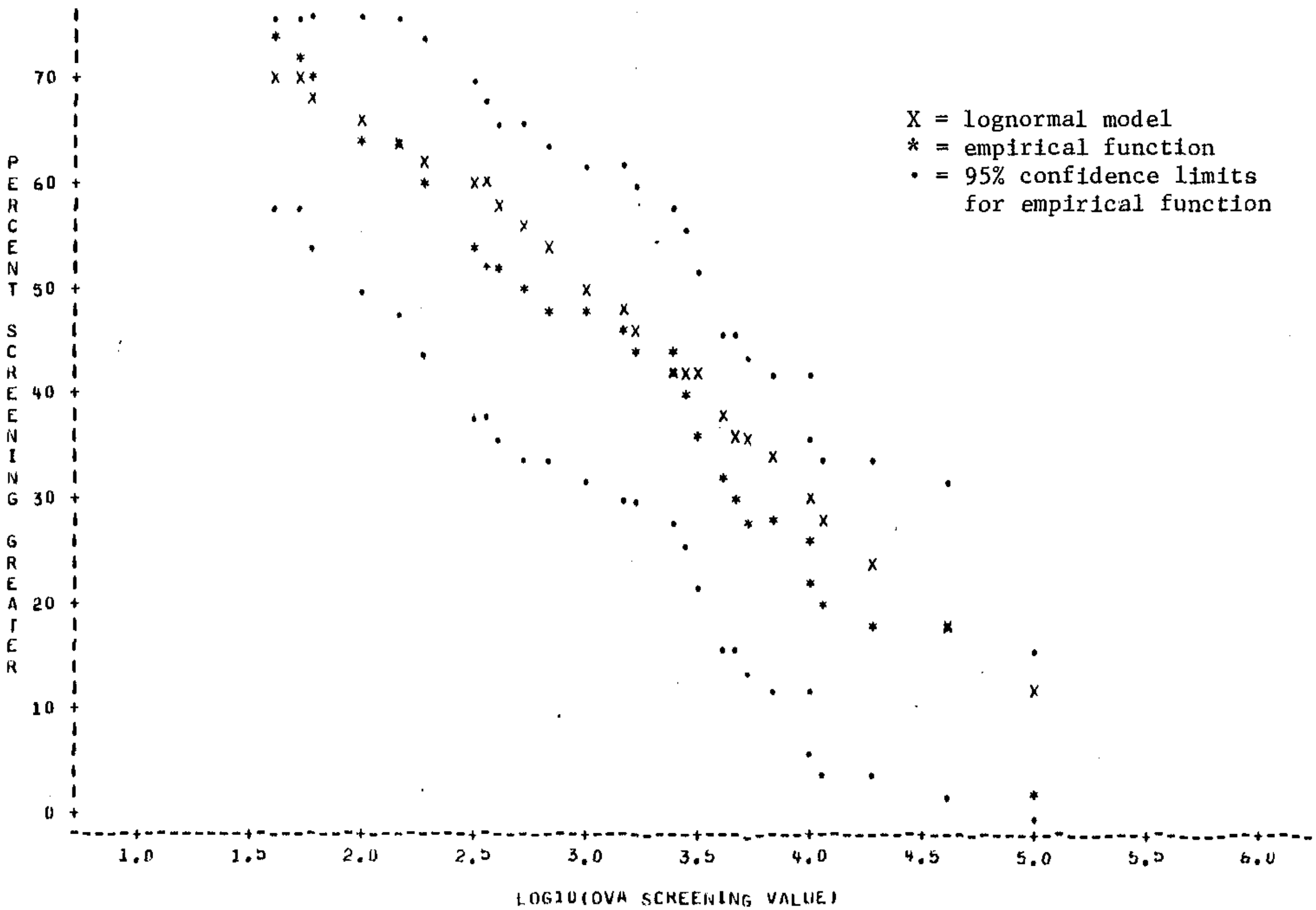


Figure 4-7. Cumulative Distribution of Sources by Screening Values - Ethylene Process, Pumps in Light Liquid Service

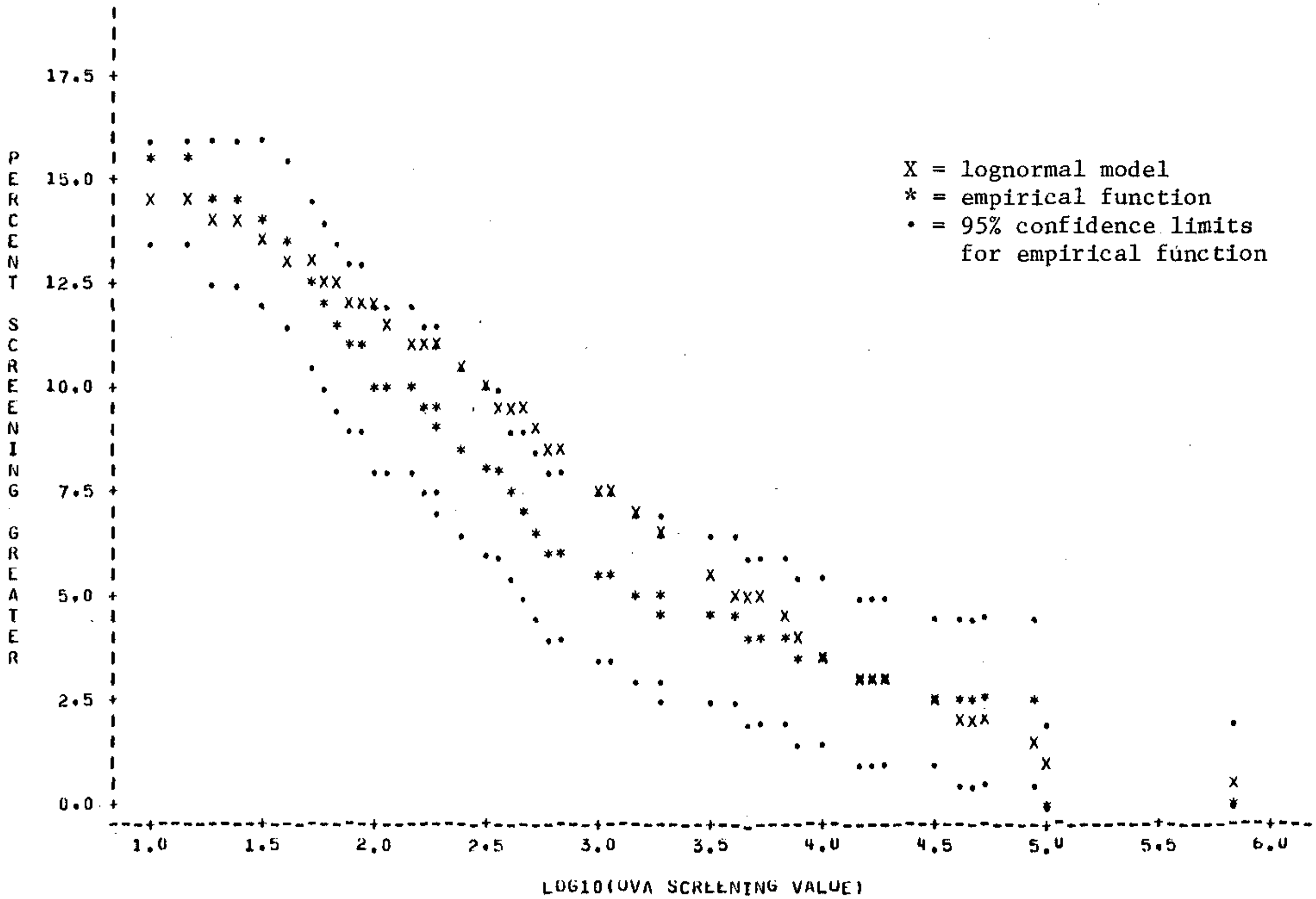


Figure 4-8. Cumulative Distribution of Sources by Screening Values – Vinyl Acetate Process, Valves in Gas Service

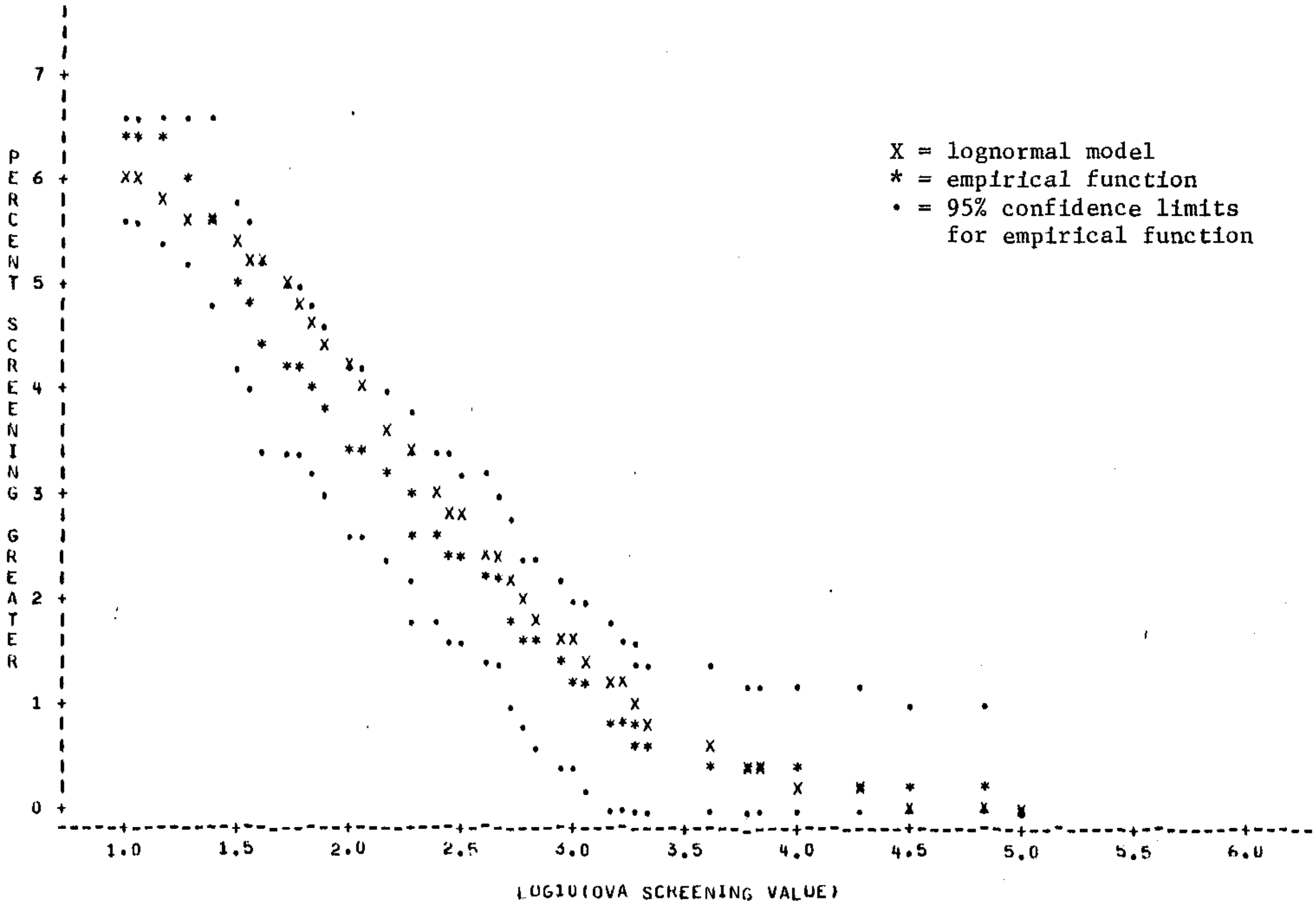


Figure 4-9. Cumulative Distribution of Sources by Screening Values - Vinyl Acetate Process, Valves in Light Liquid Service

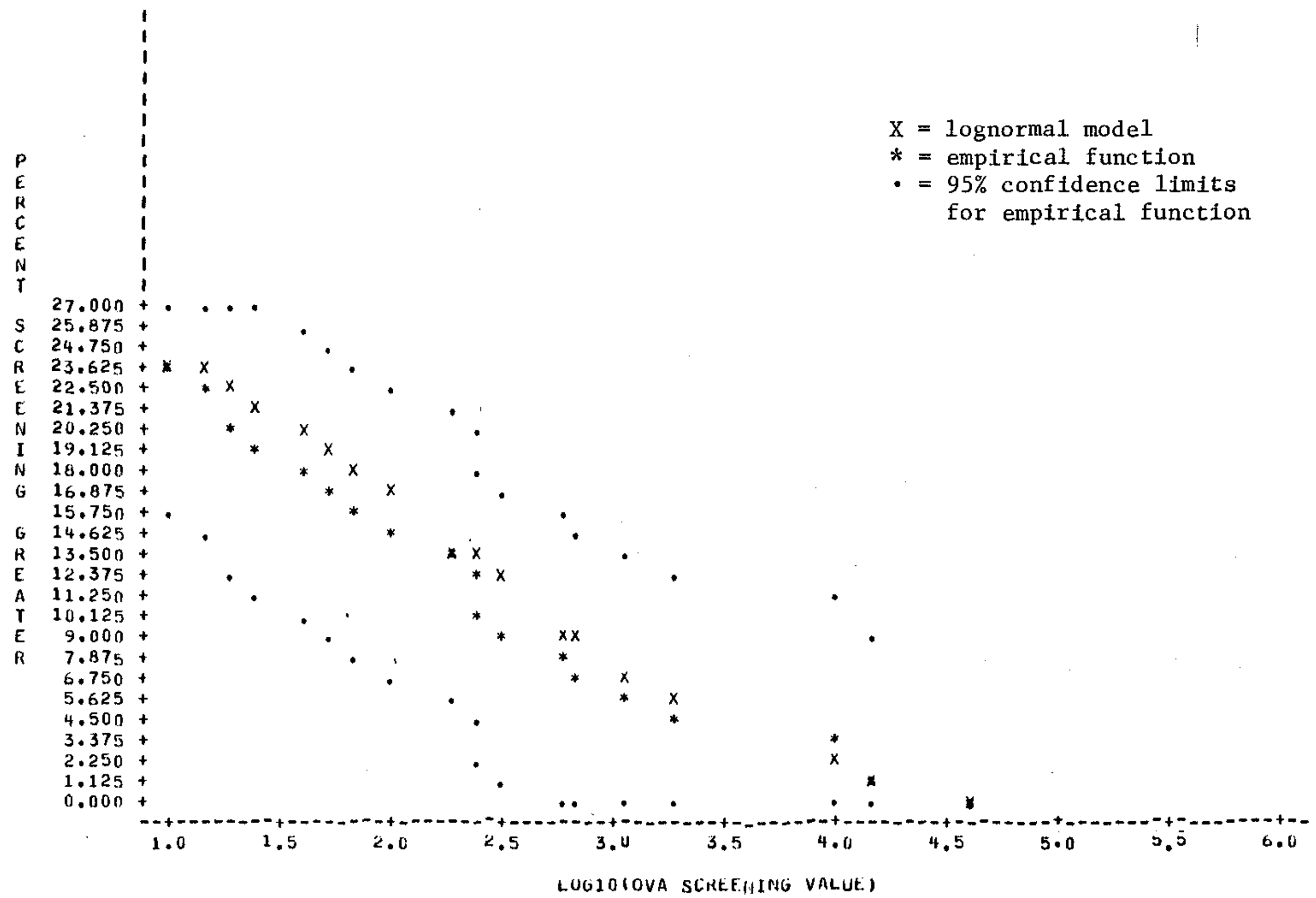


Figure 4-10. Cumulative Distribution of Sources by Screening Values Vinyl Acetate Process, Pumps in Light Liquid Service

TABLE 4-1. ESTIMATED EMISSION FACTORS FOR NONMETHANE HYDROCARBONS FROM VALVES AND PUMP SEALS

		Emission Factor (Confidence Interval)	
Source Type	Number Screened	(lbs./hr./source)	(kg./hr./source)
Valves			
Gas			
Ethylene	6,294	0.024(0.008, 0.07)	0.011(0.004, 0.03)
Cumene	448	0.011(0.003, 0.05)	0.0052(0.001, 0.02)
Vinyl Acetate	949	0.0046(0.001, 0.03)	0.0021(0.0004, 0.01)
Light Liquid			
Ethylene	4,176	0.020(0.007, 0.06)	0.010(0.003, 0.03)
Cumene	799	0.0056(0.002, 0.02)	0.0025(0.001, 0.01)
Vinyl Acetate	2,137	0.0003(0.0001, 0.002)	0.0001(0.00003, 0.001)
Pump Seals			
Light Liquid			
Ethylene	76	0.069(0.006, 0.8)	0.031(0.003, 0.4)
Cumene	25	0.052(0.001, 2.7)	0.023(0.0004, 1.2)
Vinyl Acetate	89	0.0043(0.0001, 0.1)	0.0020(0.00006, 0.06)

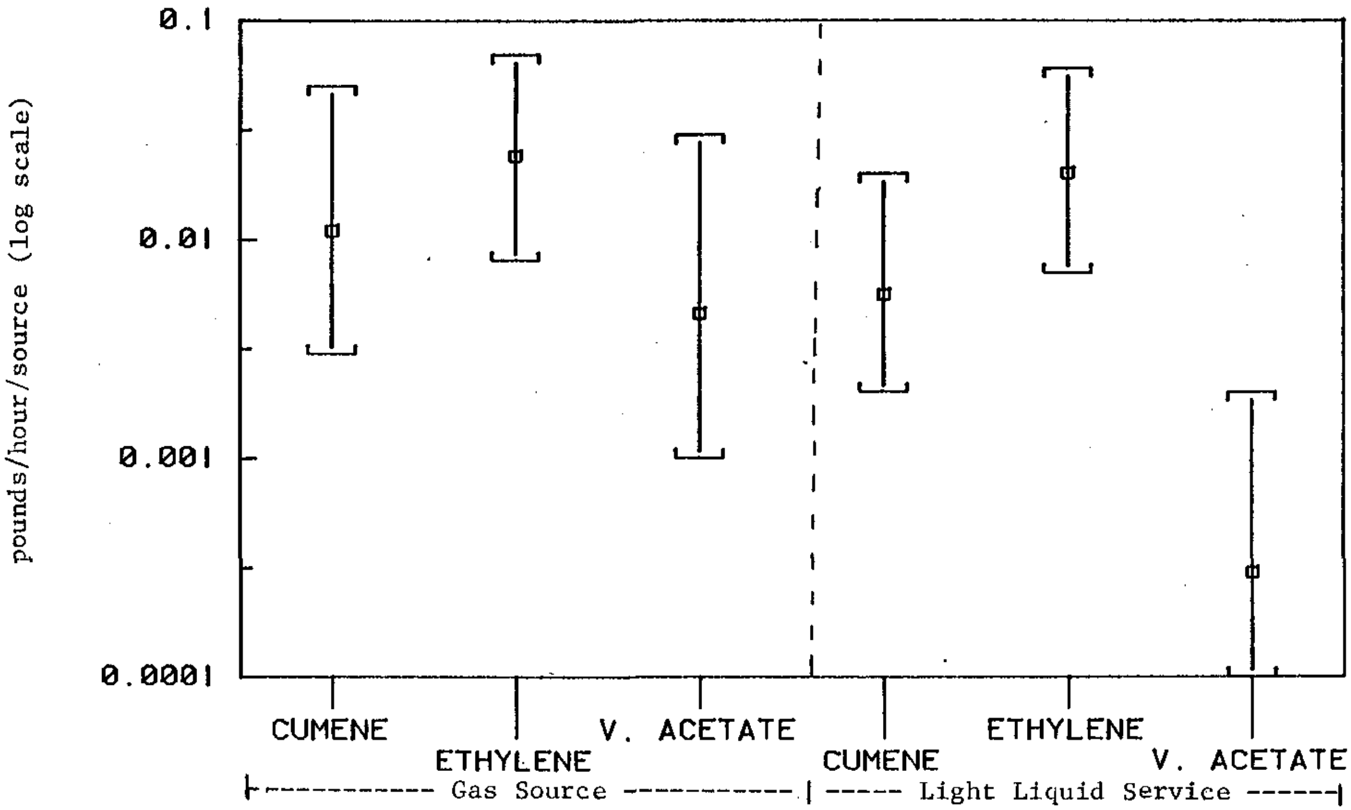


Figure 4-11. Emission Factors--Valves

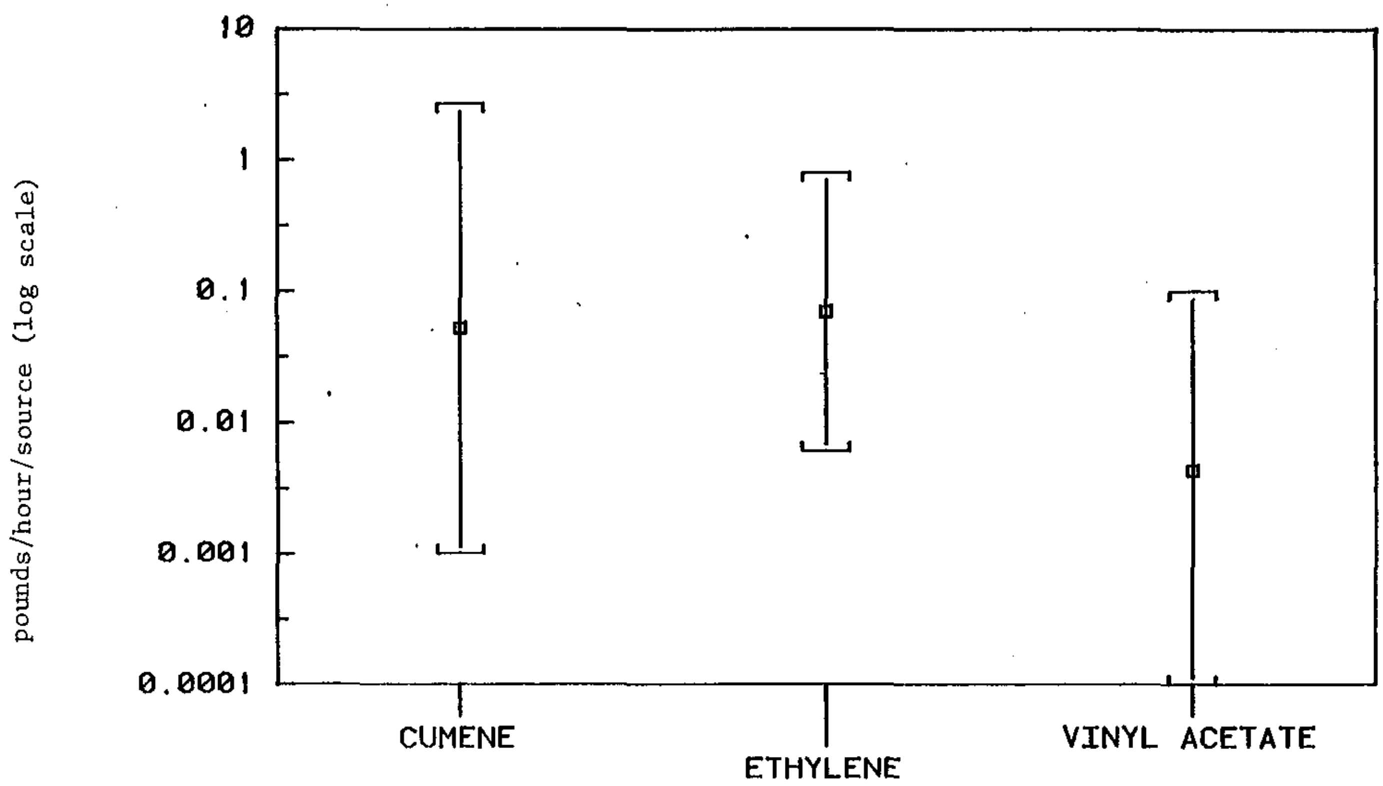


Figure 4-12. Emission Factors--Pump Seals

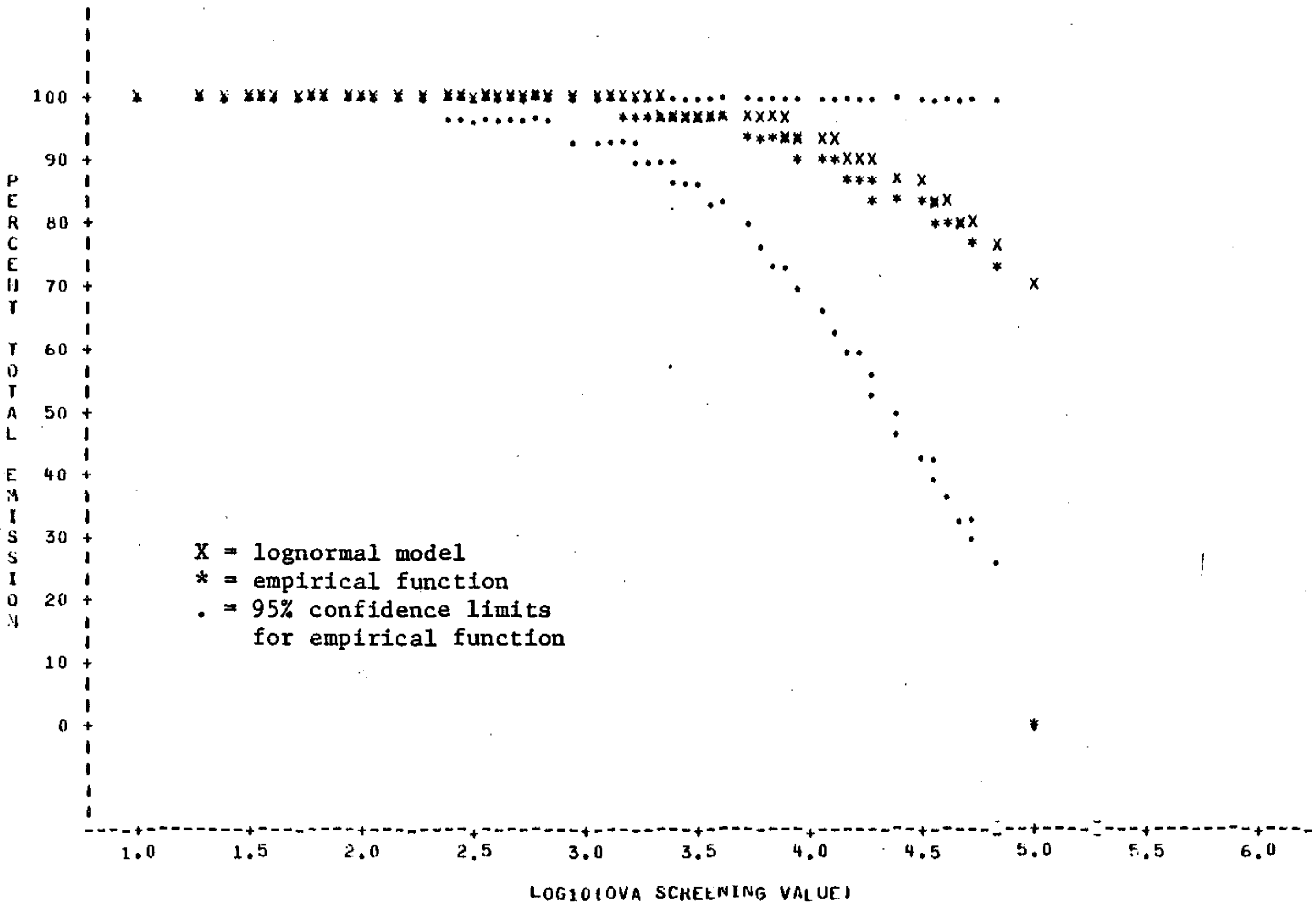


Figure 4-13. Cumulative Distribution of Total Emissions by Screening Values Cumene Process, Valves in Gas Service

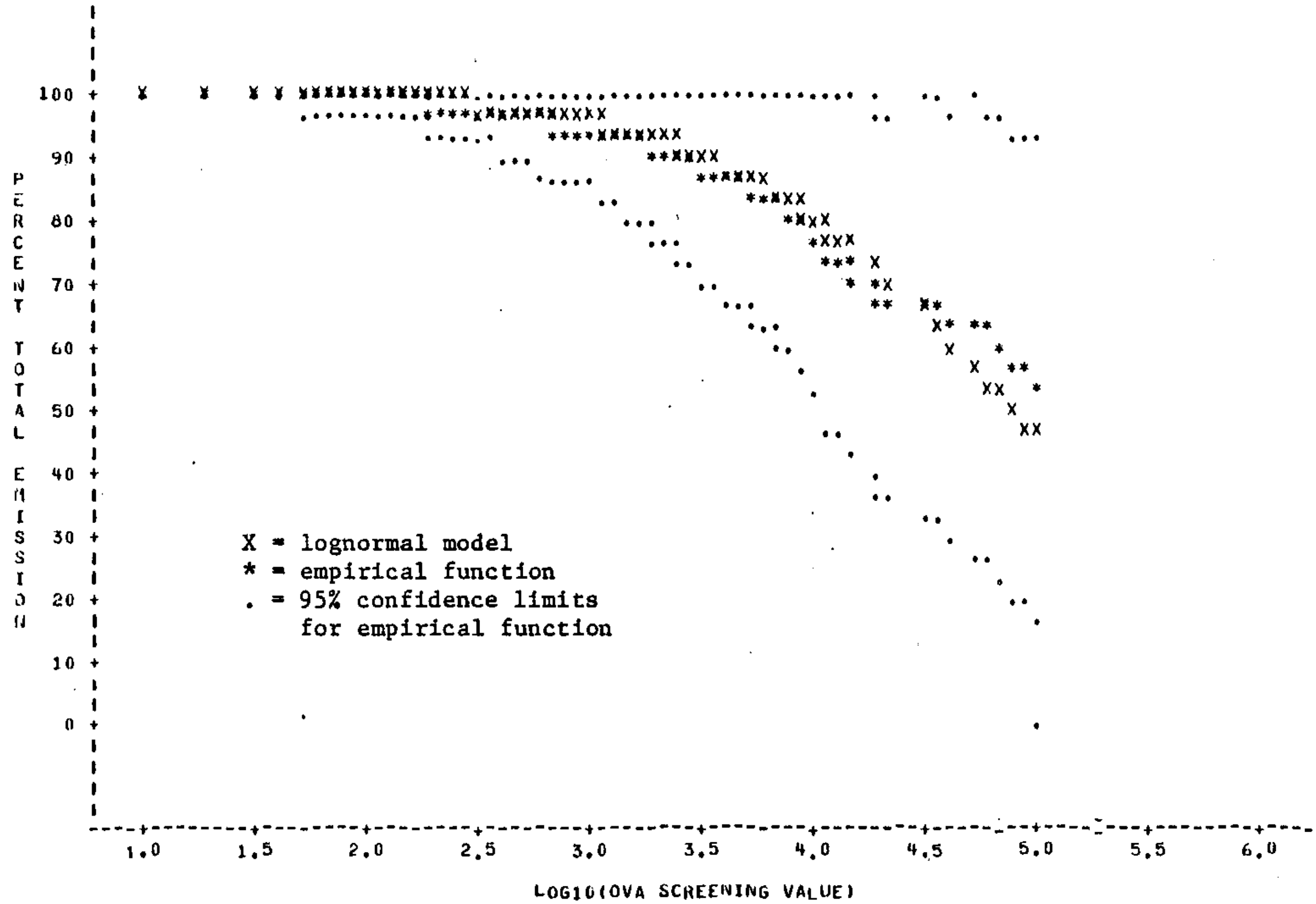


Figure 4-14. Cumulative Distribution of Total Emissions by Screening Values Cumene Process, Valves in Light Liquid Service

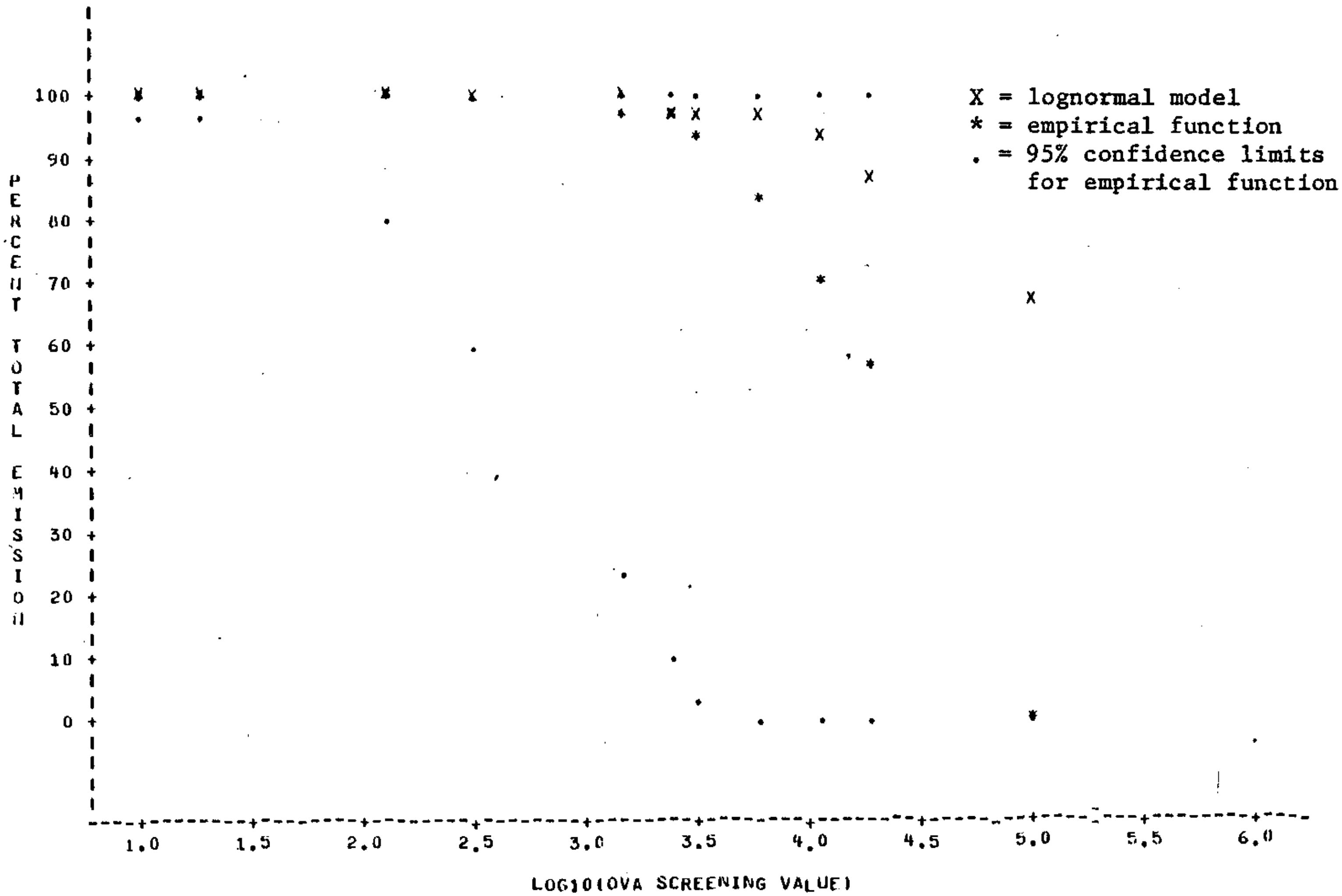


Figure 4-15. Cumulative Distribution of Total Emissions by Screening Values
Cumene Process, Pumps in Light Liquid Service

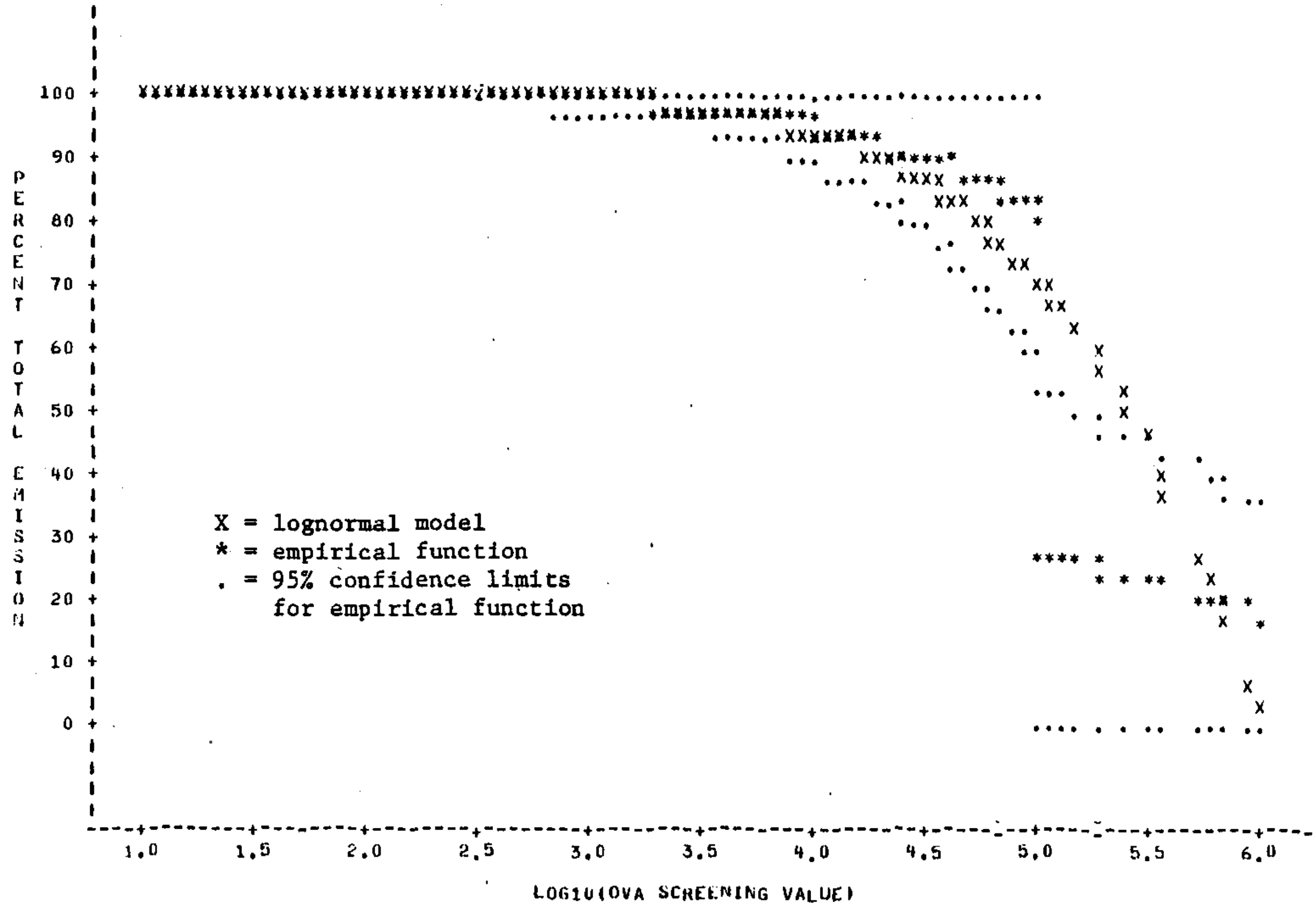


Figure 4-16. Cumulative Distribution of Total Emissions by Screening Values
Ethylene Process, Valves in Gas Service

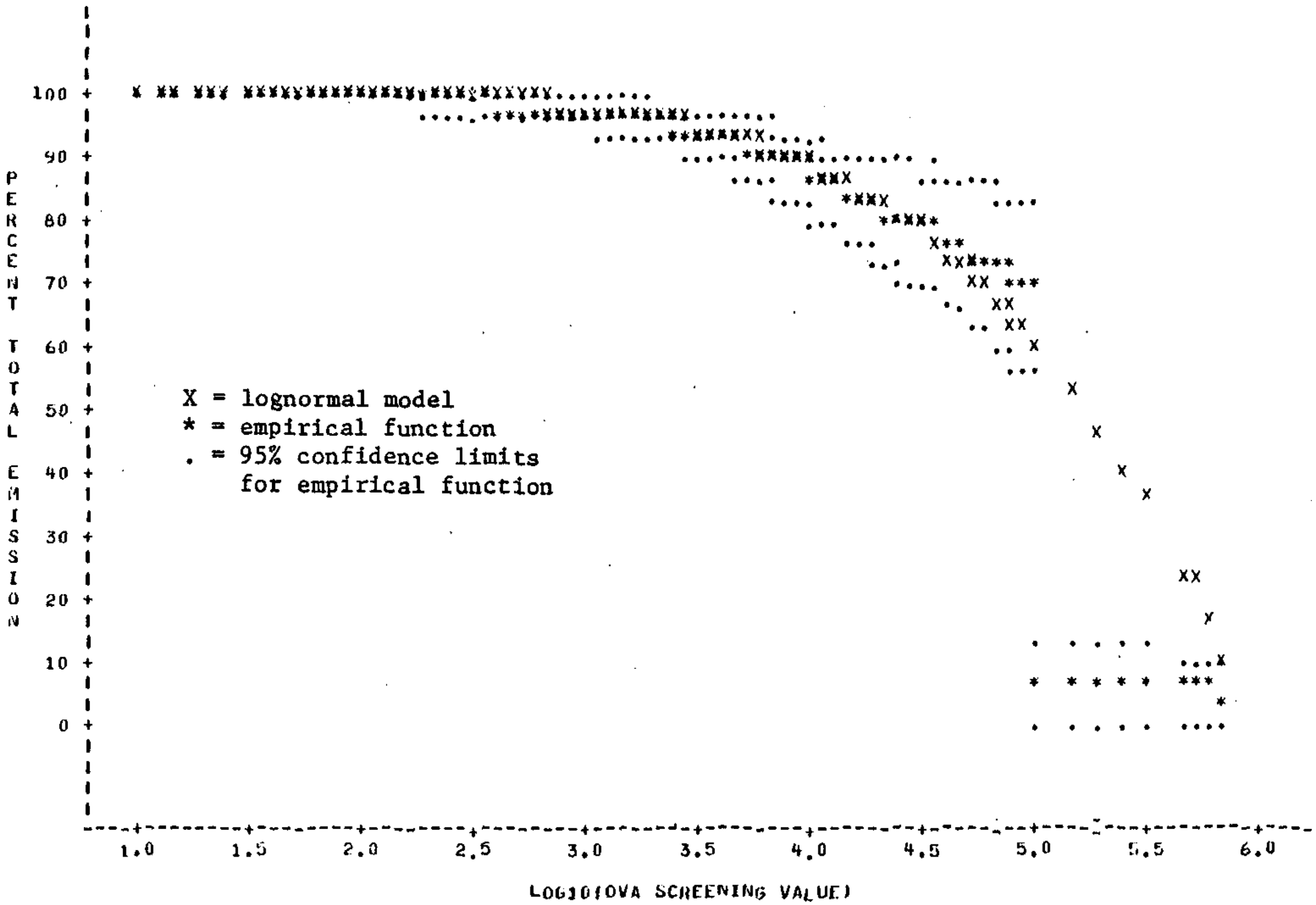


Figure 4-17. Cumulative Distribution of Total Emissions by Screening Values Ethylene Process, Valves in Light Liquid Service

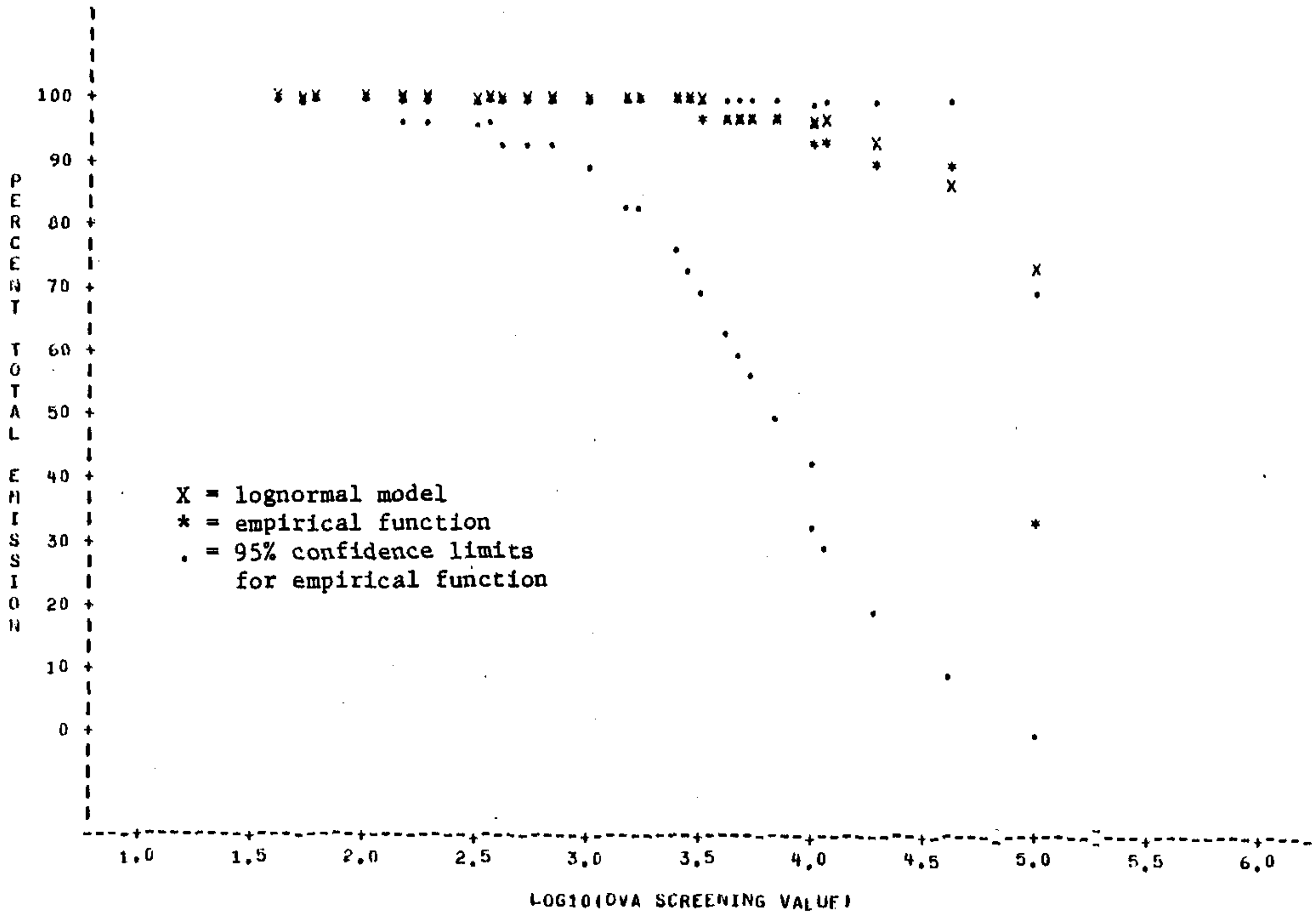


Figure 4-18. Cumulative Distribution of Total Emissions by Screening Values Ethylene Process, Pumps in Light Liquid Service

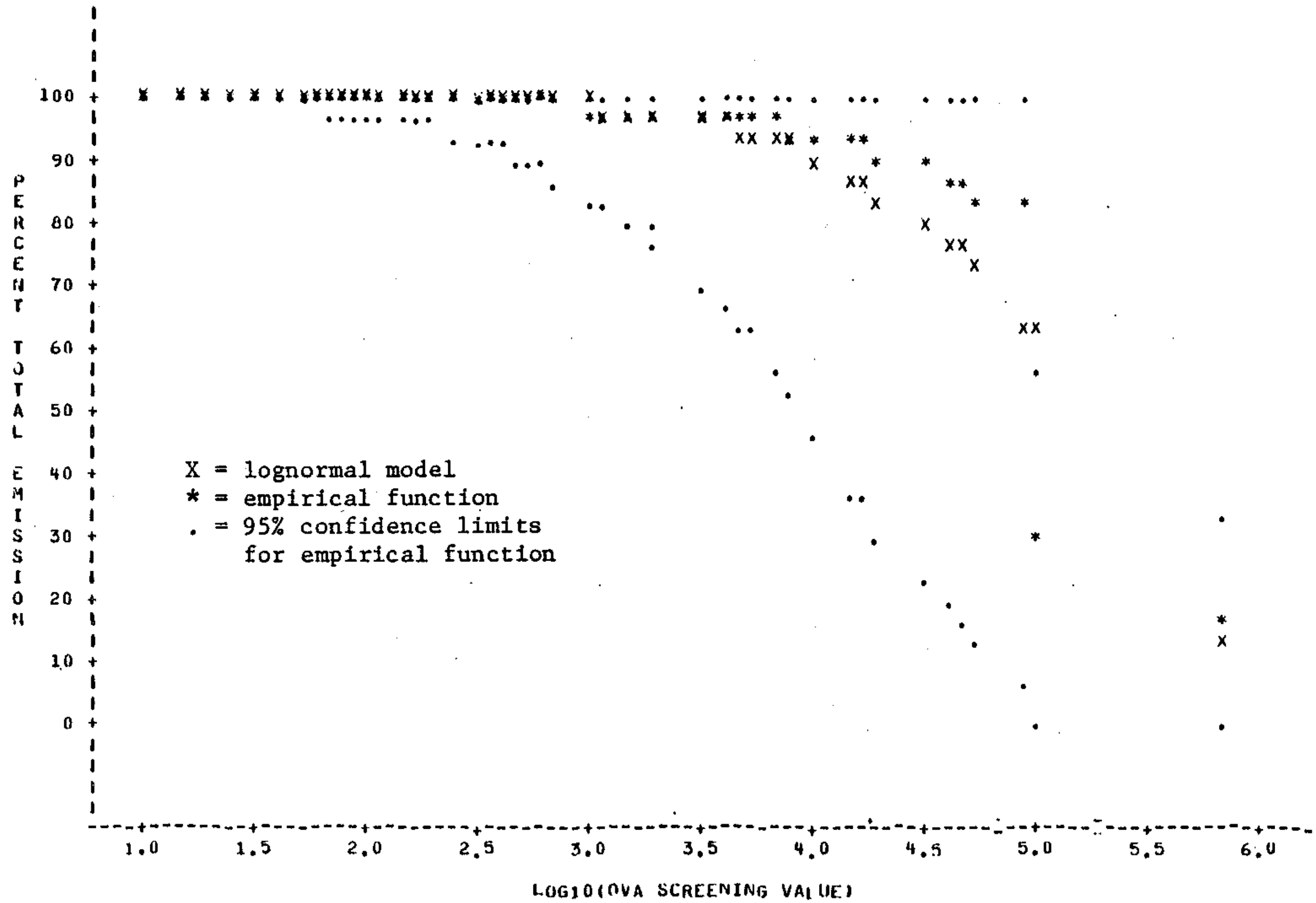


Figure 4-19. Cumulative Distribution of Total Emissions by Screening Values Vinyl Acetate Process, Valves with Light Liquid Service

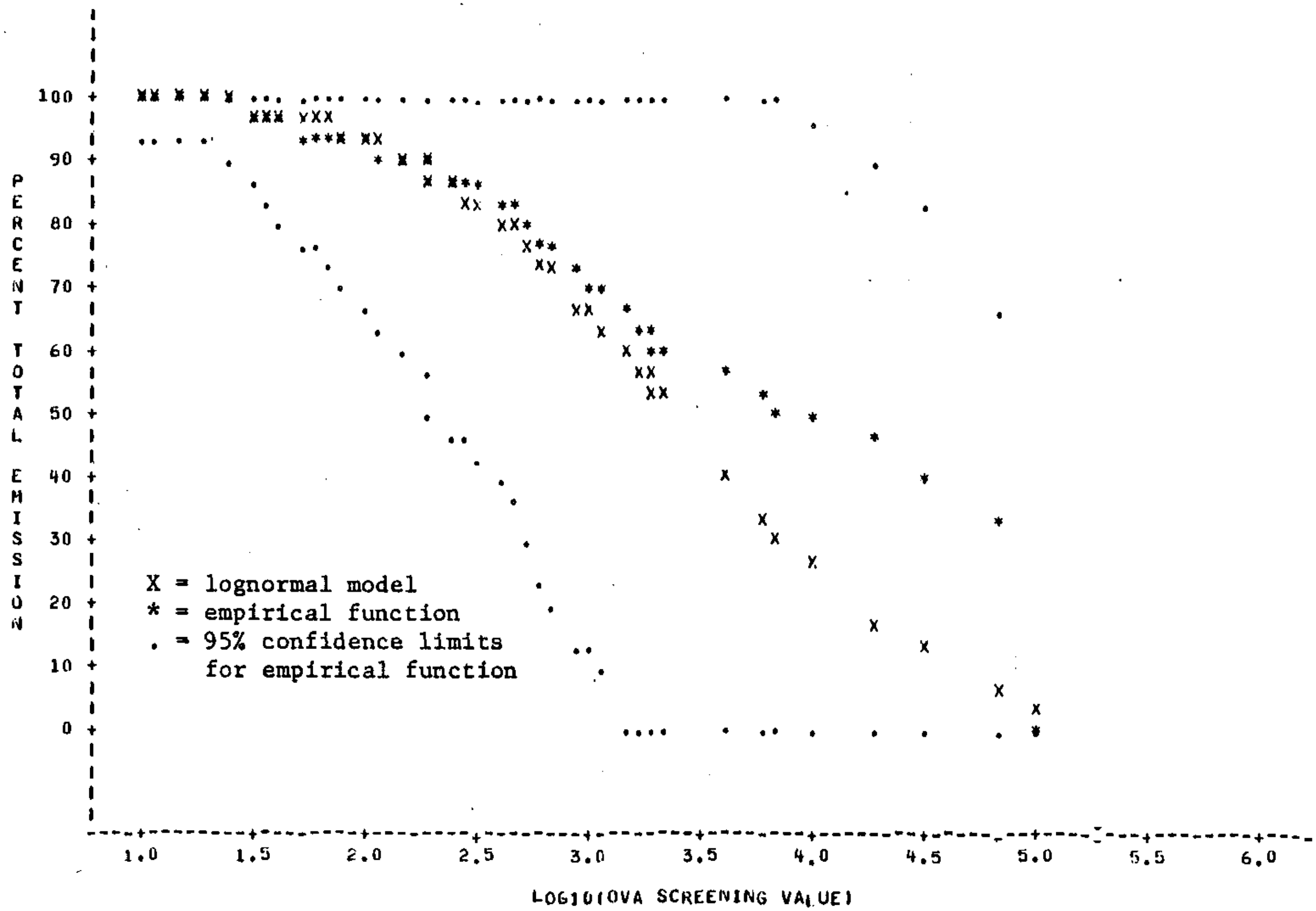


Figure 4-20. Cumulative Distribution of Total Emissions by Screening Values Vinyl Acetate Process, Valves in Light Liquid Service

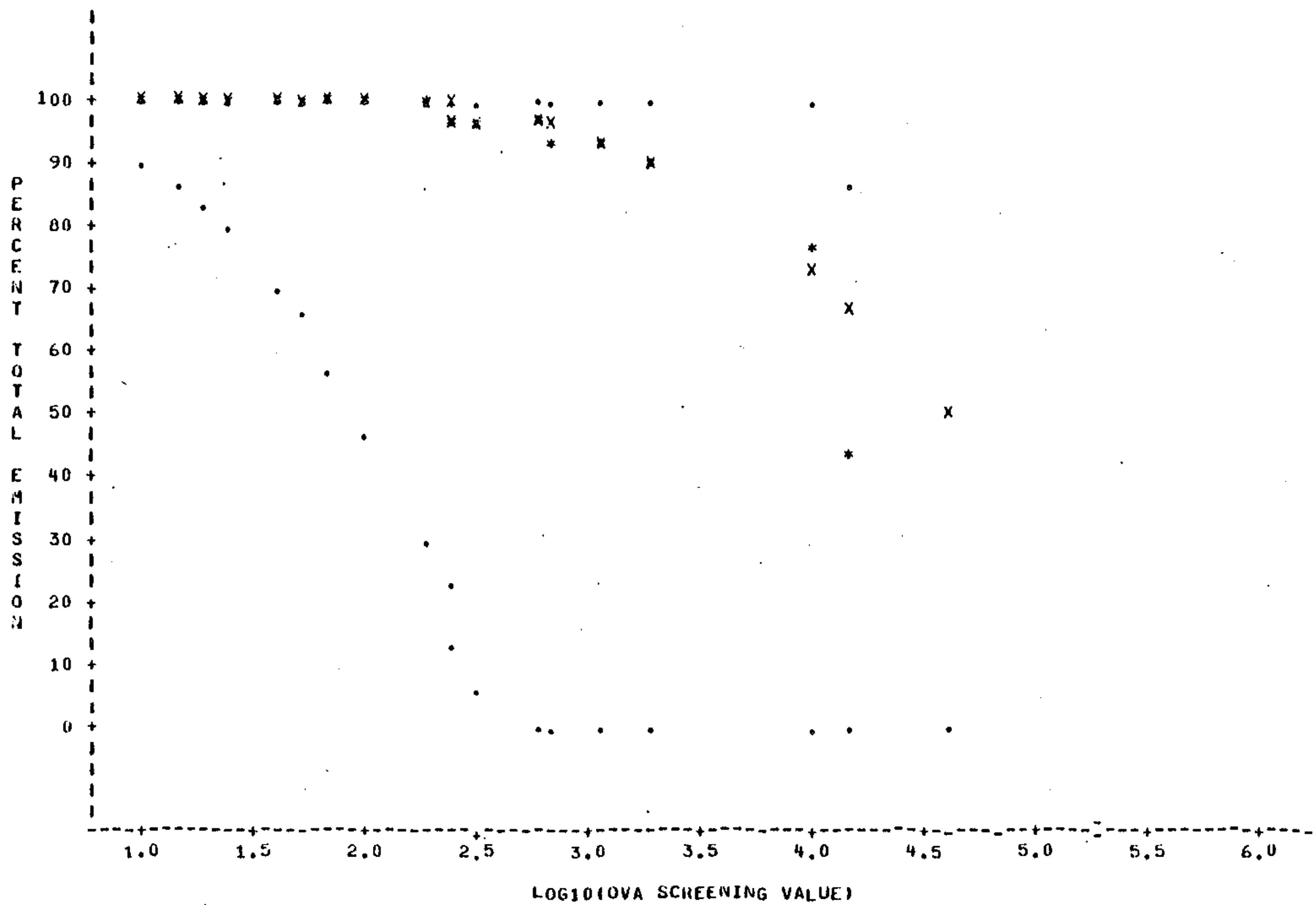


Figure 4-21. Cumulative Distribution of Total Emissions by Screening Values Vinyl Acetate Process, Pumps in Light Liquid Service

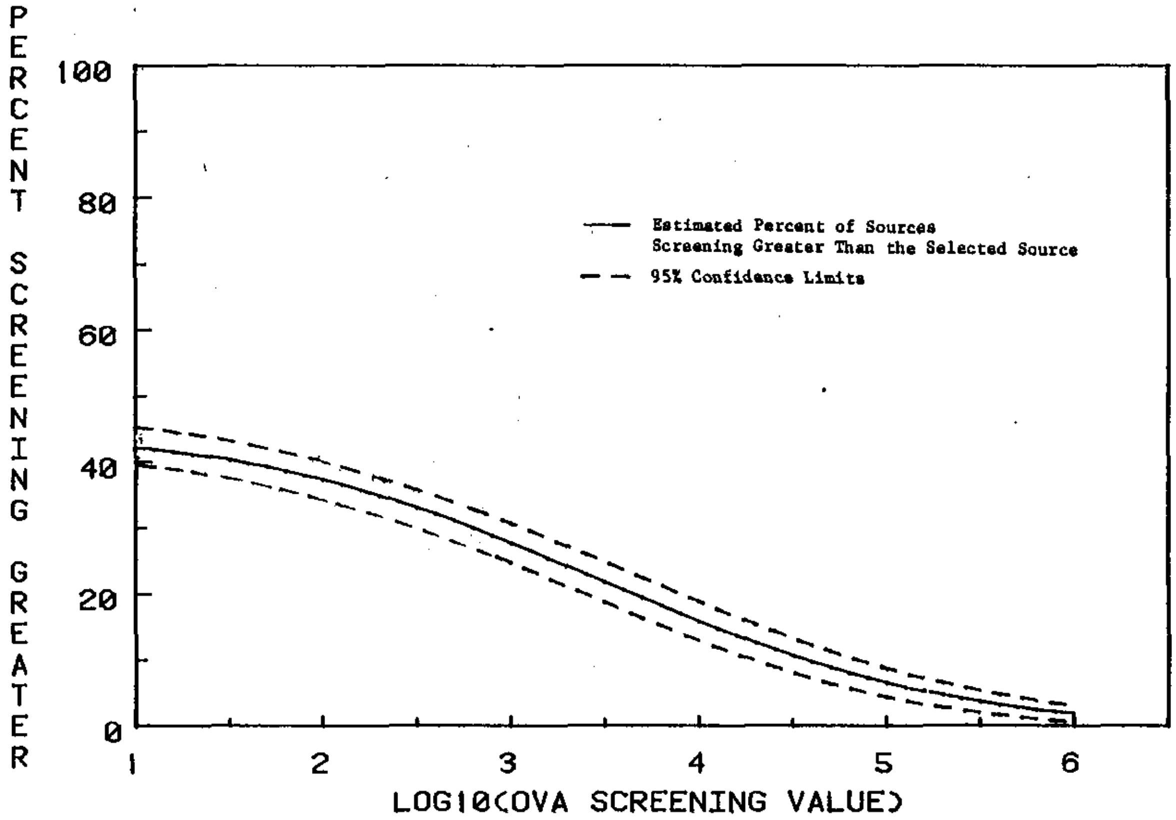


Figure 4-22a. Cumulative Distribution of Sources by Screening Values Cumene Process, Valves in Gas Service

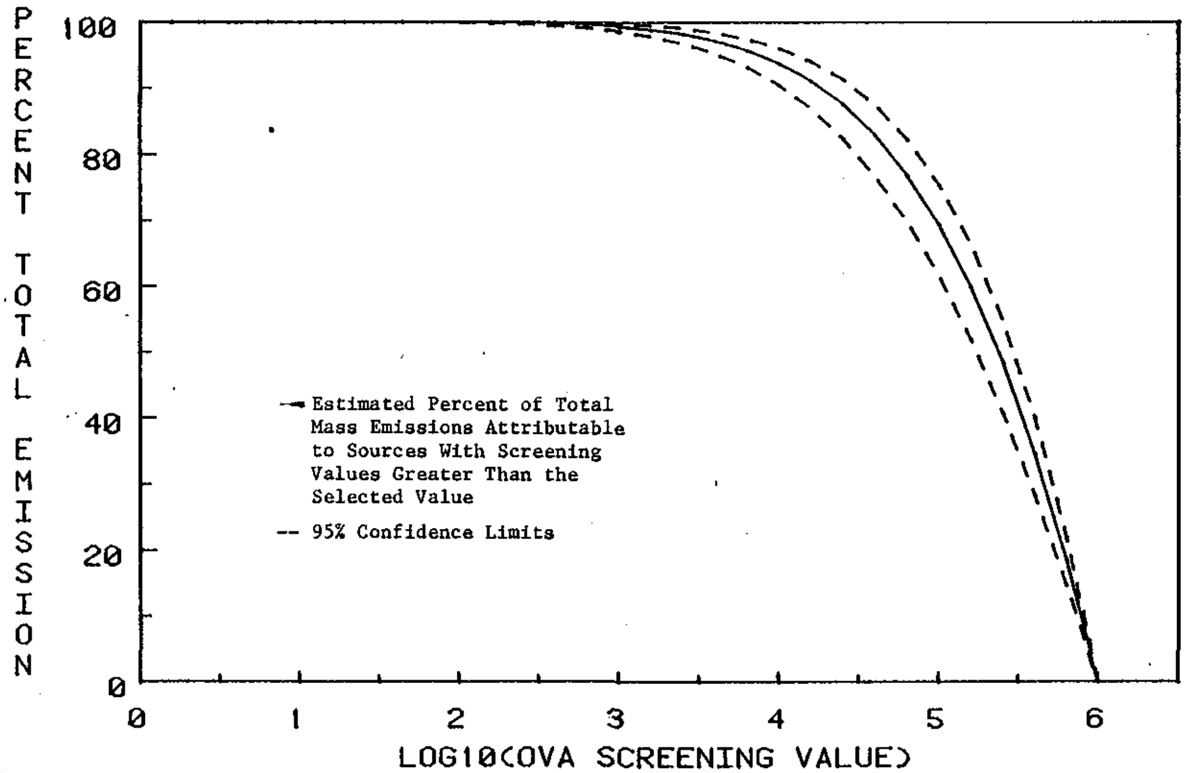


Figure 4-22b. Cumulative Distribution of Total Emissions by Screening Values - Cumene Process, Valves in Gas Service

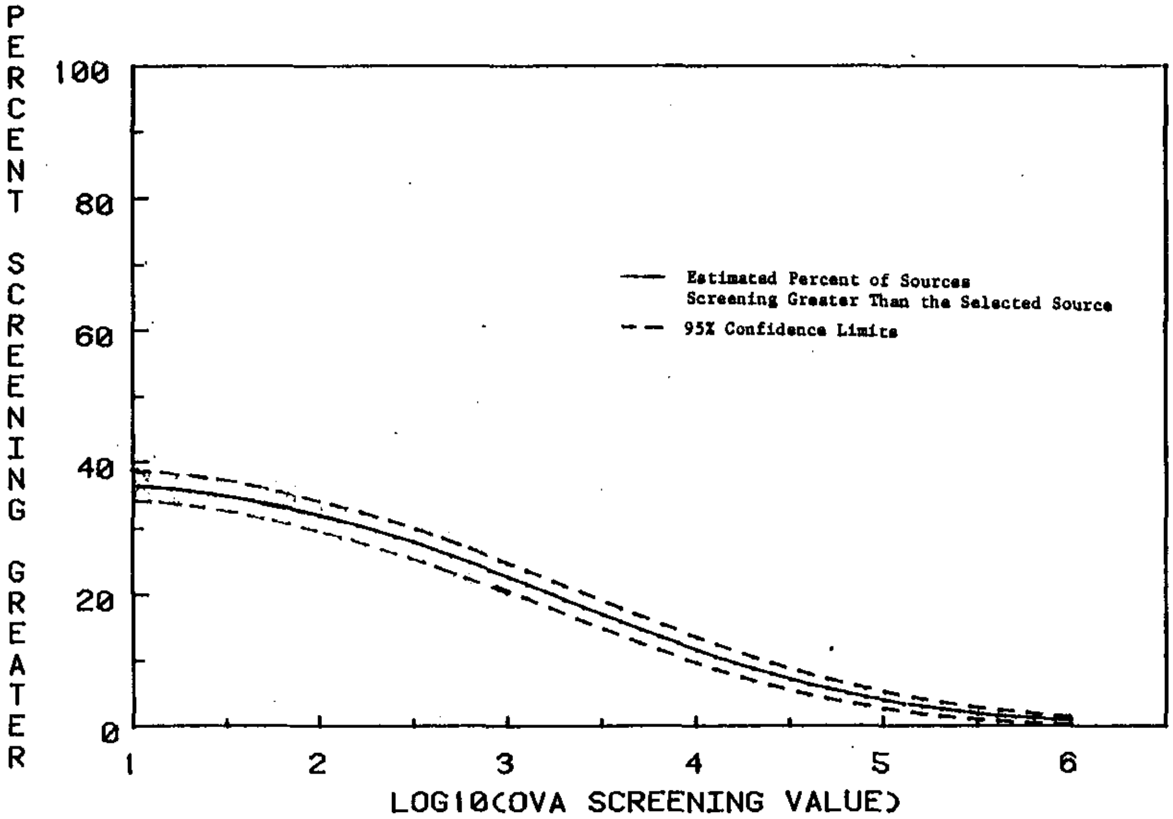


Figure 4-23a. Cumulative Distribution of Sources by Screening Values Cumene Process, Valves in Light Liquid Service

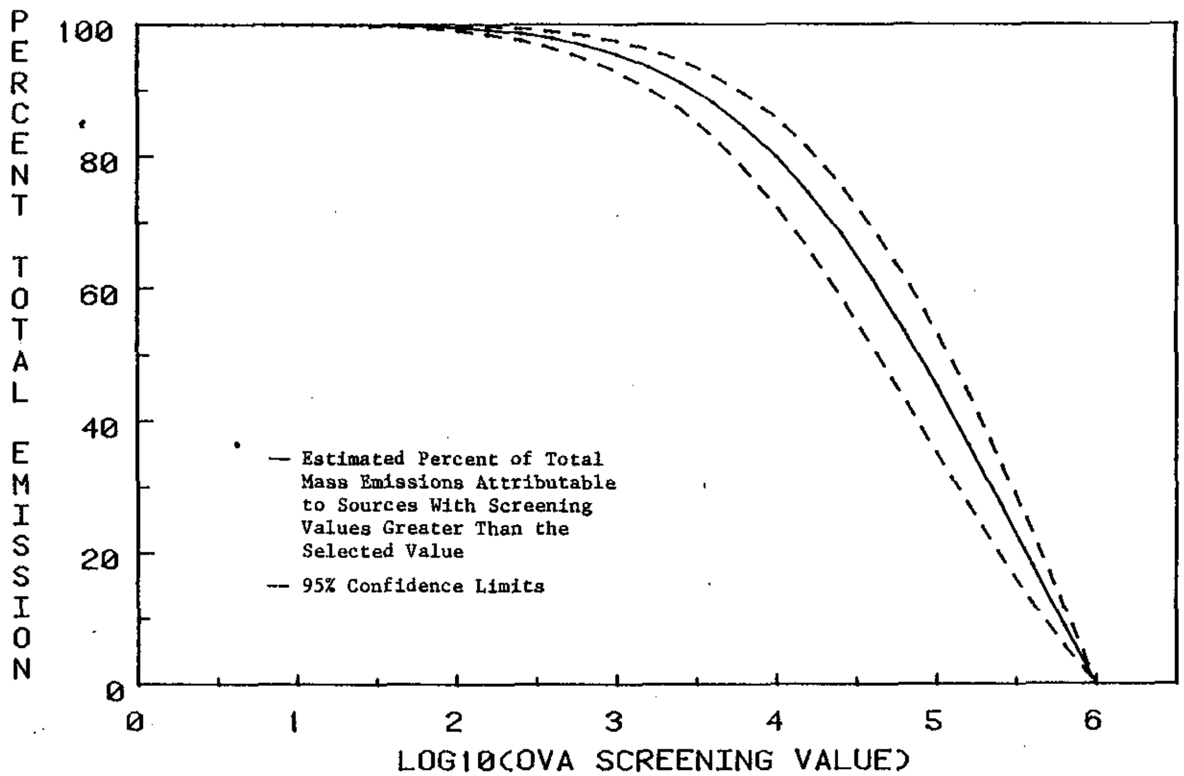


Figure 4-23b. Cumulative Distribution of Total Emissions by Screening Values - Cumene Process, Valves in Light Liquid Service

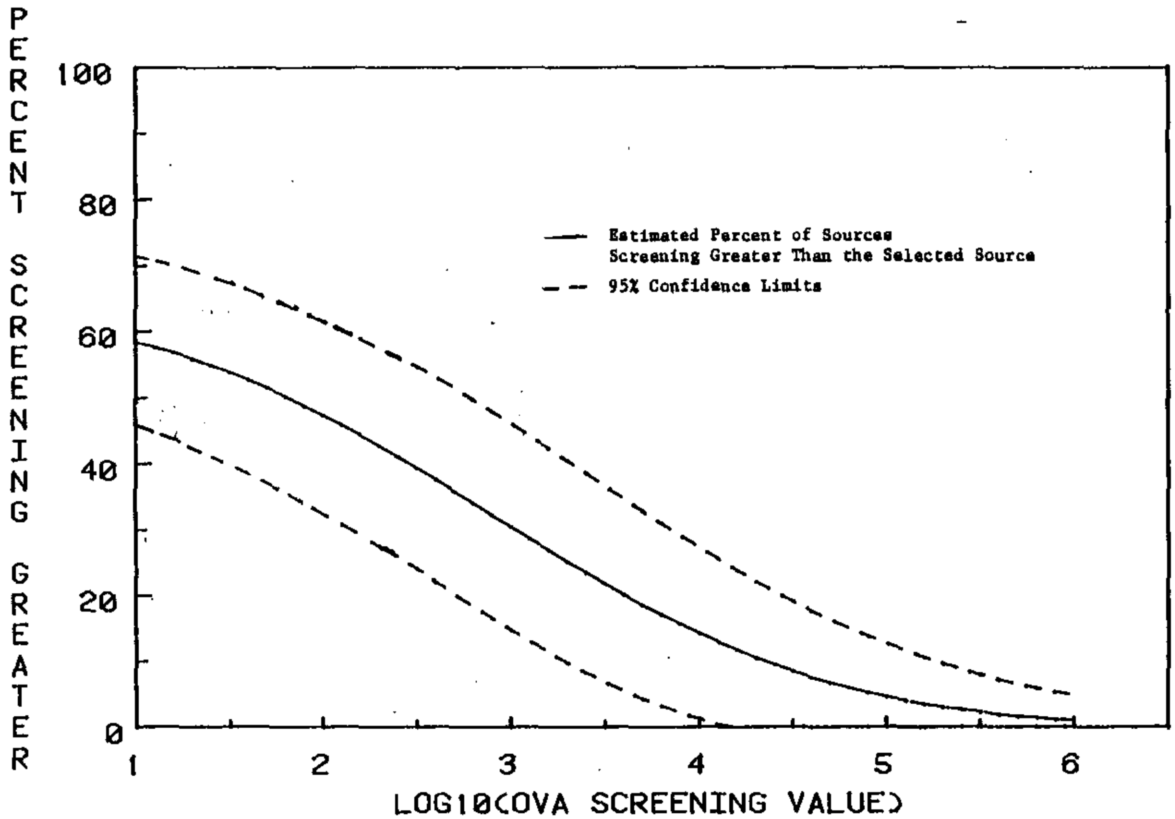


Figure 4-24a. Cumulative Distribution of Sources by Screening Values Cumene Process, Pumps in Light Liquid Service

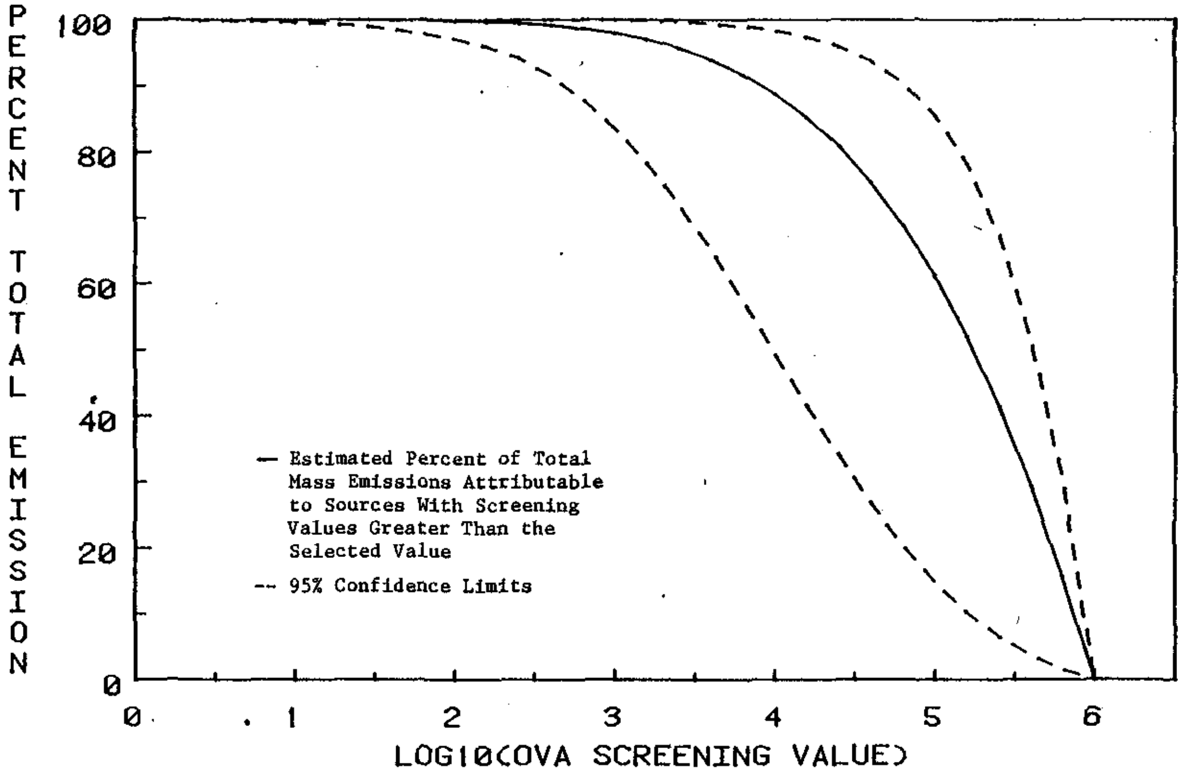


Figure 4-24b. Cumulative Distribution of Total Emissions by Screening Values - Cumene Process, Pumps in Light Liquid Service

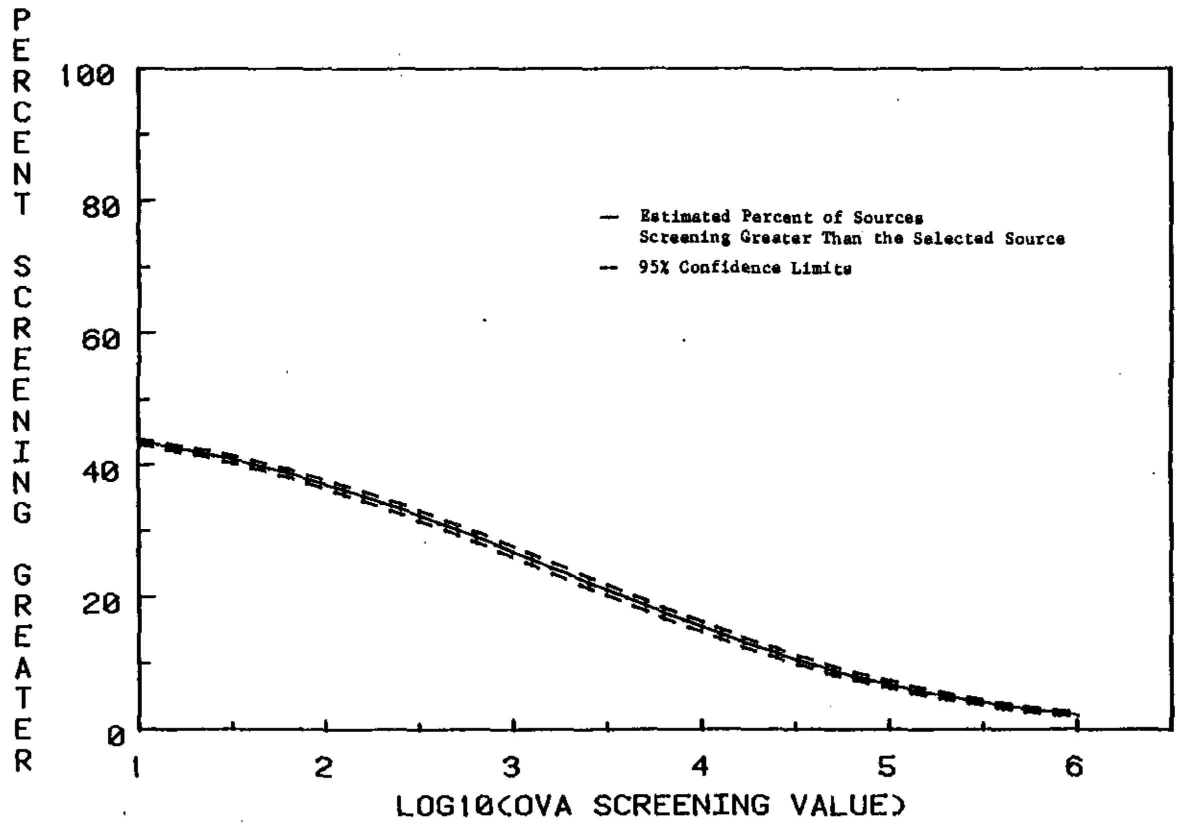


Figure 4-25a. Cumulative Distribution of Sources by Screening Values Ethylene Process, Valves in Gas Service

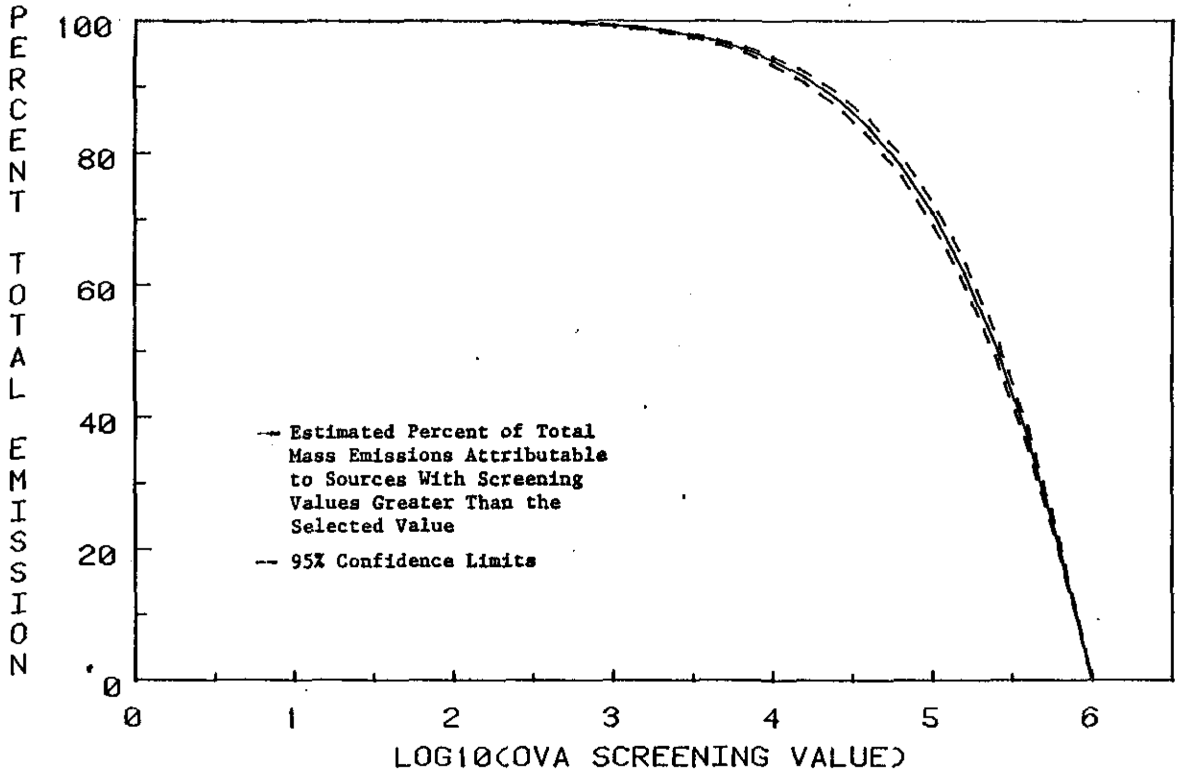


Figure 4-25b. Cumulative Distribution of Total Emissions by Screening Values - Ethylene Process, Valves in Gas Service

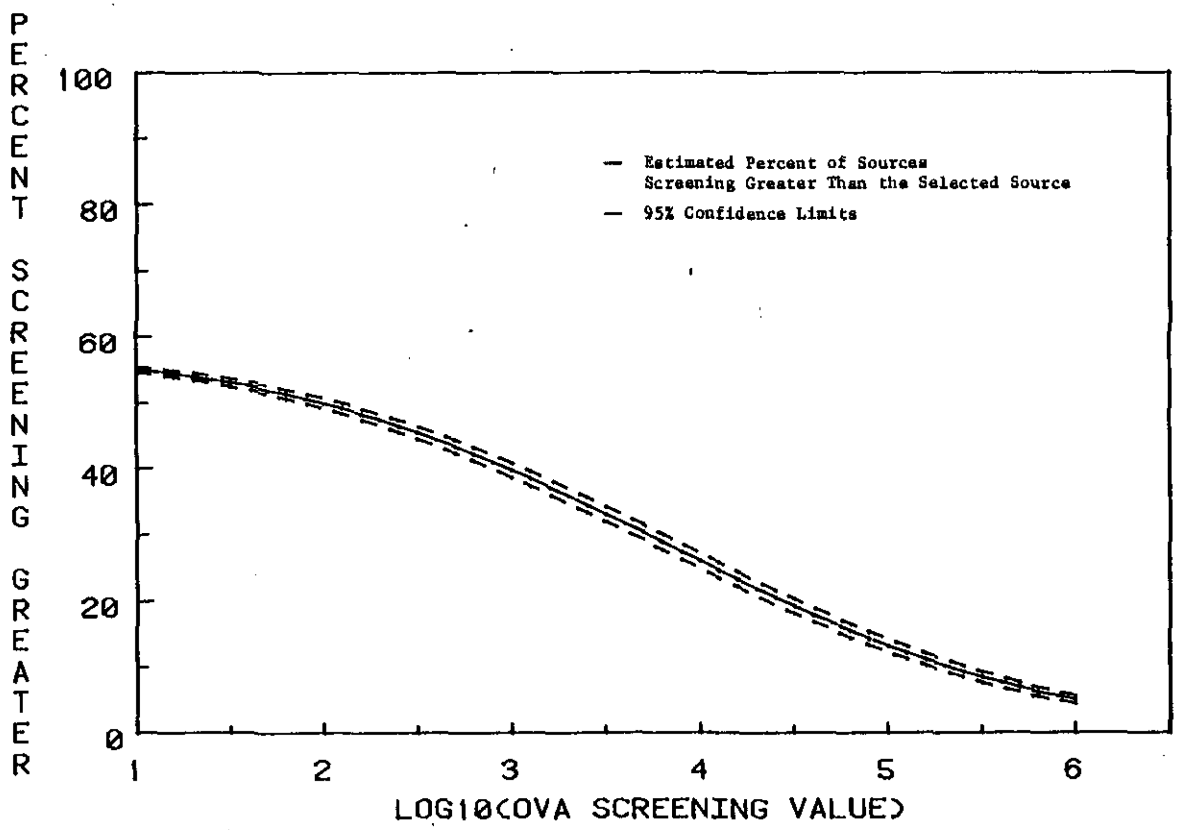


Figure 4-26a. Cumulative Distribution of Sources by Screening Values
Ethylene Process, Valves in Light Liquid Service

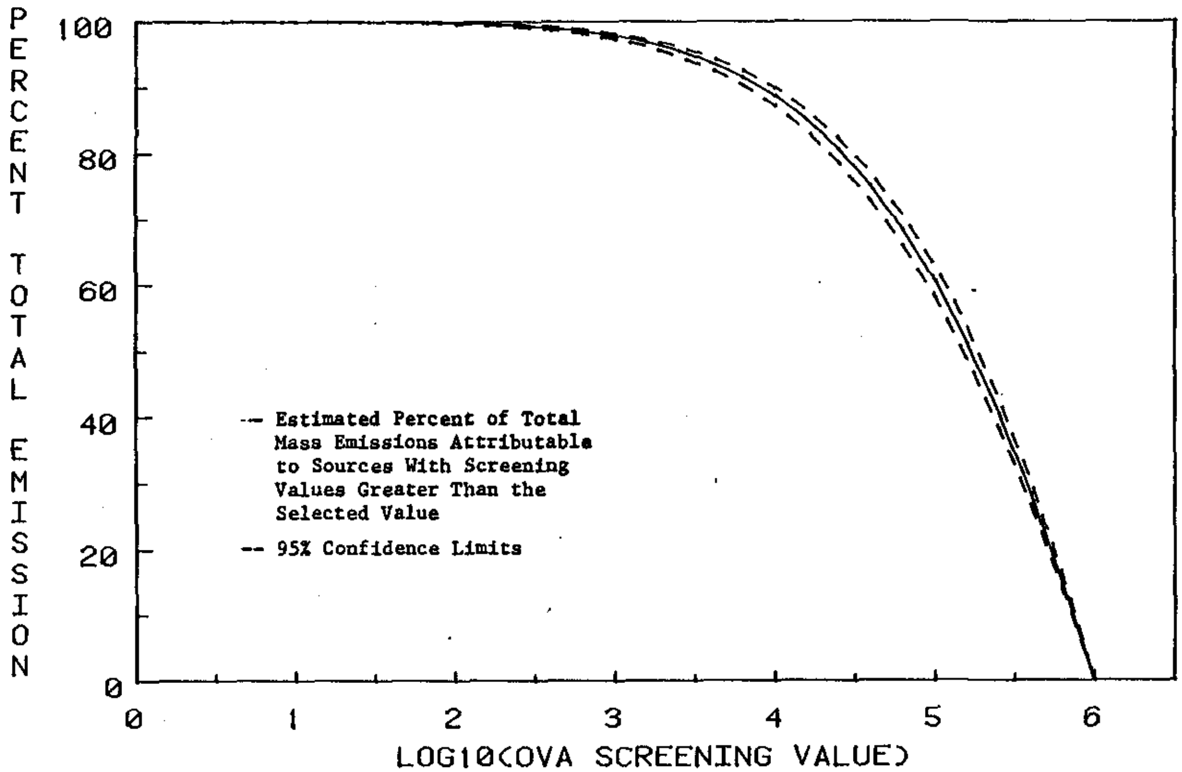


Figure 4-26b. Cumulative Distribution of Total Emissions by Screening Values – Ethylene Process, Valves in Light Liquid Service

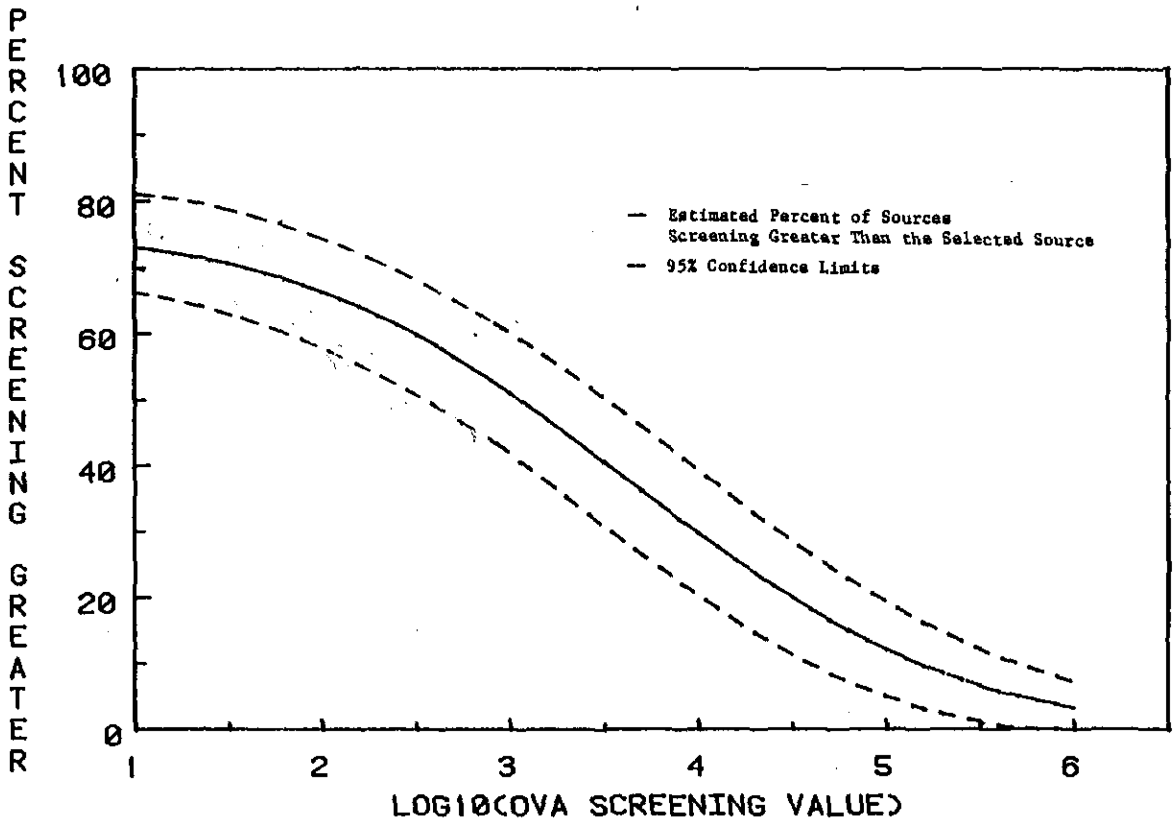


Figure 4-27a. Cumulative Distribution of Sources by Screening Values Ethylene Process, Pumps in Light Liquid Service

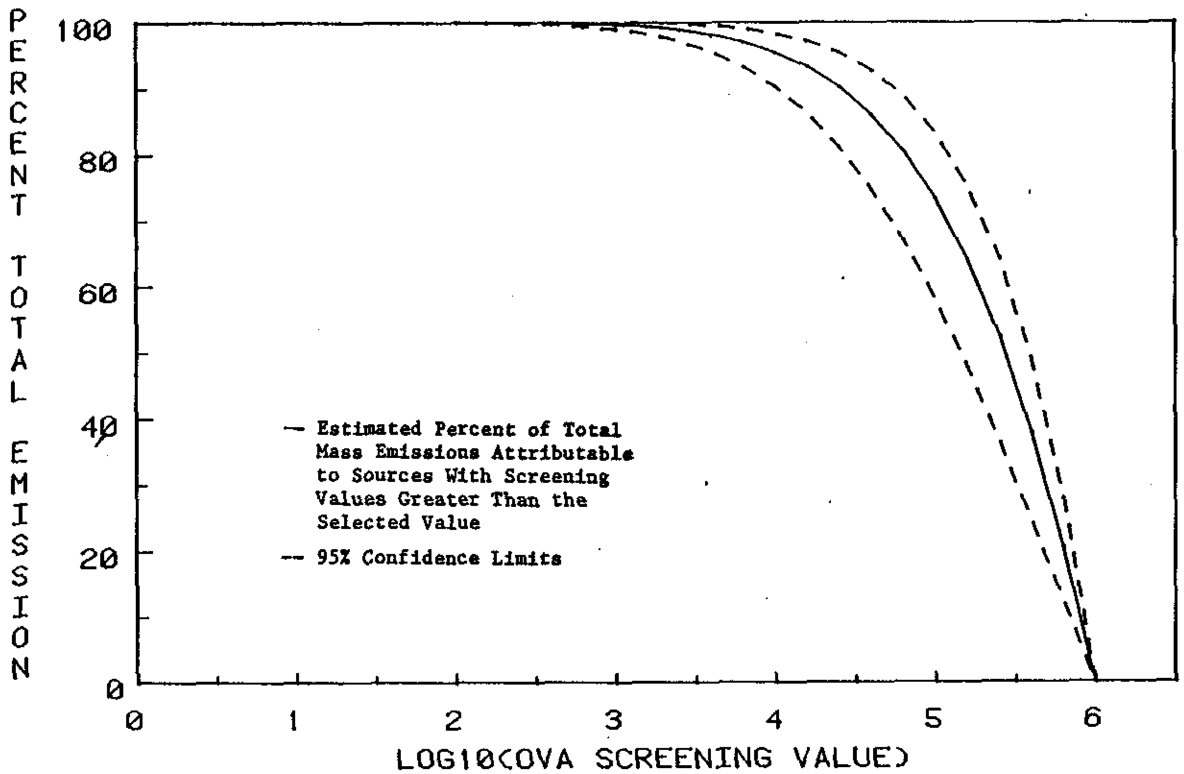


Figure 4-27b. Cumulative Distribution of Total Emissions by Screening Values - Ethylene Process, Pumps in Light Liquid Service

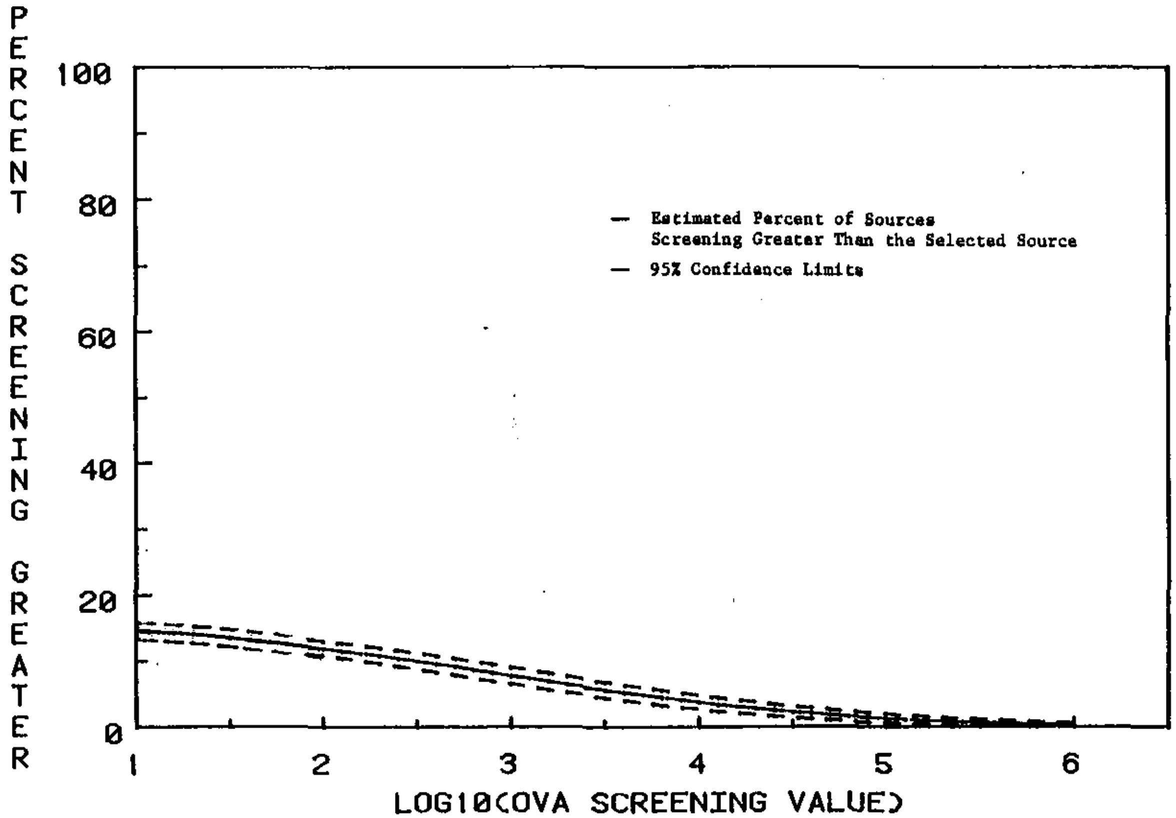


Figure 4-28a. Cumulative Distribution of Sources by Screening Values
Vinyl Acetate Process, Valves in Gas Service

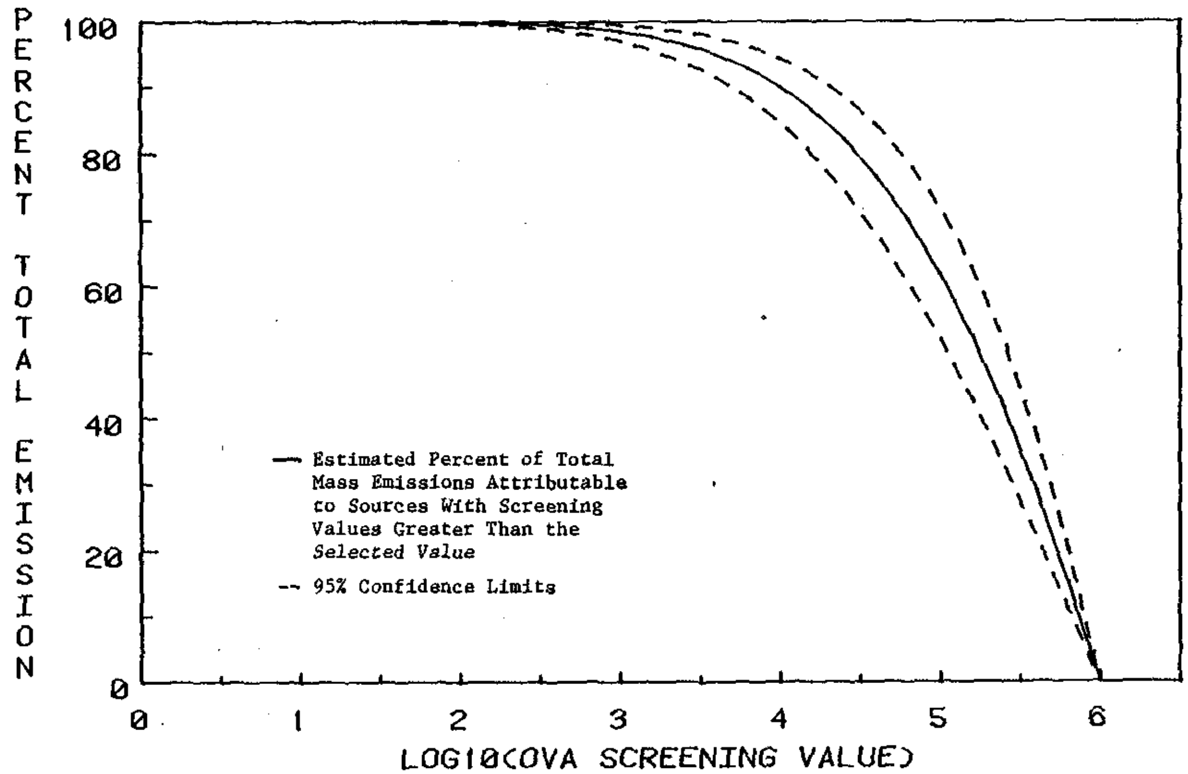


Figure 4-28b. Cumulative Distribution of Total Emissions by Screening Values - Vinyl Acetate Process, Valves in Gas Service

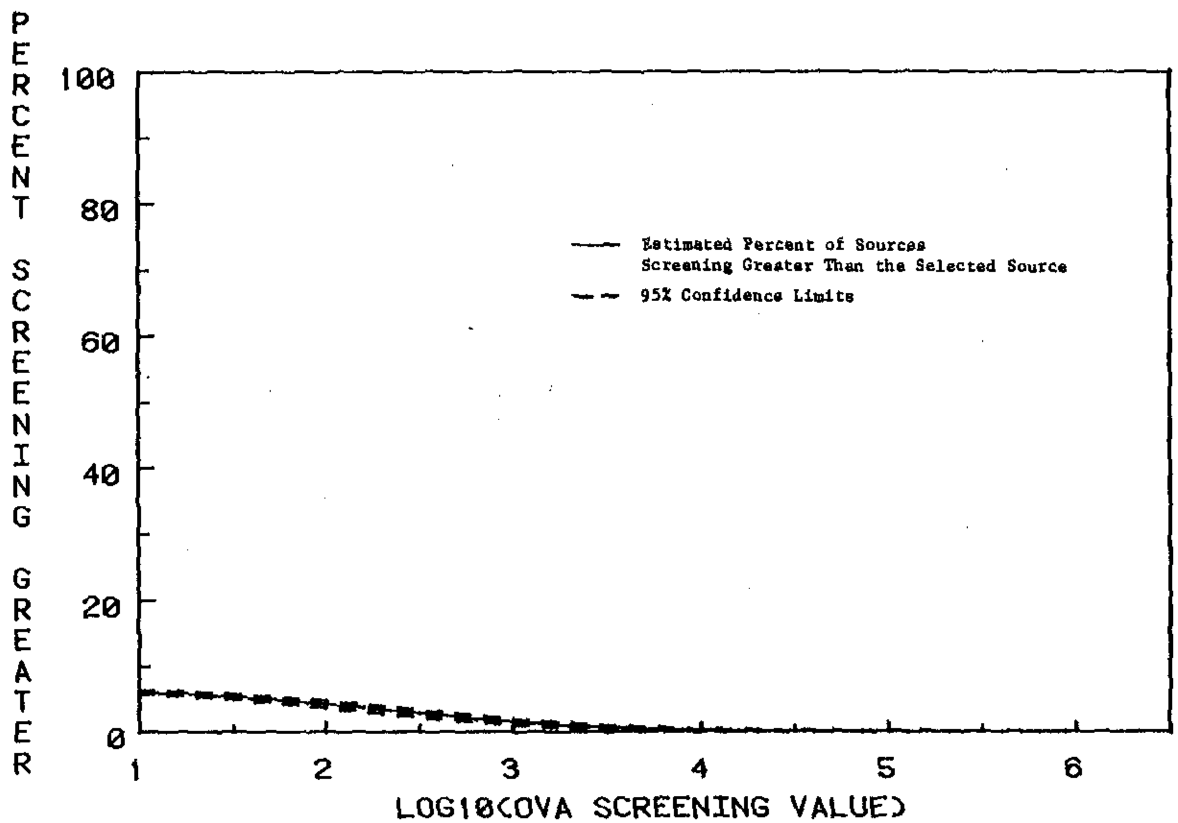


Figure 4-29a. Cumulative Distribution of Sources by Screening Values
Vinyl Acetate Process, Valves in Light Liquid

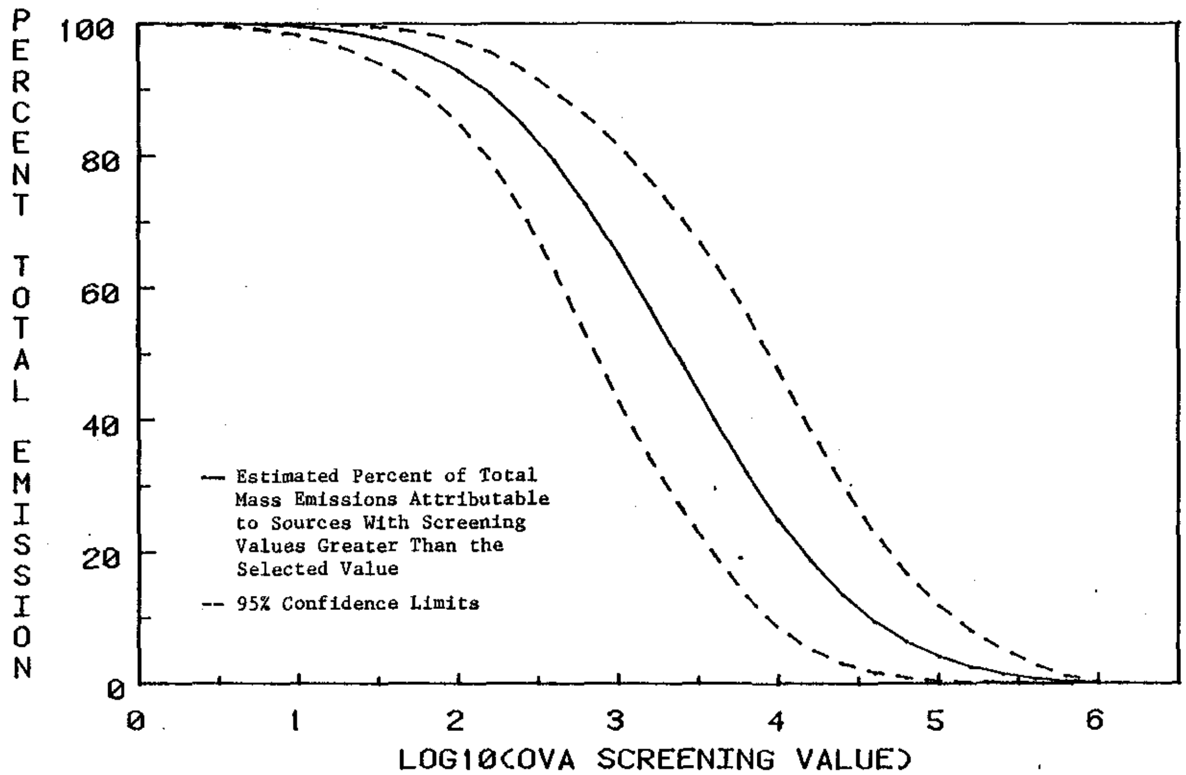


Figure 4-29b. Cumulative Distribution of Total Emissions by Screening Values - Vinyl Acetate Process, Valves in Light Liquid Service

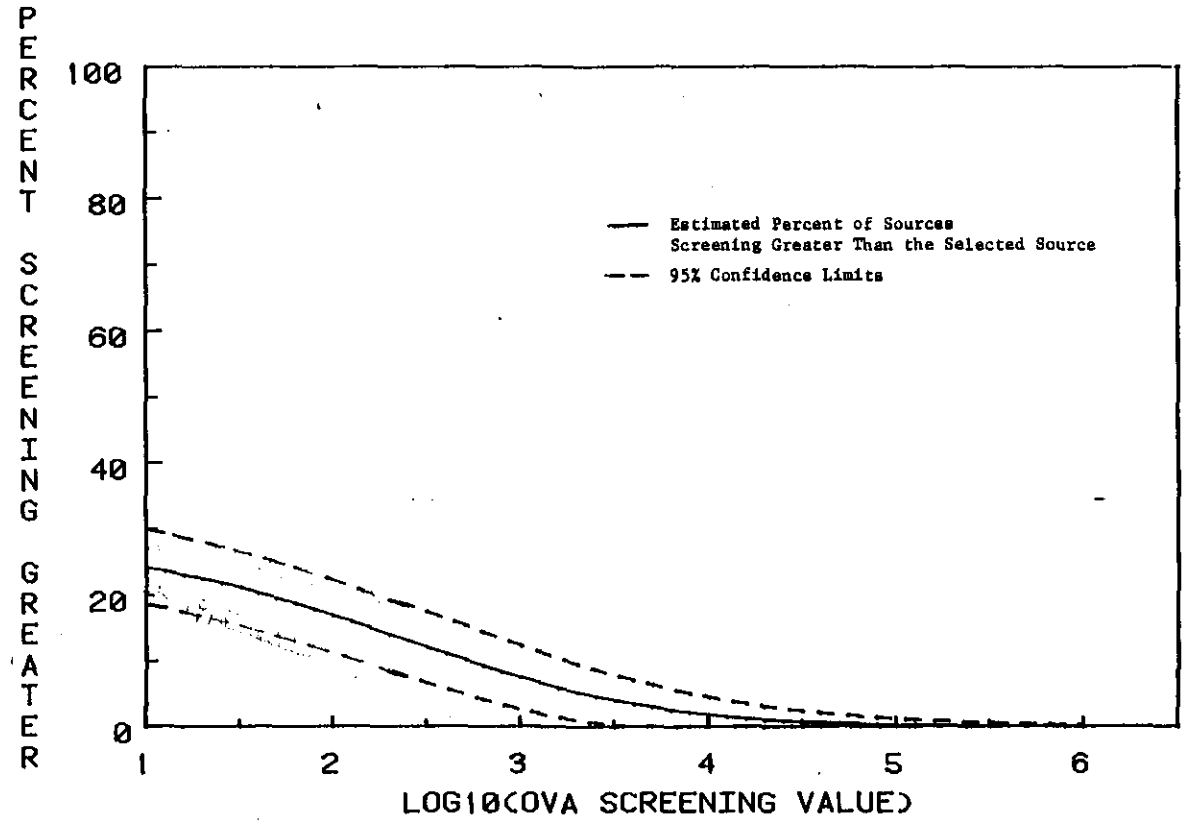


Figure 4-30a. Cumulative Distribution of Sources by Screening Values Vinyl Acetate Process, Pumps in Light Liquid Service

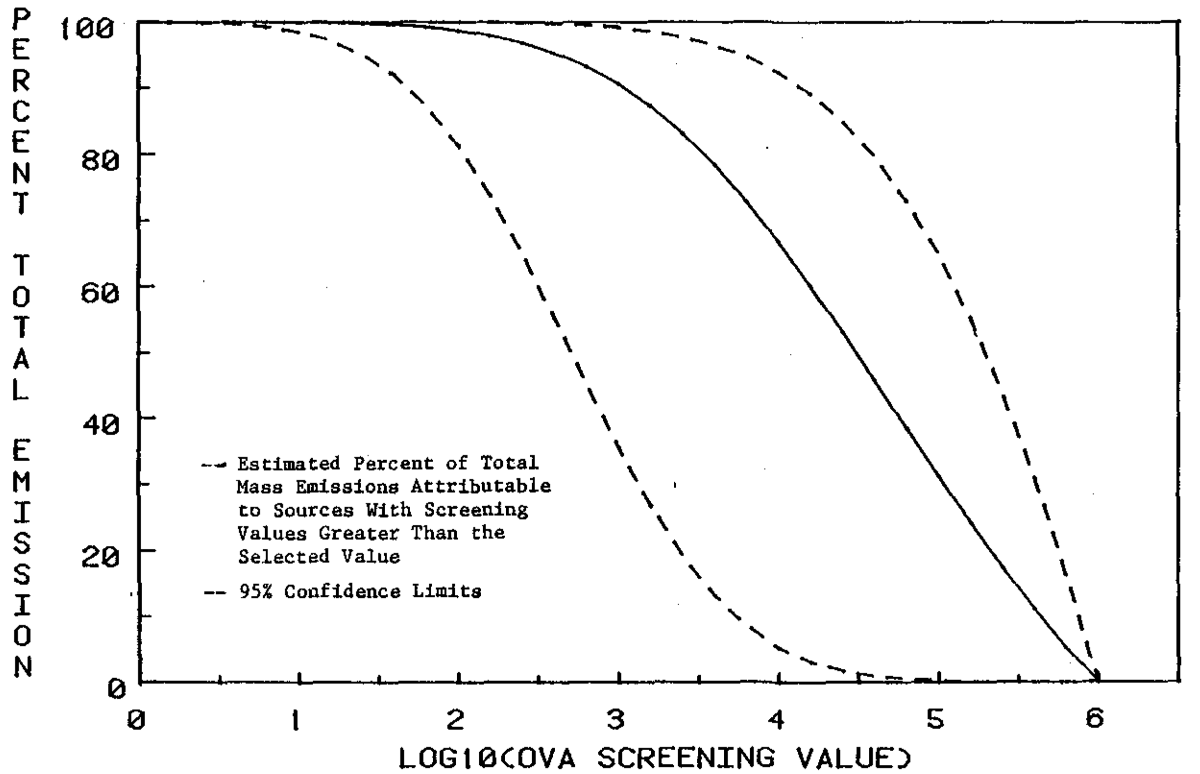


Figure 4-30b. Cumulative Distribution of Total Emissions by Screening Values - Vinyl Acetate Process, Pumps in Light Liquid Service

TABLE 4-2. SUMMARY OF PERCENT OF SOURCES DISTRIBUTION CURVES AND PERCENT OF MASS EMISSIONS CURVES AT SCREENING VALUE OF 10,000 PPMV

Source Type	Percent of Sources Screening ⩾ 10,000 ppmv: Estimate	Percent of Sources Screening ⩾ 10,000 ppmv: 95% Confidence Interval	Percent of Mass Emissions Attributable to Sources Screening ⩾ 10,000 ppmv: Estimate	Percent of Mass Emissions Attributable to Sources Screening ⩾ 10,000 ppmv: 95% Confidence Interval
Valves				
Gas				
Ethylene	15	(14, 16)	94	(93, 95)
Cumene	16	(13, 19)	94	(90, 96)
Vinyl Acetate	3.7	(2, 5)	90	(85, 94)
Light Liquid				
Ethylene	26	(24, 27)	89	(87, 90)
Cumene	12	(10, 13)	80	(72, 86)
Vinyl Acetate	0.2	(0, 0.4)	25	(9, 47)
Pump Seals				
Light Liquid				
Ethylene	30	(20, 39)	96	(90, 98)
Cumene	14	(1, 27)	89	(50, 98)
Vinyl Acetate	1.7	(0, 4)	67	(5, 92)

SECTION 5

EVALUATION OF THE EFFECTS OF LEAK OCCURRENCE, RECURRENCE, AND REPAIR ON MASS EMISSIONS

This section presents the results of investigations of leak occurrence, recurrence, and maintenance effects on VOC mass emissions. The analysis is an extension of previous work on these aspects of fugitive emissions control presented in Reference 2 (maintenance study).

EFFECT OF LEAK OCCURRENCE ON MASS EMISSIONS

Leak occurrence was defined in Reference 2 for sources initially screening $< 10,000$ ppmv as the first occurrence of a leak (screening $\geq 10,000$ ppmv) at any time after the initial screening. In the maintenance study, described in Reference 2, there were 651 valves and 89 pumps which screened below 10,000 ppmv initially, and were subsequently rescreened two to six times over a six month period. Estimated leak occurrence rates were developed in Reference 2 for both valves and pump seals. This section presents estimates of the effect on mass emissions from those leak occurrences. The statistical procedures used to develop these estimates are discussed in Section 7.

Table 5-1 show estimates of the weighted percent increase (WPI) and the increase in mass emissions for the sources for which leaks did and did not occur. The WPI is applicable as an estimate of the effect of leak occurrence on mass emissions. The mean emission estimates (lb/hr/source) are applicable only to the data from the maintenance study since they represent the combined data from three specific chemical processes.

TABLE 5-1. INCREASE IN MASS EMISSIONS BY LEAK OCCURRENCE[1)] FOR VALVES AND PUMP SEALS SCREENING < 10,000 ppmv INITIALLY

Source Category (number of sources in category)	Weighted Percent Increase (%)	Mean Emissions (lbs/hr/source) At Initial Screening	Mean Emissions (lbs/hr/source) At First Leak Occurrence or Last Screening	Mean Emissions Increase (lbs/hr/source)
Sources with leak occurrences				
Valves (30)	530 (200, 900)	0.0052 (0.001, 0.03)	0.033 (0.006, 0.1)	0.028 (0.005, 0.2)
Pump Seals (15)	75 (-100, 6000)	0.013 (0.001, 0.1)	0.99 (0.005, 10)	0.98 (0.02, 20)
Sources without leak occurrence				
Valves (621)	-37 (-56, -18)	0.00065 (0.0002, .002)	0.00041 (0.0001, 0.002)	-0.00024 (-0.001, 0.00002)
Pump Seals (74)	-47 (-100, 11)	0.0014 (0.0002, 0.01)	0.00075 (0.00004, 0.005)	-0.00066 (-0.02, 0)

1) Screening ⩾ 10,000 ppmv the first time following initial screening

Note: leak rates estimated at initial screening and measured (or estimated) at either (1) time of first occurrence of (2) time of last screening

Note: estimates are reported with an approximate 95% confidence interval

The valves with a leak occurrence had a WPI in emissions of 530% while the valves without leak occurrence showed a slight decrease in emissions (WPI = -37%). These estimates can be combined with the occurrence rates estimates in Reference 2 to estimate the total impact of leak occurrence on mass emissions. The confidence intervals for these estimates should be considered in analyses of this type. The confidence intervals for the WPI estimates for pumps are quite large and include zero (no increase).

EFFECT OF LEAK RECURRENCE ON MASS EMISSIONS FOR VALVES

Leak recurrence was defined in Reference 2 for maintained valves (screening value < 10,000 ppmv immediately after maintenance) as a leak (screening value ⩾ 10,000 ppmv) at any time after maintenance. In the maintenance study (Reference 2) there were 28 valves with the potential for leak recurrence (i.e., with screening value ⩾ 10,000 ppmv before maintenance and < 10,000 ppmv immediately after maintenance). Eight valves exhibited a leak recurrence during the six month period after maintenance. Leak recurrence rates for valves were estimated in Reference 2 using these data. This section presents estimates of the effect on mass emissions from these leak recurrences.

Table 5-2 shows estimates of the weighted percent increase (WPI) and estimates of the mean emissions before maintenance, after maintenance, and after recurrence or at time of last screening. As with the occurrence estimates, the mean emission estimates are applicable only to the data from the maintenance study. The confidence intervals for the WPI estimate include zero in both cases due to the small number of sources studied for recurrence. The estimates can be combined with recurrence rate estimates in Reference 2 to evaluate the impact of recurrence on emissions from valves, but the confidence intervals should be considered in these evaluations.

TABLE 5-2. INCREASE IN MASS EMISSIONS BY LEAK RECURRENCE[1)] FOR VALVES SCREENING $<$ 10,000 ppmv IMMEDIATELY AFTER MAINTENANCE

Source Category	Weighted Percent Increase (%)	Mean Emissions (lb/hr/source) Before Maintenance	Mean Emissions (lb/hr/source) After Maintenance	Mean Emissions (lb/hr/source) At First Recurrence or Last Screening	Mean Emissions Increase at Recurrence or Last Screening (lb/hr/source)
Valves with leak recurrence (8 valves)	510 (-100, 1700)	0.26 (0, 0.6)	0.0033 (0, 0.02)	0.02 (0, 0.08)	0.017 (-0.04, 0.2)
Valves without leak recurrence (20 valves)	-50 (-96, -5)	0.024 (0.01, 0.04)	0.0016 (0.0001, 0.01)	0.0008 (0.0001, 0.002)	-0.0008 (0.008, 0.002)

1) Screening $\geqslant$ 10,000 ppmv the first time following after maintenance screening

Note: leak rates measured (or estimated) after maintenance and at either (1) time of first recurrence or (2) time of last measurement

Note: estimates are reported with an approximate 95% confidence interval

FURTHER ANALYSIS OF EFFECT OF VALVE MAINTENANCE ON MASS EMISSIONS

A statistical analysis was done to expand on the analysis of the immediate effect of valve maintenance in Reference 2. Reference 2 reported a weighted percent reduction (WPR) of 71% (95% confidence interval of 54% to 88%) for 155 valves for which maintenance was performed. The WPR for the 97 valves with a before maintenance screening valve of $\geqslant$ 10,000 ppmv was 70% (95% confidence interval of 46% to 95%). Reference 2 also reported that only 29% of the 97 valves were "repaired" by simple on-line maintenance, where a "repair" is defined as screening below 10,000 ppmv immediately after maintenance. This analysis compares the reduction for the 29% of the sources repaired with the 71% not repaired.

Table 5-3 summarizes this comparison and Figures 5-1 and 5-2 show the before minus after maintenance leak rates plotted against the before maintenance leak rates for the "repaired" and "non-repaired" valves. The weighted percent reduction for repaired valves was 97.7% (95%, 100%) compared with 62.6% (41%, 85%) for non-repaired valves. This significant difference in emissions reduction between the two groups of valves can be seen by comparing the data plots in Figure 5-1 and 5-2.

Table 5-3 also contains estimates of the mean emissions from the valves before and after maintenance. These estimates are only applicable to the sources in the data base since they represent the combined data from valves from three specific chemical processes.

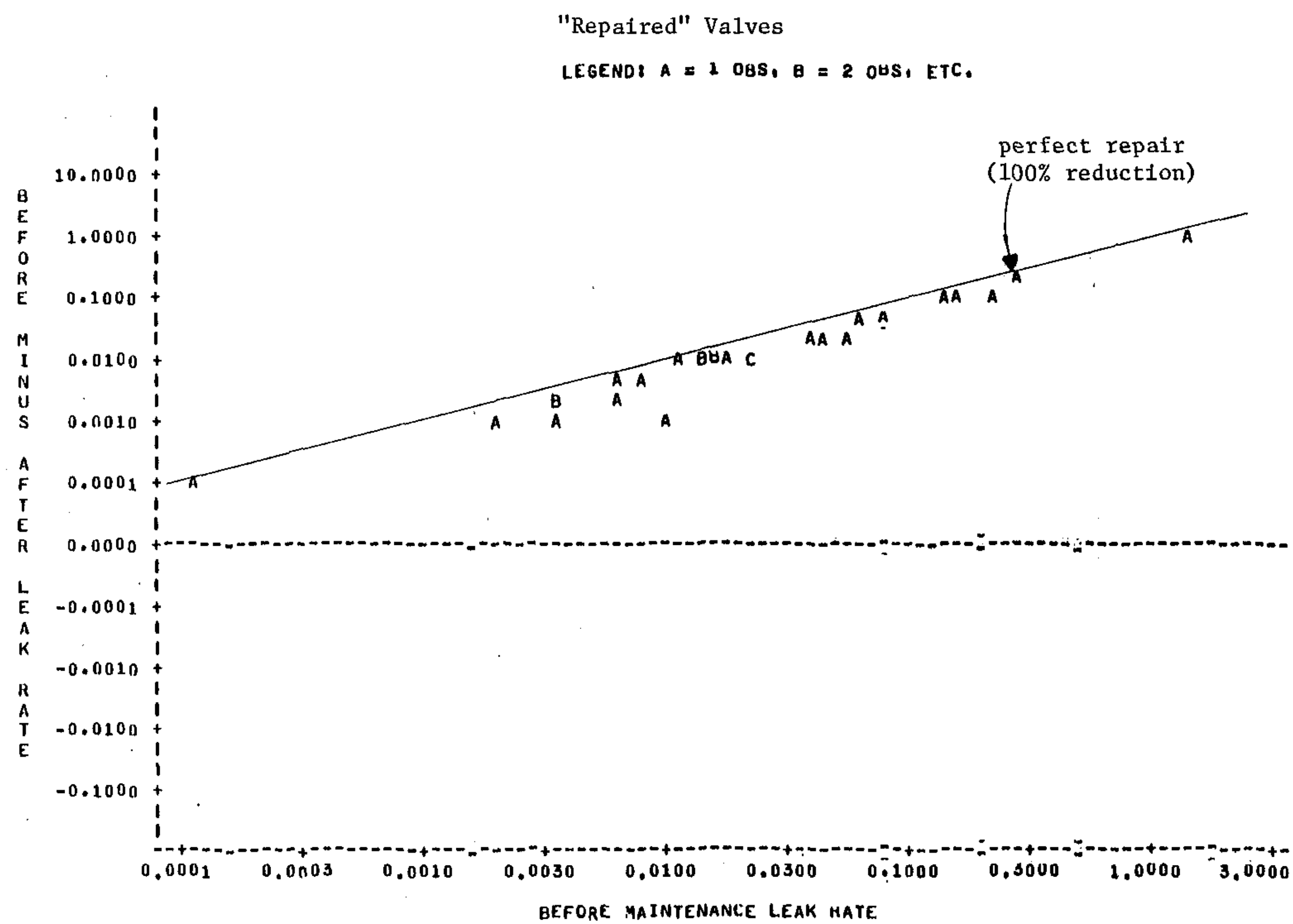


Figure 5-1. Before Minus After Maintenance Leak Rate - Valves Screening < 10,000 ppmv After Maintenance

"Non-Repaired" Valves

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

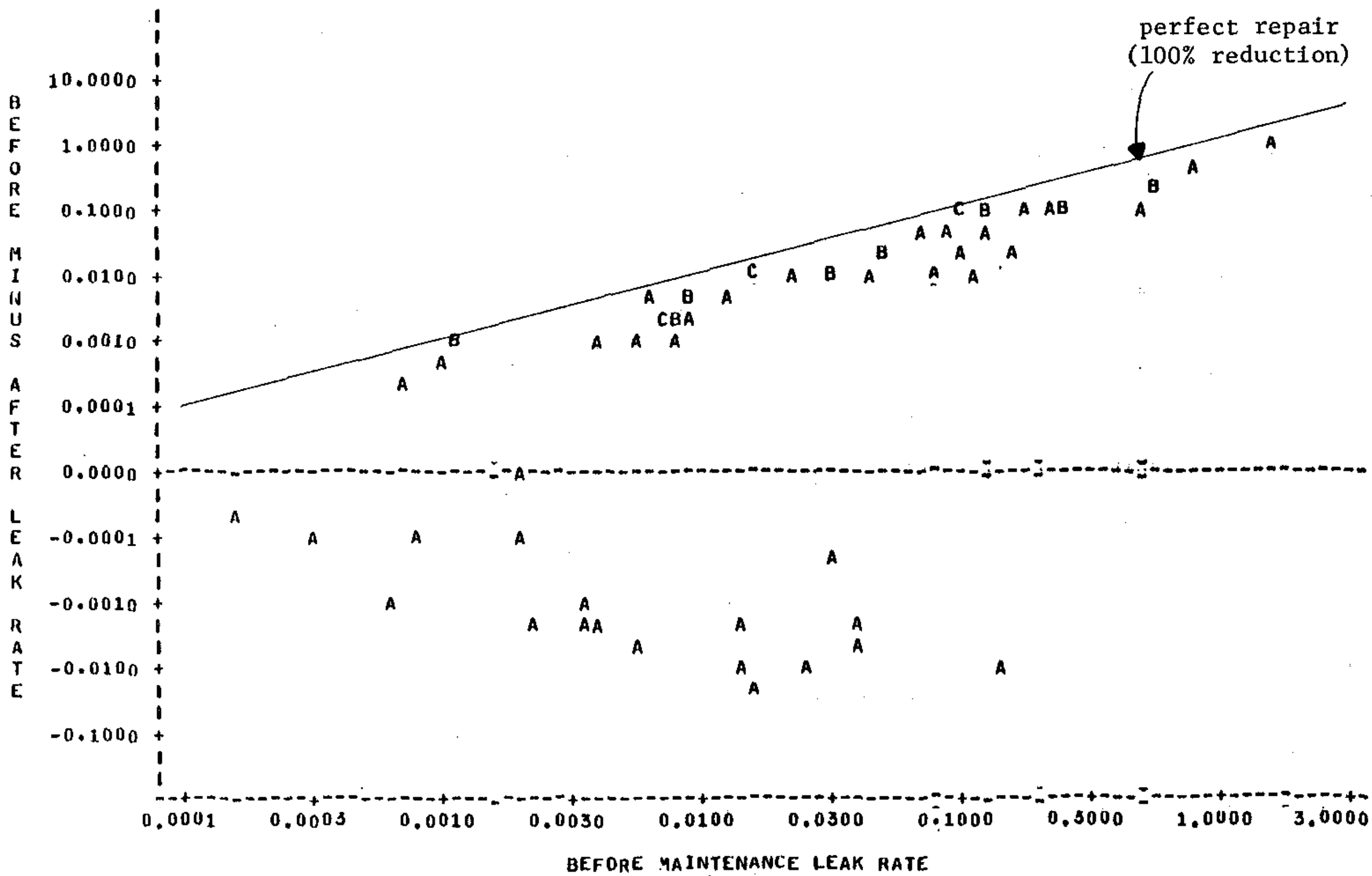


Figure 5-2. Before Minus After Maintenance Leak Rate - Valves Screening ≥ 10,000 ppmv After Maintenance

TABLE 5-3. WEIGHTED PERCENT REDUCTION IN MASS EMISSIONS FOR VALVES SCREENING $\geq$ 10,000 ppmv IMMEDIATELY BEFORE MAINTENANCE

Source Category	Weighted Percent Reduction (%)	Mean Emissions (lb/hr/source) Before Maintenance	Mean Emissions (lb/hr/source) After Maintenance	Mean Emissions Reduction (lb/hr/source)
Sources repaired[1] (28 valves)	97.7 (95, 100)	0.09 (0, 0.2)	0.0002 (0, 0.02)	0.088 (-0.007, 0.2)
Sources not repaired (69 valves)	62.6 (41, 85)	0.10 (0.04, 0.2)	0.038 (0.02, 0.05)	0.062 (0.006, 0.12)
Total (97 valves)	70.1 (46, 95)			

1) Screening < 10,000 ppmv immediately after maintenance

Note: leak rates measured before and after maintenance

Note: estimates are reported with approximate 95% confidence interval

SECTION 6

IMPACT ON LEAK FREQUENCY ESTIMATES OF APPLYING CHEMICAL RESPONSE ADJUSTMENTS

The goal of the analysis in this section was to investigate the effect of applying chemical(s) specific response adjustments to the OVA readings to estimate the frequency of leaks from SOCMI process units. This was accomplished by calculating adjusted screening values based on the original screening value and chemical response factor corrections. For the purposes of this study a source is said to be leaking if its screening value is $\geq$ 10,000 ppmv. Three different techniques were used to adjust the original OVA screening value:

1) the original OVA reading adjusted for the associated OVA response relationship of the primary chemical compound in the line (see Section 7 for more detail),

2) weighted logarithmic average of response of primary and secondary chemicals (see Section 7 for more detail),

3) weighted arithmetic average of response of primary and secondary chemicals (see Section 7 for more detail).

The percent of valves leaking was calculated for each of the three estimates for both gas and light liquid services. The three estimates were found to be similar to the leak frequency estimate based on the original screening value.

It should be noted that the total number of valves used in this analysis may not match totals from previous sections of this report. The reason is that in certain process units a dilution probe was not used. This resulted in 119 sources having a recorded OVA reading of 10,001 ppmv (indicating a concentration above 10,000 ppmv). Many of the adjustments of these data resulted in estimates just below 10,000 (i.e., ≈9,997) ppmv). Therefore, all sources with OVA readings equal to 10,001 ppmv were excluded from the analysis. These 119 observations came from the following process types:

- Acrylonitrile - 37 observations,
- Chlorinated Ethanes - 11 observations,
- Ethylene Dichloride - 28 observations,
- Formaldehyde - 1 observation, and
- Vinyl Chloride Monomer - 42 observations.

Because of these deletions, the percent leaking estimates will have a small negative bias. However, the comparison of the four estimates is still valid since the relative sizes of the estimates is the important aspect to be evaluated.

SUMMARY OF FOUR LEAK FREQUENCY ESTIMATES BY PRIMARY CHEMICAL

The percent leaking estimates resulting from the three adjustment methods are presented in Tables 6-1 and 6-2. Also included is the percent leaking estimate from unadjusted OVA readings for comparison purposes. As seen in the tables, the three leak frequency estimates based on adjusted screening values are similar to the unadjusted estimates.

SUMMARY OF FOUR LEAK FREQUENCY ESTIMATES BY PROCESS TYPE

The main question to be answered by this investigation is, "If the OVA readings for a given process unit are adjusted for chemical response, will significantly different estimates of the percent of leaking sources result?" From the summarizations shown in Tables 6-3 and 6-4, it is evident that there are no drastic changes in the estimates of percent leaking. However, there is a general trend for a small reduction in the estimated frequencies.

To show the relationship between OVA readings and Method 1 estimates, plots of these two variables are shown for specific process types in Figures 6-1 through 6-6. The effects of specific chemicals with a process type can be seen as straight lines. This is especially apparent in Figures 6-3 and 6-4. The northwest quadrant of these plots indicate valves where the original screening value was below 10,000 ppmv and the Method 1 estimates are $\geq$ 10,000 ppmv. The southeast quadrant represents the opposite situation. The other two quadrants indicate no change in the leak designation for those valves.

For the high leaking processes the adjustments to the gas service valves result in consistently lower percent leaking estimates. These estimates are approximately 3 percentage points lower. The estimates in all other cases are almost indistinguishable from the unadjusted estimate.

TABLE 6-1. PERCENT LEAKING ESTIMATES FOR VALVES IN LIGHT LIQUID SERVICE

Chemical	OVA Response Factor @ 10,000 ppmv Response	Number Screened	Percent Leaking Based on OVA Readings		Percent Leaking Based on Method 1 Adjustments[1]		Percent Leaking Based on Method 2 Adjustments[2]		Percent Leaking Based on Method 3 Adjustments[3]	
			Number Leaking	Percent Leaking	Number Leaking	Percent Leaking	Number Leaking	Percent Leaking	Number Leaking	Percent Leaking
Propylene	0.80	1583	467	29.50	417	26.34	446	28.17	431	27.23
Ethane	0.65	328	92	28.05	70	21.34	75	22.87	76	23.17
Ethylene	0.70	1230	321	26.10	271	22.03	273	22.20	283	23.01
Methane	1.00	205	36	17.56	36	17.56	47	22.93	38	18.54
Benzene	0.29	536	49	9.14	26	4.85	30	5.60	28	5.22
Methyl Ethyl Ketone	0.60	425	23	5.41	14	3.29	10	2.35	13	3.06
Sec Butyl Alcohol	0.76	202	10	4.95	8	3.96	7	3.47	7	3.47
Hydrocarbons-C_5^+	0.52	323	8	2.48	7	2.17	7	2.17	6	1.86
Acetone	0.80	209	5	2.39	4	1.91	5	2.39	4	1.91
Methanol	4.39	373	4	1.07	11	2.95	11	2.95	11	2.95
Acetic Acid	1.60	1162	6	0.52	7	0.60	8	0.69	6	0.52
Cumene	1.87	773	4	0.52	9	1.16	11	1.42	9	1.16
Acetaldehyde	1.14	456	2	0.44	2	0.44	4	0.88	2	0.44
Trichloroethylene	0.95	267	1	0.37	0	0	1	0.37	0	0
Vinyl Acetate	1.30	973	3	0.31	3	0.31	4	0.41	3	0.31
Methyl Methacrylate	0.99	393	1	0.25	0	0	1	0.25	1	0.25
Perchloroethylene	2.97	599	1	0.17	6	1.00	6	1.00	5	0.83
1,1,2 Trichloroethane	1.25	911	1	0.11	1	0.11	1	0.11	1	0.11
1,2 Ethylene Dichloride	0.95	2777	0	0	0	0	5	0.18	0	0
Acrylonitrile	0.97	1120	0	0	0	0	1	0.09	0	0
Vinyl Chloride	0.80	607	0	0	0	0	0	0	0	0
Phenol	*** [4]	594	0	0	1	0.17	2	0.34	0	0
α-Methyl Styrene	113.9	326	0	0	3	0.92	0	0	1	0.31
Acetone Cyanohydrin	3.51	191	0	0	0	0	0	0	0	0
Other Chemicals	--	1570	67	4.27	69	4.39	68	4.33	65	4.14
TOTAL		18,133[5]	1101	6.07	965	5.32	1023	5.64	990	5.46

[1] Method 1 is the adjustment to the OVA reading based on the response of the primary chemical in the line.
[2] Method 2 is the mixed chemical weighted logarithmic average technique.
[3] Method 3 is the mixed chemical weighted average technique.
[4] A response of 10,000 ppmv for Phenol was experimentally unattainable.
[5] 74 sources with OVA Reading = 10,001 ppmv were excluded.

TABLE 6-2. PERCENT LEAKING ESTIMATES FOR VALVES IN GAS SERVICE

Chemical	OVA Response Factor @ 10,000 ppmv Response	Number Screened	Percent Leaking Based on OVA Readings		Percent Leaking Based on Method 1 Adjustments[1]		Percent Leaking Based on Method 2 Adjustments[2]		Percent Leaking Based on Method 3 Adjustments[3]	
			Number Leaking	Percent Leaking	Number Leaking	Percent Leaking	Number Leaking	Percent Leaking	Number Leaking	Percent Leaking
Propylene	0.80	1119	198	17.69	168	15.01	189	16.89	173	15.46
Benzene	0.29	332	53	15.96	31	9.34	36	10.84	32	9.64
Ethylene	0.70	3104	468	15.08	422	13.60	425	13.69	437	14.08
Methane	1.00	1849	232	12.55	232	12.55	213	11.52	234	12.66
Propane	0.60	145	18	12.41	19	13.10	18	12.41	18	12.41
Ethane	0.65	379	35	9.23	25	6.60	31	8.18	29	7.65
Methyl Ethyl Ketone	0.60	116	7	6.03	4	3.45	3	2.59	3	2.59
Acetaldehyde	1.14	179	4	2.23	4	2.23	4	2.23	4	2.23
Acetic Acid	1.60	125	1	0.80	1	0.80	1	0.80	1	0.80
1,2-Ethylene Dichloride	0.95	521	0	0	0	0	0	0	0	0
Acrylonitrile	0.97	287	0	0	0	0	0	0	0	0
Vinyl Acetate	1.30	272	0	0	0	0	0	0	0	0
Vinyl Chloride	0.80	96	0	0	0	0	1	1.04	0	0
Other Chemicals	---	850	41	4.82	40	5.29	40	4.71	37	4.35
TOTAL		9374[4]	1057	11.28	946	10.09	961	10.25	968	10.33

[1] Method 1 is the adjustment to the OVA reading based on the response of the primary chemical in the line.
[2] Method 2 is the mixed chemical weighted logarithmic average technique.
[3] Method 3 is the mixed chemical weighted average technique.
[4] 45 sources with OVA Readings = 10,001 ppmv were excluded.

TABLE 6-3. PERCENT LEAKING ESTIMATES FOR VALVES IN LIGHT LIQUID SERVICE BY PROCESS TYPE

Process (unit #'s)	Number Screened	Percent Leaking Based on OVA Readings		Percent Leaking Based on Method 1 Adjustments[1]		Percent Leaking Based on Method 2 Adjustments[2]		Percent Leaking Based on Method 3 Adjustments[3]	
		Number Leaking	Percent Leaking	Number Leaking	Percent Leaking	Number Leaking	Percent Leaking	Number Leaking	Percent Leaking
Ethylene (2,4,11)	4121	966	23.44	852	20.67	895	21.72	882	21.40
Cumene (5,6)	762	80	10.50	62	8.14	69	9.06	63	8.27
Methyl Ethyl Ketone (31,32)	671	34	5.07	23	3.43	18	2.68	21	3.13
Acetaldehyde (33)	551	3	0.54	3	0.54	4	0.73	2	0.36
Vinyl Acetate (1,3)	2137	8	0.37	9	0.42	12	0.56	9	0.42
Acetone/Phenol (12)	1818	6	0.33	9	0.50	9	0.50	6	0.33
Chlorinated Ethanes (60,61,62)	1982	3	0.15	7	0.35	8	0.40	6	0.30
Methyl Methacrylate (34)	1058	1	0.09	0	0	1	0.09	1	0.09
1,2-Ethylene Dichloride (21,29)	2232	0	0	0	0	4	0.18	0	0
Acrylonitrile (65,66)	1466	0	0	0	0	2	0.14	0	0
Vinyl Chloride Monomer (20,28)	1197	0	0	0	0	1	0.08	0	0
Formaldehyde (22)	121	0	0	0	0	0	0	0	0
Adipic Acid (35,64)	17	0	0	0	0	0	0	0	0
TOTAL	18,133	1101	6.07	965	5.32	1023	5.64	990	5.46

[1] Method 1 is the adjustment to the OVA reading based on the response of the primary chemical in the line.

[2] Method 2 is the mixed chemical weighted logarithmic average technique.

[3] Method 3 is the mixed chemical weighted average technique.

TABLE 6-4. PERCENT LEAKING ESTIMATES FOR VALVES IN GAS SERVICE BY PROCESS TYPE

Process (unit #'s)	Number Screened	Percent Leaking Based on OVA Readings		Percent Leaking Based on Method 1 Adjustments[1]		Percent Leaking Based on Method 2 Adjustments[2]		Percent Leaking Based on Method 3 Adjustments[3]	
		Number Leaking	Percent Leaking	Number Leaking	Percent Leaking	Number Leaking	Percent Leaking	Number Leaking	Percent Leaking
Ethylene (2,4,11)	6050	932	15.40	849	14.03	856	14.15	873	14.43
Cumene (5,6)	1443	63	14.22	45	10.16	49	11.06	44	9.93
Methyl Ethyl Ketone (31,32)	207	19	9.18	13	6.28	12	5.80	11	5.31
Acetaldehyde (33)	178	8	4.49	8	4.49	8	4.49	8	4.49
Vinyl Acetate (1,3)	949	35	3.69	31	3.27	33	3.48	32	3.37
1,2-Ethylene Dichloride (21,29)	397	0	0	0	0	1	0.25	0	0
Acrylonitrile (65,66)	387	0	0	0	0	1	0.26	0	0
Vinyl Chloride Monomer (20,28)	382	0	0	0	0	0	0	0	0
Methyl Methacrylate (34)	190	0	0	0	0	0	0	0	0
Adipic Acid (35,64)	95	0	0	0	0	0	0	0	0
Chlorinated Ethanes (60,61,62)	48	0	0	0	0	0	0	0	0
Formaldehyde (22)	40	0	0	0	0	1	2.50	0	0
Acetone/Phenol (12)	8	0	0	0	0	0	0	0	0
TOTAL	9374	1057	11.28	946	10.09	961	10.25	968	10.33

[1] Method 1 is the adjustment to the OVA reading based on the response of the primary chemical in the line.

[2] Method 2 is the mixed chemical weighted logarithmic average technique.

[3] Method 3 is the mixed chemical weighted average technique.

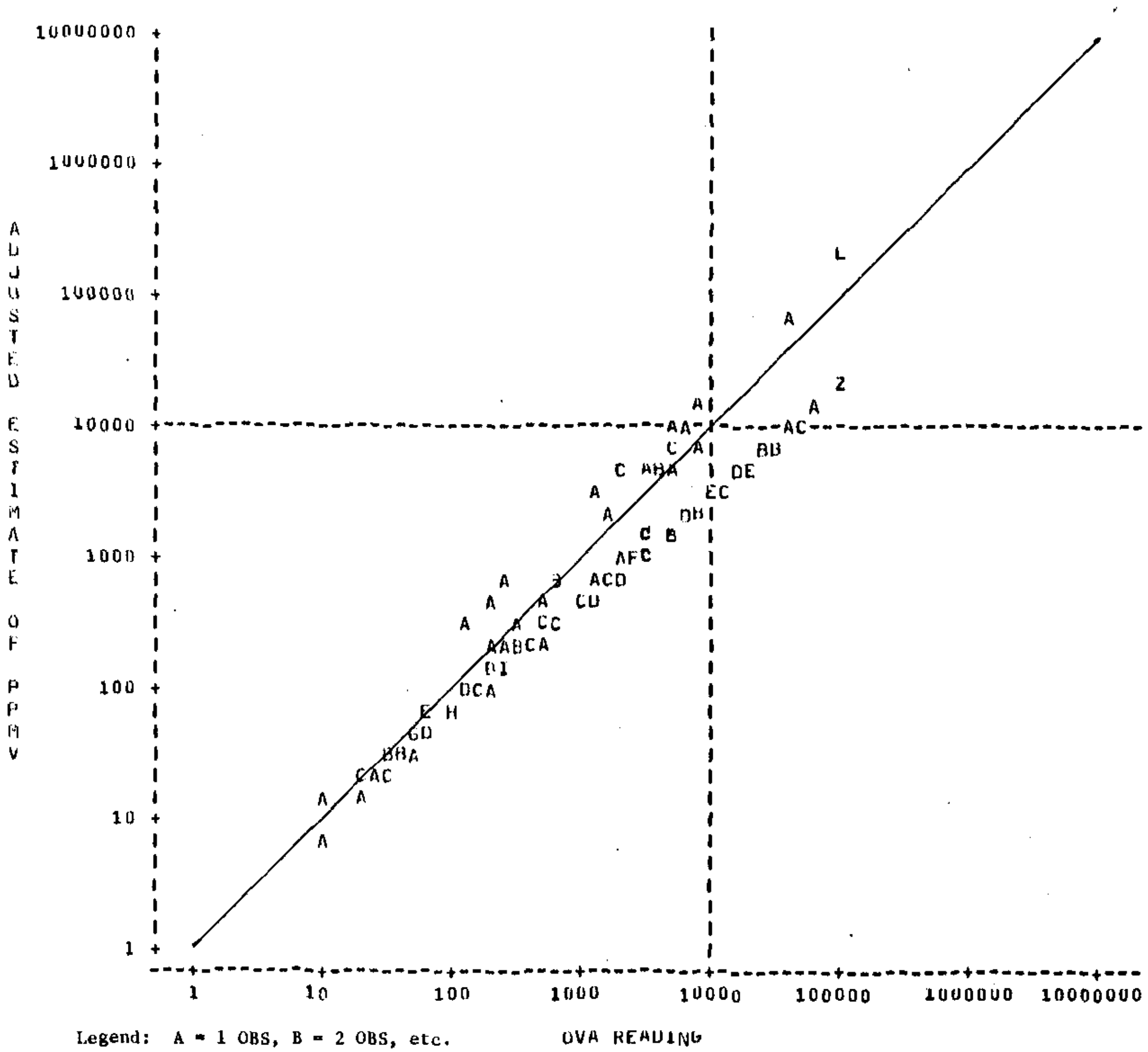
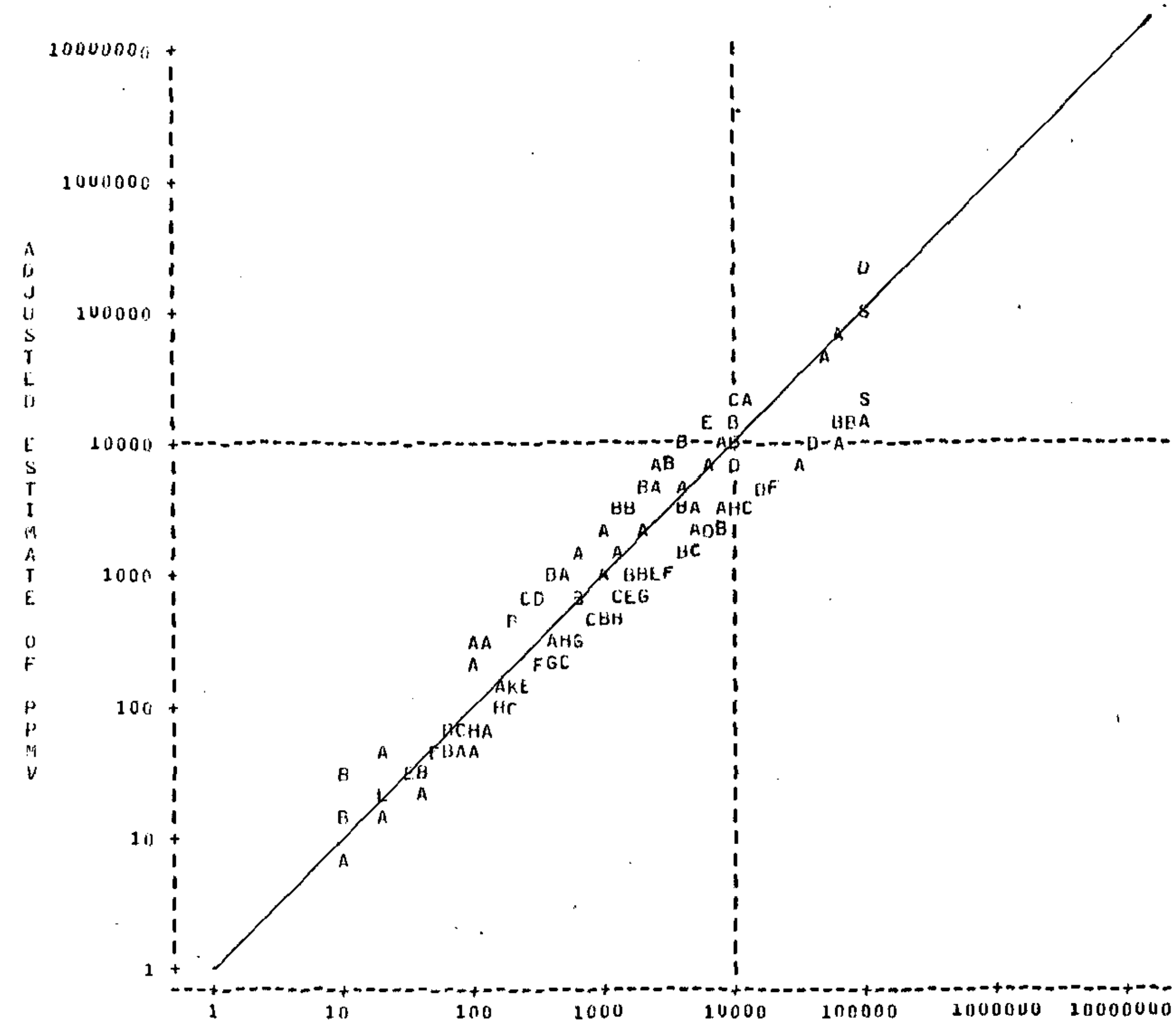


Figure 6-1. OVA Reading vs. Method 1 Adjustment for Cumene Process Valves in Gas Service



Legend: A = 1 OBS, B = 2 OBS, etc.

Figure 6-2. OVA Reading vs. Method 1 Adjustment for Cumene Process Valves in Light Liquid Service

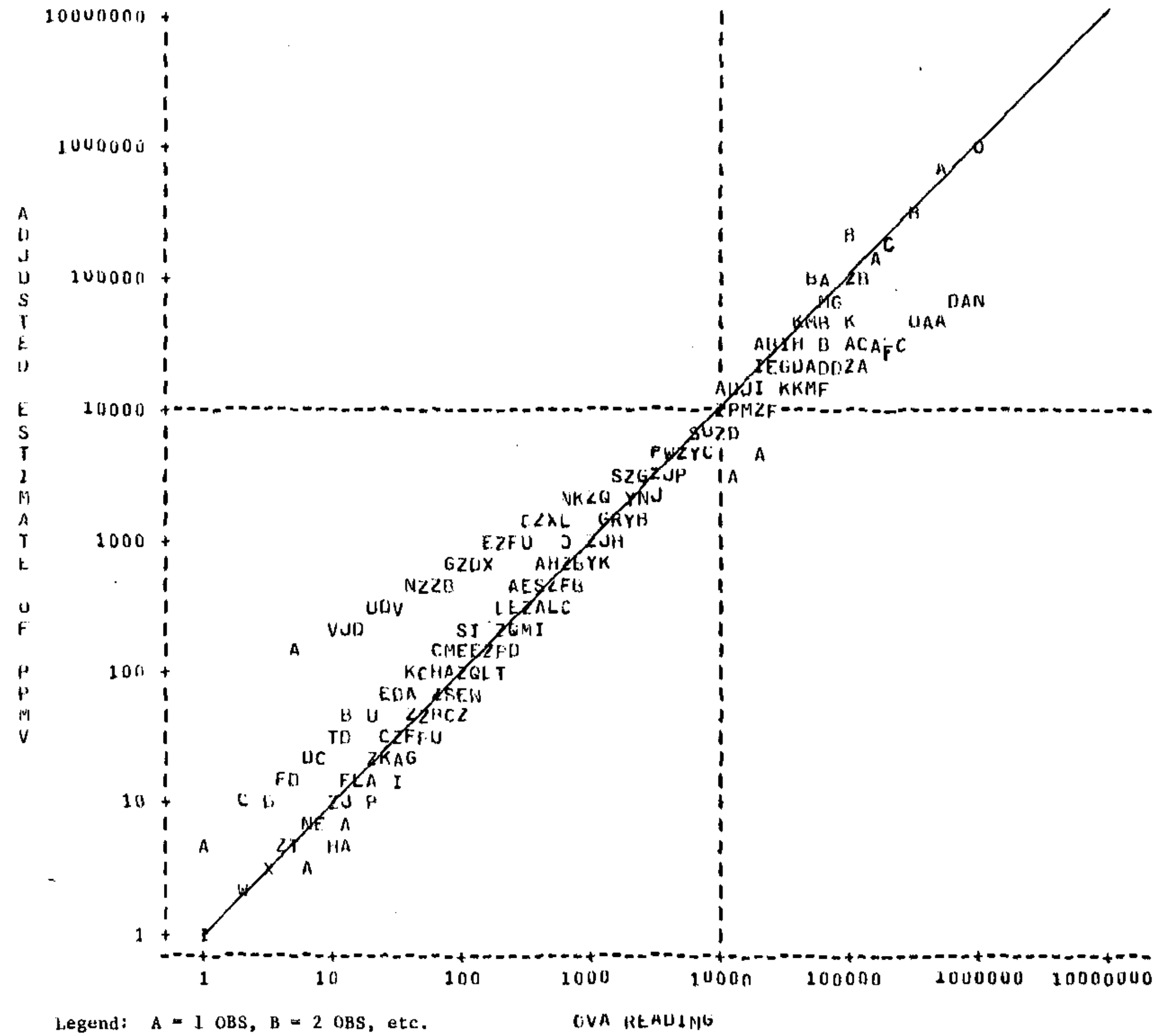


Figure 6-3. OVA Reading vs. Method 1 Adjustment for Ethylene Process Valves in Gas Service

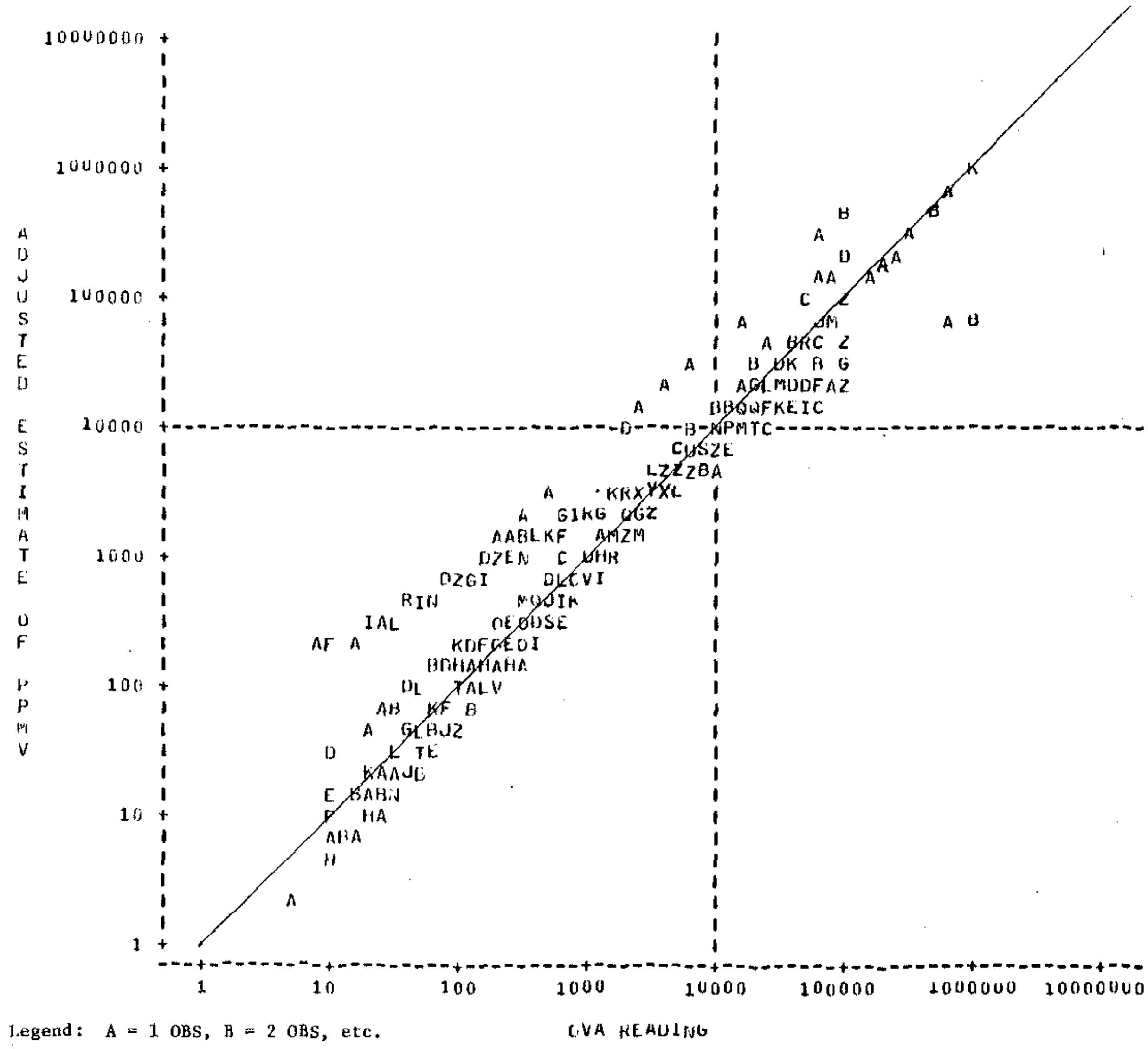
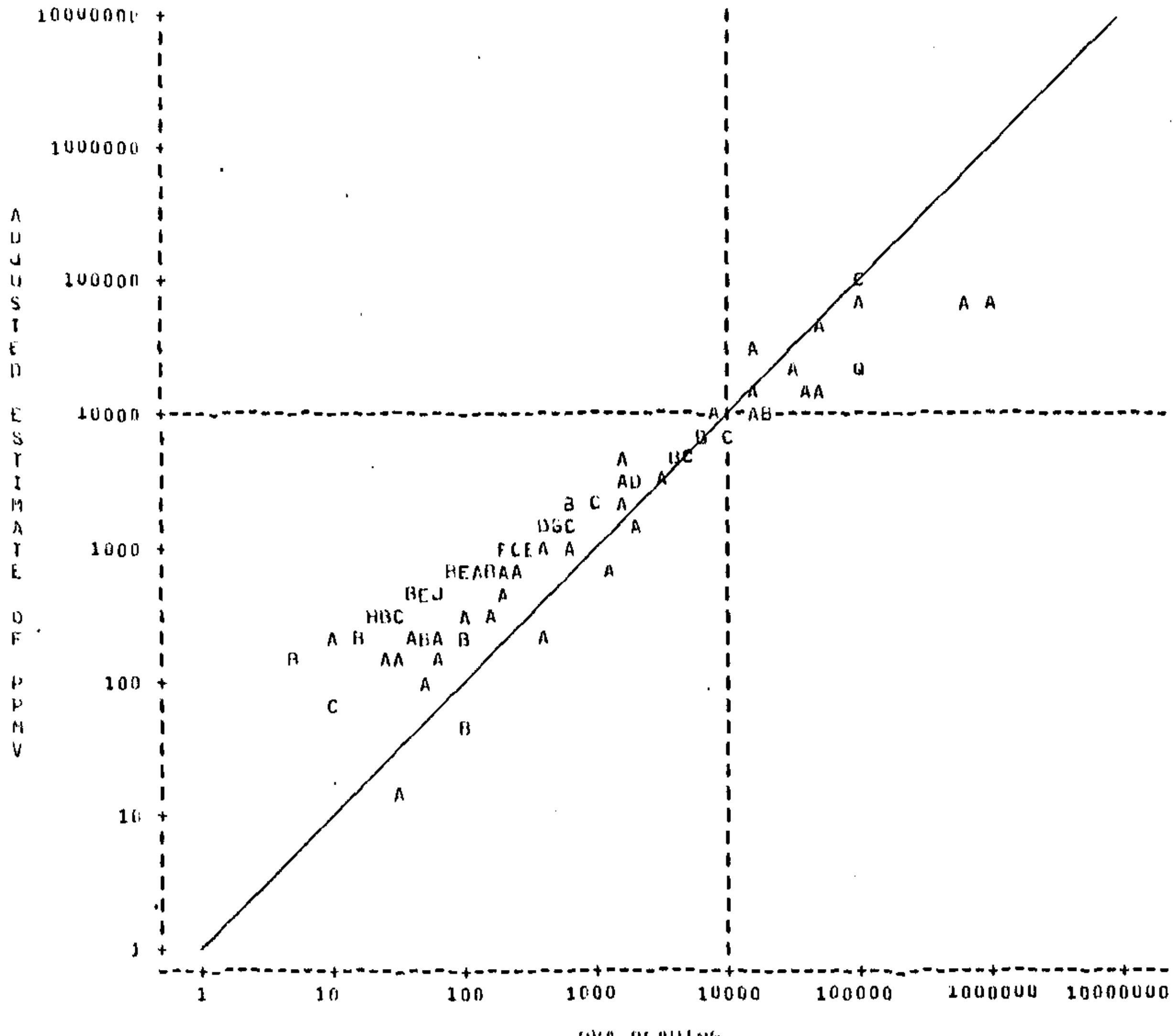
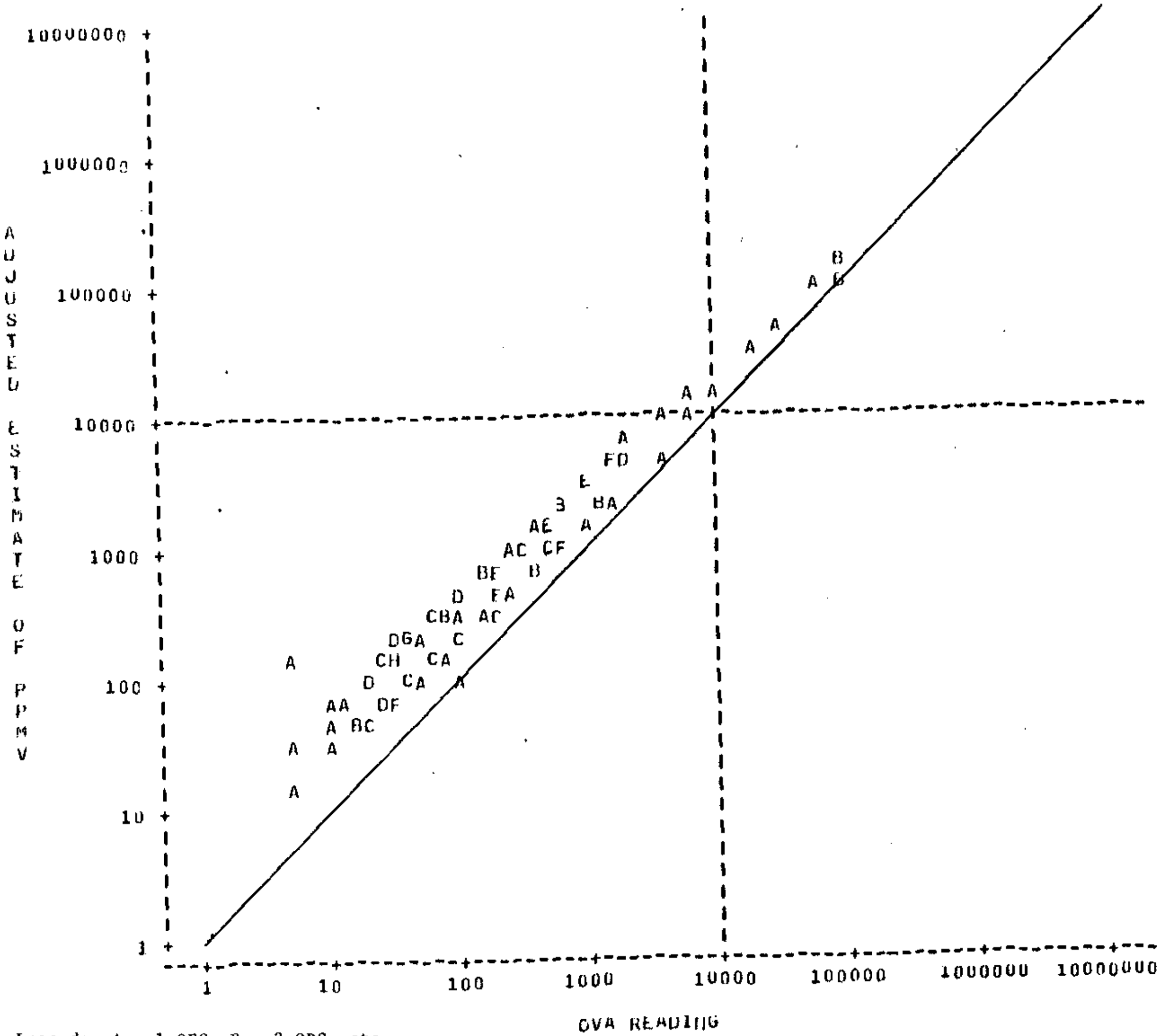


Figure 6-4. OVA Reading vs. Method 1 Adjustment for Ethylene Process Valves in Light Liquid Service



Legend: A = 1 OBS, B = 2 OBS, etc.

Figure 6-5. OVA Reading vs. Method 1 Adjustment for Vinyl Acetate Process Valves in Gas Service



Legend: A = 1 OBS, B = 2 OBS, etc.

Figure 6-6. OVA Reading vs. Method 1 Adjustment for Vinyl Acetate Process Valves in Light Liquid Service

SECTION 7

STATISTICAL CONSIDERATIONS

This section discusses the assumptions and technical details of the statistical methods employed in the analysis of data within this study.

STATISTICAL CATEGORICAL ANALYSIS USING FUNCAT (SECTION 3)

The Funcat procedure in SAS (a computer software system) was used to test for significance in leak frequency between categories. This procedure is used in Section 3 to consider leak frequency as a function of line temperature and pressure for valves in gas stream service.

The analysis is based on fitting a log-linear model to the cell frequencies. The model is:

$$\ln(F_{ijk}) = \theta + \alpha_i + \gamma_j + \alpha\gamma_{ij} \qquad \text{where:}$$

F_{ijk} = expected cell frequency of leaking or not leaking at each level of temperature and pressure

θ = intercept term

α_i = main effect of factor α at level i (in this case, temperature)

γ_j = main effect of factor γ at level j (in this case, pressure)

$\alpha\gamma_{ij}$ = interaction (combined effects) of temperature and pressure

The program tests the significance of the main effects and interaction via χ^2 tests. The resulting analysis tables and interpretations are similar to analysis of variance tables and their interpretations.

The following table is typical of the form of the output from Funcat Analysis.

Source	df	CHI-SQUARE	P
Temperature	3	54.35	0.0001
Pressure	3	252.31	0.0001
Interaction	9	39.69	0.0001

In this example the main effects, temperature and pressure, are significant as is the interaction of these two variables. The P statistics is the probability of making an incorrect significance statement. The interaction, or combined effect, can be seen graphically when either pressure or temperature is plotted against percent leaking, with a separate line drawn for each level of the other variable. Where there is significant interaction, the lines will be non-parallel.

CHI-SQUARE TEST FOR INDEPENDENCE (SECTION 3)

The two-way chi-square test is a technique for testing that two characteristics are independent. Here the term "independent" means the distribution of one characteristic should be the same regardless of the level of the other characteristic. This test is used in Section 3.

When there are two levels of both variables in the two-way classification, the computational formula for testing the hypothesis of independence is:

$$\chi^2 = \frac{N\left(|AD-BC| - \frac{N}{2}\right)^2}{(A+B)(C+D)(A+C)(B+D)}$$

where the letters A through D refer to the cell frequencies, N is the total number of observations and the data is tabulated in a 2 x 2 table as shown:

	VARIABLE I	
VARIABLE II	A	B
	C	D

The degrees of freedom for the χ^2 calculated from this formula is one. A χ^2 value which exceeds the tabulated value (the specified probability (P) point of a chi-squre distribution) indicates a dependence of one variable on the other.

CONFIDENCE INTERVALS FOR PERCENT SOURCES LEAKING (SECTION 3)

Confidence intervals for the percent of leaking sources were computed using the Binomal Distribution. The Binomial is used to model data when a random sample is selected and each item is classified into one of two categories (leaking or non-leaking here). Exact confidence limits (level $1-\alpha$) for the estimate of percent leaking can be obtained by iteration, solving for P_L in

$$\sum_{i=k}^{n} \binom{n}{i} P_L^{\,i} \, (1 - P_L)^{n-i} = \frac{\alpha}{2}$$ for the lower limit and for P_u in

$$\sum_{i=o}^{k} \binom{n}{i} P_u^{\,i} \, (1 - P_u)^{n-i} = \frac{\alpha}{2}$$ for the upper limit,

where n = number of sources screened and k = number of leaking sources. Tables of these solutions (Reference 6), available for most cases, were used to develop 95% confidence intervals reported in Section 3.

SCREENING VALUE DISTRIBUTIONS (SECTION 4)

In order to utilize the results of previous work on the estimation of mass emissions over a range of screening values (Reference 8), it was necessary to confirm that the screening values followed a distribution close to lognormal in form. Summary statistics for Log_e (OVA screening value) were generated, including coefficients of skewness and kurtosis, for cumene units, ethylene units, vinyl acetate units, and for each source type and service. From an earlier study (Reference 2), it was decided that since the detection limit of the OVA is approximately 10 ppmv, that this number would be used to define an emitting (not leaking) source. Separate statistics for screening values below 10 ppmv and for screening values between 10 and 100,000 ppmv were generated to evaluate the effect of a larger-than-expected number of observations at 100,000 ppmv. The patterns of skewness and kurtosis were similar in both cases. An empirical approach was taken in the development of the screening value distributions and their confidence intervals for comparison with the lognormal models (described later).

Chi-square tests were performed to compare the percentage of each screening value category (processes and units within process by source type and service) $\geq$ 10 ppmv. The statistic computed was

$$\chi^2(r-1,d.f.) = \sum_{\substack{\text{All}\\ \text{Categories}}} \frac{(O-E)^2}{E} ,$$

where

$$r = \begin{cases} 3, \text{ comparing 3 processes} \\ 2 \text{ or } 3, \text{ comparing 2 or 3 units within a process} \end{cases} ,$$

O = Observed number of sources < 10 ppmv. or $\geq$ 10 ppmv., for each process or unit,

E = Expected number of sources < 10 ppmv. or $\geq$ 10 ppmv., for each process or unit, and

d.f. = the degrees of freedom.

The empirical cumulative distribution function (CDF) of screening values, defined by

$$\hat{F}(x_0) = \frac{\text{Number of sources screening} \leq x_0}{\text{Total number of sources}}$$

for each category (process by source type by service) was computed. The curves displayed in Figures 4-2 through 4-10 are of the reverse cumulative distribution functions (RCDF):

$$(1-\hat{F}\ (x_0)) \times 100 \text{ vs. } \mathrm{Log}_{10}(x_0)$$

showing the percentage of sources screening greater than given value x_0.

Confidence limits for the RCDF were constructed using a Kolmogorov 2-sided critical value, w (using tables from Reference 4). Upper and lower approximate 95 percent confidence limits for $\hat{F}(x)$ (UCL and LCL, respectively) were obtained using the two following equations:

$$\hat{F}_u(x) = \begin{cases} \hat{F}(x) + w, & \text{if } \hat{F}(x) + w \leq 1 \\ 1.0 & \text{, if } \hat{F}(x) + w > 1 \end{cases}$$

and

$$\hat{F}_\ell(x) = \begin{cases} \hat{F}(x) - w, & \text{if } \hat{F}(x) - w \geq 0 \\ 0 & \text{, if } \hat{F}(x) - w < 0 \end{cases}$$

where w is the tabulated critical value and n is the number of sources screened in the given category. The resulting limits for the RCDF are

$$UCL(x) = (1-\hat{F}_{\ell}(x)) \times 100$$

and

$$LCL(x) = (1-\hat{F}_{u}(x)) \times 100.$$

A lognormal distribution was used to model the distribution of screening values greater than 10 ppmv. This distribution has the property that when the original data are transformed by taking natural logarithms, the transformed data will follow a normal distribution. The lognormal distribution is often appropriate when the standard error of an individual value is proportional to the magnitude of the value. The form of the lognormal distribution is as follows:

$$f(x) = \begin{cases} \dfrac{\exp\left[-\dfrac{\ell n\ x - \mu)^2}{2\sigma^2}\right]}{x\sigma\sqrt{2\pi}} & \text{for } 0 > x > \infty \\ 0 & \text{for } x \leqslant 0\ . \end{cases}$$

In order to develop cumulative screening value distribution curves, the "non-emitting" sources (with screening values less than 10 ppmv) also had to be modeled. A mixed distribution, specifically a lognormal distribution with a discrete probability mass at 0, was used for this purpose. Letting ρ equal the fraction of non-emitting sources in the population, this mixed-lognormal distribution has the following form:

$$f(x) = \begin{cases} \dfrac{(1-\rho)\ \exp\left[-\dfrac{(\ln(x)-\mu)^2}{2\sigma^2}\right]}{x\sigma\sqrt{2\pi}} & \text{for } 10 < x < \infty \\ \rho & \text{for } 0 \leqslant x \leqslant 10 \\ 0 & \text{for } x < 0 \end{cases}$$

$$\text{Mean} = (1-\rho)\ \exp\left[\mu + \frac{\sigma^2}{2}\right]$$

Another set of curves (4-22a through 4-30a) contains the estimated cumulative distribution of log screening values. The curves show 100 percent minus the cumulative percent, or the estimated percent of sources which would have screening values greater than any particular screening value. These cumulative distribution functions were estimated by fitting a lognormal distribution, as described above, to the screening data and then generating the cumulative distribution.

There was some difficulty in fitting the lognormal distribution to the screening values. Figure 4-1 shows a typical histogram of log screening values for valves in gas service. The histogram appears to approximate a normal distribution adequately up to 100,000 ppmv (5.0 on $\log_{10}$ scale). The spike at 100,000 ppmv was due to the inability of the screening device to measure beyond 100,000 without a modification to the dilution probe. The modified dilution probe was used in only a few cases in the screening process during this program.

To overcome the bias caused by this spike, only log screening values less than 5.0 were used to estimate the parameters of this distribution. Formulas from "censored" normal distribution theory (discussed in Reference 3) were then used to arrive at unbiased estimates of the entire distribution. These estimates were used to generate the cumulative distribution function for each source type/process stream grouping.

Confidence intervals for these cumulative functions were obtained using the Binomial Distribution. The 95 percent confidence interval for individual probabilities were approximated using

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

where $\hat{p}$ is the estimated cumulative percent and n is the number of screening values for each particular source type and stream group.

The estimated lognormal cumulative distribution functions were compared with the empirical distribution function and appeared to fit the data reasonably well. Figures 4-2 through 4-10 show the lognormal and empirical distributions for the source type and service classifications. Discrepancies were found at the 100,000 ppmv screening value (5.0 log screening value) in almost all cases, but this was to be expected since the sample function had a big jump at this point.

EMISSION FACTOR DEVELOPMENT (SECTION 4)

Predicted log leak rates were generated for all sources with screening values greater than 10 ppmv, using the prediction equations (Reference 2) developed from modeling the available measured leak rates with associated OVA screening values. Emission factors were estimated from the predicted leak rates using

$$\text{Log}_{10}\ (\text{leak rate}) = \alpha + \beta\ [\text{Log}_{10}\ (\text{OVA Value})] + Z\ (\text{standard error})$$

where α and β are model parameters developed in the maintenance study

(Reference 2) Z is a standard normal random number and the standard error is associated with the prediction equation. Because the true leak rate/screening relationship is unknown, there is a potential bias introduced when these predicted leak rates are used in developing emission factors. This potential bias was taken into account in developing confidence intervals discussed below.

As described in the previous subsection, a lognormal distribution was used to model the distribution of leak rates for emitting sources (i.e., sources with a screening value > ppmv). Coefficients of skewness and kurtosis for Log_e (leak rates) were computed and histograms examined for normality. This assumption is adequate for the generated emissions data. To account for the non-leaking sources, a mixed distribution with a discrete probability mass at zero was fit to the data. The precise form of this distribution was given earlier in this section. The best, unbiased estimator of the population mean emission rate from this distribution is:

$$m = [(1-\hat{p})\ \exp(\bar{y})]\quad g\left(\frac{s^2}{2}\right),$$

where

$g\ \frac{s^2}{2}$ = bias correction factor (discussed in detail in Reference 8).

Confidence intervals for the percent of sources screening > 10 ppmv were computed using the Binomial Distribution. Binomial Confidence Interval tables, available for most cases, were used for computing 97.5 percent confidence intervals which were then used in developing confidence intervals for emission factors. The 97.5 percent was selected so that approximate 95 percent confidence intervals for emission factors would result when the estimated percent leaking was combined with the estimated mean leak rate (0.975 x 0.975 = 0.95).

The 97.5 percent confidence intervals were computed for the average, $\bar{y}$, of the Log_e leak rate estimates using:

$$C_\ell = \text{lower limit} = \bar{y} - 2.24\ [s^2/(n - r)]^{1/2}$$

and

$$C_u = \text{upper limit} = \bar{y} + 2.24\ [s^2/(n - r)]^{1/2}$$

where

s^2 = the variance of the $\log_e$ leak rate estimates and
$(n - r)$ = the number of leaking sources.

Then confidence intervals for the mean leak rate (emission factor estimate) was computed using

$$C_\ell' = \text{lower limit} = \exp[C_\ell]\ g(s^2/2)$$

and

$$C_u' = \text{upper limit} = \exp[C_u]\ g(s^2/2)$$

where

$g(\frac{s^2}{2})$ is the bias correction factor.

To obtain 95 percent confidence limits for the emission factors, the confidence limits for the percent leaking and for the mean leak rate were combined as follows:

lower 95% limit for emission factor = $P_\ell\ (C_\ell')$

upper 95% limit for emission factor = $P_u\ (C_u')$

These confidence intervals are conservative in the sense that 95 percent is a lower bound for the confidence coefficient for the intervals. The intervals consider random sampling variation and random test error, with no adjustments for potential bias in the estimation of the $\log_e$ rates.

An adjustment was applied to the emission factor confidence intervals to account for the potential bias due to estimating leak rates. The standard error of the predicted average $\log_{10}$ leak rate (SEP) was calculated from

$$SEP = \sigma \left(\frac{1}{n} + \frac{\Sigma x_i^2}{k\Sigma(x_i - \bar{x})^2} \right)^{1/2}$$

where n = number of leaking sources,

k = number of data pairs used to estimate the prediction equation, and

x_i = ith screening value (Log_{10} scale) used to estimate the prediction equation.

The reported confidence intervals for the emission factors were widened by a factor of

$$10^{2(SEP)}.$$

A similar procedure was used to adjust the confidence intervals for the mean emission estimate in Section 5.

As a Quality Control measure on the emission factor estimation, an alternative approach to estimate emission factors was also explored. The alternative model was

$$\text{E.F. alternative} = \frac{1}{n} \sum_{i=1}^{n} C \cdot 10^{\log_{10} \text{(leak rate)}},$$

where n = number of sources and C = bias correction factor. This approach employs an estimator based on the arithmetic mean computed in arithmetic scale of the leak rates. (The bias correction factor is actually part of the predicted leak rate in the arithmetic scale as discussed in Reference 2). This alternative estimator is unbiased regardless of the distribution of leak rates and avoids using the generated error term Z (standard error of estimate) for the predicted leak rates. Comparison of the results of these approaches is shown in Table 7-1.

Confidence limits for the alternative estimates of mean leak rates were based on computing the mean leak rates for each of the two limiting distributions of screening values given by the confidence bounds for the empirical CDF as described earlier in this section. These bounds were further adjusted to account for the potential bias in using predicted leak rates. For the alternative estimates, the standard error of the mean (SEM) was calculated from

$$SEM = \frac{\sigma(\text{Log}_e\ 10)}{n} \times \left(\sum_{i=1}^{n} C\ 10 \left([\text{Log}_{10}(\text{leak rate})]^2 \right) \right)^{1/2}$$

where σ = residual error for the fitted prediction equation. The confidence limits were adjusted by adding or subtracting 2.24 SEM to the upper or lower confidence limits, respectively. The results (Table 7-1) are an attempt to approximate 95 percent confidence limits for these alternative estimates. Note that the lower confidence is zero in most cases for the alternative estimate indicating that the ± SEM limits do not adequately reflect the skewness of the distribution of the alternate estimates.

The emission factor estimates are not consistently higher or lower than the quality control estimate.

TABLE 7-1. COMPARISON OF EMISSION FACTORS WITH QUALITY CONTROL ESTIMATES OF MEAN LEAK RATES FOR VALVES AND PUMP SEALS

Process	Source Type	Service	Emission Factor[1] (lbs./hr./source)	Quality Control Estimate[2] (lbs./hr./source)
Cumene	Valves	Gas	0.011(0.003, 0.05)	0.0079(0, 0.02)
		Light Liquid	0.0056(0.002, 0.02)	0.0061(0, 0.02)
	Pump Seals	Light Liquid	0.052(0.001, 2.7)	0.030(0, 0.3)
Ethylene	Valves	Gas	0.024(0.008, 0.07)	0.010(0.004, 0.02)
		Light Liquid	0.020(0.007, 0.06)	0.013(0.008, 0.02)
	Pump Seals	Light Liquid	0.069(0.006, 0.8)	0.085(0,0.7)
Vinyl Acetate	Valves	Gas	0.0046(0.001, 0.03)	0.0027(0, 0.03)
		Light Liquid	0.0003(0.0001, 0.002)	0.0003 (0,0.005)
	Pump Seals	Light Liquid	0.0043(0.0001, 0.1)	0.0051(0,0.06)

[1]Emission factor reported with 95% confidence interval

[2]Quality Control estimate reported with approximate 95% confidence interval based on estimate ±2 (standard error of the estimate)

CUMULATIVE EMISSION FUNCTIONS

A cumulative function for the percentage of total mass emissions for all sources screening greater than a given value was estimated by integrating the leak/screening regression relationship over a lognormal distribution of screening values. This function has the following form:

$$CF = \int_0^{S_0} \frac{C(10)^{B_0}(x)^{B_1}}{x\sigma\sqrt{2\pi}} \exp\left[-\frac{(\ell n(x) - u)^2}{2\sigma^2}\right] dx \Big/ D$$

where

- S_0 = selected upper screening value for integration,
- C = log/arithmetic scale bias correction factor,
- B_0 = $\log_{10}$ regression intercept term,
- B_1 = $\log_{10}$ regression slope term,
- u = mean of the $\log_e$ (screening values),
- σ^2 = variance of the $\log_e$ (screening values),
- x = screening values over which the integration is being done, and
- CF = cumulative function described above in lbs/hr
- D = numerator of CF evaluated at S_0 = 1,000,000

The form of the cumulative function can be simplified by algebraic reduction and change of variables to obtain:

$$CF = \Phi\left[\frac{\ell n(S_0) - u - B_1\sigma^2}{\sigma}\right] \Big/ \Phi\left[\frac{\ell n(1{,}000{,}000) - u - B_1\sigma^2}{\sigma}\right]$$

where Φ is the cumulative function of a standard normal distribution.

This function was used in developing the cumulative emissions function shown on the nomographs. The censored distribution parameter estimates described earlier were used for the lognormal distribution parameters in each case. The log/log least-squares regression estimates were used for the scale bias correction factor and for B_0 and B_1. Division by the numerator of the function evaluated at one million ppmv forced the function to 1.0 at one million ppmv. These function values were then subtracted from 1.0 and multiplied by 100.0 to obtain the functions shown in Figures 4-22b through 4-30b.

The estimated lognormal cumulative emissions functions were compared with the empirical functions (discussed below) and found to adequately approximate the data. Figures 4-13 through 4-21 show the lognormal and empirical functions for the source type and service classifications. The biggest discrepancies were near the 100,000 ppmv screening value where the sample function has a big jump. This area is more critical for this function than the cumulative distribution function since most of the emissions are attributable to sources with screening values greater than 100,000 ppmv. It is important to note that very little screening data are available with screening values greater than 100,000 ppmv. Thus, this portion of the curve is based on extrapolations using models developed from screening values less than 100,000 ppmv.

This cumulative function is a very complex nonlinear function of three sample statistics. Due to the complexity of this function, it was not possible to derive a closed-form analytical expression for the confidence intervals. Thus, a Monte-Carlo computer method was used to generate the confidence intervals.

This method involved regenerating the cumulative function 200 times. Each time, the data collected in the project (the number of sources with screening values greater than 10 ppmv) were regenerated, except with an independent set of random variations. The distributional properties of the leak rate and screening data were used in computing the required random numbers.

For each of the 200 trials, sample estimates of the three parameters required to compute the cumulative function were computed. Then these estimates were used to generate a new cumulative function. The one percent lower result and the 99 percent upper result from the 200 trials for any given screening value were then selected as approximate 95 percent confidence limits for the population cumulative function.

Since these confidence limits address the uncertainty in the cumulative function for the entire sampled population of a particular source type, they are not necessarily applicable to a finite sample of sources in a particular situation. The variation of this function depends on the number of sources in a complex manner, so it is not possible to draw a general conclusion for the effect of sample size.

Empirical functions computing the percentage of total mass emissions for all sources screening greater than a given screening value were developed using the estimator

$$\hat{G}(x_0) = \frac{\sum_{x \leqslant x_0} C \cdot 10^{\text{Log}_{10}\,(\text{leak rate})}}{\sum_{\text{all } x} C \cdot 10^{\text{Log}_{10}\,(\text{leak rate})}}$$

in addition to the approach based on the lognormal distribution discussed earlier. Note that the denominator of $\hat{G}(x_0)$ is an expression for the total mass emission used in the quality control check for estimating emission factors.

Confidence bounds for $\hat{G}(x_0)$ were obtained by evaluating $\hat{G}(x_0)$ for the screening value distributions corresponding to the confidence bounds shown in Figures 4-13 through 4-21. Applying a standard approximation to calculate the variance of a ratio (Reference 5), the following expression for the standard error of $\hat{G}(x_0)$ was derived:

$$SE = \sigma(\mathrm{Log}_e(10))\left(\frac{\sum\limits_{x \leqslant x_0} A}{\sum\limits_{\mathrm{All}\ x} A}\right)^2 \left(\sum_{x \leqslant x_0} A^2 \left[\frac{\sum\limits_{x > x_0} A - \sum\limits_{x \leqslant x_0} A}{\left(\sum\limits_{x \leqslant x_0} A\right)^2 \left(\sum\limits_{\mathrm{All}\ x} A\right)}\right] + \sum_{\mathrm{All}\ x} A^2 \left[\frac{1}{\left(\sum\limits_{\mathrm{All}\ x} A\right)^2}\right]\right),$$

where $A = 10^{[\mathrm{Log}_{10}\ (\mathrm{leak\ rate})]}$.

The confidence bounds were adjusted by adding or subtracting 2.24 x SE to the upper or lower confidence bounds, respectively.

INCREASE IN MASS EMISSIONS DUE TO OCCURRENCE AND RECURRENCE (SECTION 5)

Increase (or reduction) of mass emissions reported in this study has been expressed in two ways:

- Weighted percent increase (reduction)
- Mean increase (reduction)

The first measure of change in mass emissions has been discussed in detail in Reference 2 as Weighted Percent Reduction (WPR), defined as the percent of total emissions reduced due to maintenance:

$$WPR = \frac{(\sum^{n} \text{mass emissions before} - \sum^{n} \text{mass emissions after})}{\sum^{n} \text{mass emissions before}} \times 100\%$$

(See Reference 2 also for a discussion of the development of confidence intervals for this estimate.) Weighted percent increase (WPI) is defined as WPI = -WPR, where "before" and "after" refer to before and after leak occurrence, recurrence, or maintenance, depending upon the application.

The mean increase is defined as the difference in mass of the average before and after maintenance emissions from individual sources. Confidence intervals for this measure of increase in mass emissions are given by:

$$\text{Mean increase} \pm t_{0.975} \times \text{SE},$$

$$\text{SE} = \text{Standard deviation of increase}/\sqrt{n}\text{, where n = number of sources.}$$

Reference 2 provides details of the estimation of nonmeasured leak rates from screening values via prediction equations appropriate to source type and service type. The equations, as expressed in arithmetic scale, were applied as discussed in Reference 2, except for sources in unit 1. In unit 1 there was no information on service type for valves in the occurrence analysis.

The following equation was used for these valves:

$$\text{Predicted Leak Rate} = 5.08 \cdot 10^{[-5.22 + 0.67 \text{ Log}_{10}(\text{OVA Screening Value})]}$$

This equation represents an average between the equations for valves/gas service and valves/liquid service. The confidence intervals for the average emission estimates were adjusted for potential bias from using these equations. The adjustment procedure was previously described in this section.

RESPONSE MODEL ADJUSTMENTS TO SCREENING VALUES (SECTION 6)

Three methods were used to adjust the OVA readings for the response characteristics of the chemicals in the line. The first method (Method 1) was to simply adjust the OVA reading by the response curve of the primary chemical. If a response adjustment technique were to be incorporated in a monitoring program this would represent the simplest approach.

The underlying model for this adjustment is

$$r = a(C_T)^b$$

where, r = OVA response
C_T = actual total concentration
a,b = *parameters of the model.*

The parameters a and b were estimated for 168 different chemical compounds in an earlier study (Reference 7).

To estimate the actual concentration for a given OVA response, r_o, for chemical i, calculate

$$\hat{C}_T = \exp\left(\frac{\log(r_o) - a_i}{b_i}\right)$$

The other two adjustment methods used to estimate actual concentration take into account the mixed nature of the chemical composition. The OVA response to a mixture of compounds is intermediate to the individual responses to each compound at the same concentration. Using this concept, one of the mixed chemical adjustment methods (Method 3) used a weighted average of the responses to estimate actual concentration. An estimate of the weighted response is

$$R_A = \sum p_i a_i C_T^{b_i} e^{\frac{1}{2}s^2_i} \qquad (1)$$

where, R_A = the estimated weighted average response,

p_i = the fraction of the mixture total concentration accounted for by compound i ($P_i = C_i/C_T$),

a_i = exp (A) with "A" from Brown, et al (1980) for component i,

b_i = coefficient "B" from Brown, et al (1980) for component i,

s_i = parameters "SE" from Brown, et al (1980) for component i,

C_T = ΣC_i, the total concentration, and

C_i = the concentration in the mixture of compound i.

The coefficients A, B, and SE can be found in Tables 5-169 and 5-170 of Brown, et al (1980) (Reference 7) for selected compounds.

The above discussion involves the prediction of an instrument response when the actual concentration of mixture components are known. For this study, the reverse is the case: the response is observed and it is desired to estimate the total concentration of the constituents. Basically, this cannot be done without some additional information. The compound identification of the constituents must be known. If the constituent proportions are also know, the total concentration can be computed assuming the above model is correct. The total concentration (C_T) is estimated by solving equation 1.

Equation 1 cannot be solved explicitly for total concentration. An iterative solution is required. This can be done using the Newton-Raphson method. Let

$$f(C_T) = \sum_i p_i a_i \, C_T^{b_i} \, e^{\frac{1}{2}s_i^2} - R$$

where R is the observed instrument response, and

$$f'(C_T) = \sum_i p_i b_i a_i C_T^{b_i - 1} e^{\frac{1}{2}s_i^2}$$

Then the iteration formula is

$$C_{j+1} = C_j - f(C_j)/f'(C_j),$$

A reasonable starting value C_o is R, the observed instrument response.

The other mixed chemical adjustment method (Method 2) used for estimating actual concentration was a weighted logarithmic average. In this case

$$\log(R_L) = \sum_i p_i \left[\log a_i + \tfrac{1}{2}s_i^2 + b_i \log C_T\right] \qquad (2)$$

where R_L is the estimated instrument response using a weighted logarithmic average

In contrast to the previously given weighted arithmetic average model (equation 1), this weighted logarithmic average model (equation 2) has an explicit solution for actual total concentration:

$$\hat{C}_T = \exp\left[\frac{\log R - \sum p_i \, (\log a_i + \frac{1}{2}s_i^2)}{\sum p_i b_i}\right]$$

Both of the chemical mixture methods used the information on primary and secondary chemicals and their percentage of the total concentration. If their percentages did not total 100 percent, (i.e., there were other chemical compounds in the line) the rest of the percentage was assigned a response factor of 1.

REFERENCES

1. Blacksmith, J. R., G. E. Harris, and G. J. Langley. Frequency of Leak Occurrence for Fittings in Synthetic Organic Chemical Plant Process Units: Final Report. EPA-600/2-81-003 (NTIS No. PB81-14566), U. S. Environmental Protection Agency, Research Triangle Park, N. C., 1980.

2. Langley, G. J. and R. G. Wetherold. Evaluation of Maintenance for Fugitive VOC Emissions Control: Final Report. EPA-600/S2-81-080, U. S. Environmental Protection Agency, Cincinnati, Ohio, 1981.

3. Wetherold, R. G. and L. P. Provost. Emission Factors and Frequency of Leak Occurrence for Fittings in Refinery Process Units. EPA-600/2-79-044, U. S. Environmental Protection Agency, Washington, D. C., 1979.

4. Conover, W. J. Practical Nonparametric Statistics. John Wiley and Sons Inc., New York, 1971.

5. Mood, A. M., F. A. Graybill, and D. C. Boes. Introduction to the Theory of Statistics, Third Edition. McGraw-Hill Book Company, New York, 1974.

6. Beyer, W. H. (ed.). CRC Handbook of Tables for Probability and Statistics, Second Edition. The Chemical Rubber Co., Cleveland, Ohio, 1968.

7. Brown, G. E., D. A. DuBose, W. R. Phillips, and G. E. Harris. Response Factors of VOC Analyzers Calibrated with Methane for Selected Organic Chemicals. EPA-600/2-81-002 (NTIS No. PB81-136194), U. S. Environmental Protection Agency, Research Triangle Park, N.C., 1980.

8. Wetherold, R. G. and D. D. Rosebrook. Environmental Assessment of Atmospheric Emissions from Petroleum Refinery. EPA-600/2-80-075a (NTIS No. PB80-225-253), U. S. Environmental Protection Agency, Research Triangle Park, N. C., 1980.

APPENDIX A

SCREENING DATA SUMMARY

Section 3 of this report contains an analysis of screening data collected on an earlier EPA project (Reference 1). This appendix gives detailed source type groupings of this data. Table A-1 gives the number of sources screened, the number leaking and the percent leaking for each possible source type and for each type of stream service, including heavy liquids.

TABLE A-1. DATA SUMMARY OF LEAK FREQUENCIES FOR VARIOUS SOURCES IN VARIOUS STREAM SERVICES

Source	Service	Number Screened	Number Leaking[1]	Percent Leaking[1]
Flange	Gas	1450	66	4.5
	Light Liquid	2833	36	1.3
	Heavy Liquid	607	0	0.0
Process Drain	Gas	83	2	2.4
	Light Liquid	496	19	3.8
	Heavy Liquid	28	2	7.1
Open-End Line	Gas	923	54	5.8
	Light Liquid	3605	141	3.9
	Heavy Liquid	477	6	1.3
Agitator Seal	Gas	7	1	14.3
	Light Liquid	8	0	0.0
	Heavy Liquid	1	0	0.0
Relief Valve	Gas	84	3	3.6
	Light Liquid	68	2	2.9
	Heavy Liquid	3	0	0.0
Block Valve-Gate Type	Gas	6976	952	13.6
	Light Liquid	11017	1059	9.6
	Heavy Liquid	2034	9	0.4
Block Valve-Globe Type	Gas	145	15	10.3
	Light Liquid	755	8	1.1
	Heavy Liquid	129	0	0.0
Block Valve-Plug Type	Gas	440	0	0.0
	Light Liquid	2479	2	0.1
	Heavy Liquid	1031	0	0.0
Block Valve-Ball Type	Gas	1272	18	1.4
	Light Liquid	2732	4	0.1
	Heavy Liquid	251	4	1.6

[1]Leaking defined as OVA reading ⩾10,000 ppmv.

(continued)

TABLE A-1. DATA SUMMARY OF LEAK FREQUENCIES FOR VARIOUS SOURCES IN VARIOUS STREAM SERVICES (CONTINUED)

Source	Service	Number Screened	Number Leaking[1]	Percent Leaking[1]
Block Valve - Butterfly Type	Gas	160	9	5.6
	Light Liquid	157	2	1.3
	Heavy Liquid	8	0	0.0
Block Valve - Other Types	Gas	275	16	5.8
	Light Liquid	378	17	4.5
	Heavy Liquid	35	0	0.0
Control Valve - Gate Type	Gas	61	15	24.6
	Light Liquid	182	22	12.1
	Heavy Liquid	27	0	0.0
Control Valve - Globe Type	Gas	207	36	17.4
	Light Liquid	417	61	14.6
	Heavy Liquid	107	0	0.0
Control Valve - Plug Type	Gas	10	0	0.0
	Light Liquid	91	3	3.0
	Heavy Liquid	0	-	-
Control Valve - Ball Type	Gas	15	4	26.7
	Light Liquid	33	1	3.0
	Heavy Liquid	3	0	0.0
Control Valve - Butterfly Type	Gas	91	35	38.5
	Light Liquid	34	3	8.9
	Heavy Liquid	6	0	0.0
Control Valve - Other Types	Gas	17	3	17.6
	Light Liquid	25	1	4.0
	Heavy Liquid	1	0	0.0
On-Line Pump Seals Single Mechanical-Emission Point at Seal	Light Liquid	215	28	13.0
	Heavy Liquid	60	2	3.3

[1]Leaking defined as OVA reading ≥10,000 ppmv.

(continued)

TABLE A-1. DATA SUMMARY OF LEAK FREQUENCIES FOR VARIOUS SOURCES IN VARIOUS STREAM SERVICES (CONTINUED)

Source	Service	Number Screened	Number Leaking[1]	Percent Leaking[1]
On-Line Pump Seals Single Mechanical - Emission Point at Vent	Light Liquid	24	0	0.0
	Heavy Liquid	0	-	-
On-Line Pump Seals Single Mechanical - Other Emission Point	Light Liquid	30	2	6.7
	Heavy Liquid	0	-	-
On-Line Pump Seals Double Mechanical - Emission Point at Seal	Light Liquid	92	13	14.1
	Heavy Liquid	2	0	0.0
On-Line Pump Seals Double Mechanical - Emission Point at Vent	Light Liquid	3	1	33.3
	Heavy Liquid	0	-	-
On-Line Pump Seals Double Mechanical - Other Emission Point	Light Liquid	0	-	-
	Heavy Liquid	0	-	-
On-Line Pump Seals Single, Packed, Emission Point at Seal	Light Liquid	5	0	0.0
	Heavy Liquid	1	0	0.0
On-Line Pump Seals Single, Packed, Emission Point at Vent	Light Liquid	0	-	-
	Heavy Liquid	0	-	-
On-Line Pump Seals Single, Packed, Other Emission Point	Light Liquid	1	0	0.0
	Heavy Liquid	0	-	-
On-Line Pump Seals Sealess Pumps	Light Liquid	0	-	-
	Heavy Liquid	0	-	-

[1]Leaking defined as OVA reading ≥10,000 ppmv.

(continued)

TABLE A-1. DATA SUMMARY OF LEAK FREQUENCIES FOR VARIOUS SOURCES IN VARIOUS STREAM SERVICES (CONTINUED)

Source	Service	Number Screened	Number Leaking[1]	Percent Leaking[1]
Off-Line Pump Seals				
Single Mechanical -				
Emission	Light Liquid	139	9	6.5
Point at Seal	Heavy Liquid	24	0	0.0
Off-Line Pump Seals				
Single Mechanical -				
Emission	Light Liquid	9	0	0.0
Point at Vent	Heavy Liquid	0	-	-
Off-Line Pump Seals				
Single Mechanical -				
Other	Light Liquid	17	0	0.0
Emission Point	Heavy Liquid	1	0	0.0
Off-Line Pump Seals				
Double Mechanical -				
Emission	Light Liquid	86	3	3.5
Point at Seal	Heavy Liquid	1	0	0.0
Off-Line Pump Seals				
Double Mechanical -				
Other	Light Liquid	1	0	0.0
Emission Point	Heavy Liquid	0	-	-
Off-Line Pump Seal				
Single, Packed				
Emission	Light Liquid	19	0	0.0
Point at Seal	Heavy Liquid	8	0	0.0
Off-Line Pump Seals,				
Single, Packed				
Emission	Light Liquid	2	0	0.0
Point at Vent	Heavy Liquid	0	-	-
Off-Line Pump Seals,				
Single, Packed				
Other	Light Liquid	0	-	-
Emission Point	Heavy Liquid	0	-	-

[1]Leaking defined as OVA reading 10,000 ppmv.

(continued)

TABLE A-1. DATA SUMMARY OF LEAK FREQUENCIES FOR VARIOUS SOURCES IN VARIOUS STREAM SERVICES (CONTINUED)

Source	Service	Number Screened	Number Leaking[1]	Percent Leaking[1]
Off-Line Pump Selas, Sealess Pumps	Light Liquid	0	-	-
	Heavy Liquid	0	-	-
On-Line Compressor Seals, Single, Mechanical, Emission Point at Seal	Gas	0	-	-
On-Line Compressor Seals, Single, Mechanical, Emission Point at Vent	Gas	0	-	-
On-Line Compressor Seals, Single, Mechanical, Other Emission Point	Gas	3	1	33.3
On-Line Compressor Seals, Double, Mechanical, Emission Point at Seal	Gas	6	0	0.0
On-Line Compressor Seals, Double, Mechanical, Emission Point at Vent	Gas	1	0	0.0
On-Line Compressor Seals, Double, Mechanical, Other Emission Point	Gas	4	0	0.0
On-Line Compressor Seals, Single, Packed, Emission Point at Seal	Gas	1	0	0.0
On-Line Compressor Seals, Single, Packed, Emission Point at Seal	Gas	1	1	100.0

[1]Leaking defined as OVA reading ≥10,000 ppmv.

(continued)

TABLE A-1. DATA SUMMARY OF LEAK FREQUENCIES FOR VARIOUS SOURCES IN VARIOUS STREAM SERVICES (CONTINUED)

Source	Service	Number Screened	Number Leaking[1]	Percent Leaking[1]
On-Line Compressor Seals, Single, Packed, Other Emission Point	Gas	1	0	0.0
Other Source Types	Gas	19	3	15.8
	Light Liquid	33	2	6.1
	Heavy Liquid	2	0	0.0

[1]Leaking defined as OVA reading ≥10,000 ppmv.

APPENDIX B

DETAILED INFORMATION ON
LINE TEMPERATURE AND LINE PRESSURE

Section 3 contains an analysis of the effect of temperature and pressure on leak frequency. This appendix contains statistical information on temperature and pressure.

Tables B-1 to B-3 contain summary statistics for line pressure and line temperature for gas, light liquid, and heavy liquid stream services. Separate values are given for each of the major source types. Differences between the types of processes, ethylene versus high leaking, and also between the groups of primary chemicals in the line can be seen at this stage. For example, the average line temperature for the high leaking process units appears to be much higher than that for the ethylene units. The minimum temperature for the ethylenes is also much lower. Line pressure seems to differ more by type of chemical in the line. The heavy liquids are not broken down by primary material groups in the line since they had a low leak frequency.

Although line temperature and pressure were recorded as continuous variables, they are grouped for evaluating leak frequency. Tables B-4 to B-16 show the number screened, percent screened, number leaking, and percent leaking at different levels of temperature and pressure. This information is given for ethylene process units and for high leaking process units and also for primary material groups for all source types but pump seals. Possible reasons for some of the differences in leak frequencies for the different categories can be seen from these tables. None of the high leaking group sources are at very low temperatures. This group also has some screening values for each source type at the higher temperatures. The ethylene group exhibits a different distribution of temperatures. There are some values in the very low temperature group; and on the average, the temperatures found in the ethylene unit sources are lower. If the data were not separated into these groups, differences that were actually attributable to the type of process unit might appear to be due to line temperature.

Figures B-1 to B-4 show the distributions of the sources screened as a function of line temperature and line pressure for valves in gas and light liquid service.

TABLE B-1. SUMMARY STATISTICS FOR LINE TEMPERATURE AND LINE PRESSURE FOR GAS SERVICE

Variable	Type	PRIMARY CHEMICAL Group[1]: Statistics	High Leaking Process Units: Group 5	High Leaking Process Units: Group 6	Ethylene Process Units: Group 1	Ethylene Process Units: Group 2
Line Temperature (°F)	Valves	Average	210.8	217.0	60.7	-
		Standard Deviation	153.2	195.4	101.8	-
		Minimum	30	20	-267	-
		Maximum	825	1000	1570	-
	Flanges	Average	271.3	235.3	73.3	-
		Standard Deviation	146.8	228.5	94.0	-
		Minimum	30	20	-267	-
		Maximum	800	1000	750	-
	Open Ended Lines	Average	128.2	218.1	46.1	-
		Standard Deviation	82.1	190.6	74.7	-
		Minimum	30	20	-267	-
		Maximum	392	1000	720	-
Line Pressure (psig)	Valves	Average	184.7	56.4	166.7	-
		Standard Deviation	167.4	99.5	178.7	-
		Minimum	-10	-15	0	-
		Maximum	600	650	1050	-
	Flanges	Average	273.6	37.7	184.6	-
		Standard Deviation	184.9	85.0	160.0	-
		Minimum	-9	-15	0	-
		Maximum	600	590	805	-
	Open Ended Lines	Average	132.0	52.1	120.6	-
		Standard Deviation	142.5	92.9	160.3	-
		Minimum	0	-15	1	-
		Maximum	600	450	805	-

[1]See Figure 3-2 for explanation of groups.

TABLE B-2. SUMMARY STATISTICS FOR LINE TEMPERATURE AND LINE PRESSURE FOR LIGHT LIQUID SERVICE

			High Leaking Processing Units		Ethylene Process Units	
		PRIMARY CHEMICAL Group[1]:	Group 7	Group 8	Group 3	Group 4
Variable	Type	Statistics				
Line Temperature (°F)	Valves	Average	147.2	145.5	20.3	129.4
		Standard Deviation	94.1	90.8	86.4	57.2
		Minimum	20	15	-267	40
		Maximum	500	1000	190	235
	Pump Seals	Average	129.5	133.8	8.0	112.6
		Standard Deviation	82.4	68.2	73.6	70.8
		Minimum	32	32	-145	40
		Maximum	540	345	118	235
	Flanges	Average	165	148.3	44.7	128.4
		Standard Deviation	93	102.8	71.9	49.6
		Minimum	20	30	-212	40
		Maximum	500	1000	190	235
	Open Ended Lines	Average	142.8	137.2	44.4	154.6
		Standard Deviation	100.6	83	84.5	74.7
		Minimum	30	20	-267	40
		Maximum	500	1000	190	235
Line Pressure (psig)	Valves	Average	161.0	80.2	372.0	101.8
		Standard Deviation	190.5	78.5	368.1	111.6
		Minimum	-10	-20	0	2
		Maximum	740	700	2270	500
	Pump Seals	Average	116.2	79.3	512.2	65.1
		Standard Deviation	152.8	77.5	427.6	57.4
		Minimum	0	0	80	2
		Maximum	720	700	1960	165
	Flanges	Average	247.3	70.6	380.7	79.2
		Standard Deviation	210.4	77.0	396.3	79.8
		Minimum	-9	-20	0	2
		Maximum	740	700	2270	500
	Open Ended Lines	Average	123.7	66.9	379.4	75.5
		Standard Deviation	171.1	67.4	383.9	96.6
		Minimum	0	-20	0	0
		Maximum	740	700	2270	500

[1]See Figure 3-2 for explanation of groups.

TABLE B-3. SUMMARY STATISTICS FOR LINE TEMPERATURE AND LINE PRESSURE IN HEAVY LIQUID SERVICE WITHIN HIGH AND ETHYLENE PROCESS UNITS

Variable	Type	Statistics	High Leaking Process Units	Ethylene Leaking Process Units
Line Temperature (°F)	Valves	Average	228.8	128.1
		Standard Deviation	177.7	70.0
		Minimum	60	25
		Maximum	600	370
	Pump Seals	Average	153.6	168.1
		Standard Deviation	146.8	60.5
		Minimum	72	90
		Maximum	460	300
	Flanges	Average	219.9	124.8
		Standard Deviation	63.4	63.8
		Minimum	60	25
		Maximum	500	300
	Open Ended Lines	Average	93.9	156.6
		Standard Deviation	41.1	90.1
		Minimum	60	60
		Maximum	260	30
Line Pressure (psig)	Valves	Average	58.5	97.0
		Standard Deviation	55.4	110.4
		Minimum	1	0
		Maximum	230	540
	Pump Seals	Average	78.6	48.4
		Standard Deviation	10.2	57.7
		Minimum	62	0
		Maximum	92	170
	Flanges	Average	63.9	89.5
		Standard Deviation	67.3	112.9
		Minimum	1	0
		Maximum	230	320
	Open Ended Lines	Average	50.0	68.8
		Standard Deviation	40.4	95.9
		Minimum	1	0
		Maximum	120	480

TABLE B-4. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON PERCENT LEAKING FOR VALVES IN GAS SERVICE WITHIN ETHYLENE PROCESS UNITS

	Group 1[1] PRIMARY CHEMICALS			
Pressure (psig)	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking
-15 - -1	0	0	-	-
0 - 49	2123	35.1	94	4.4
50 - 99	1072	17.8	171	16.0
100 - 149	681	11.3	110	16.2
150 - 199	157	2.6	36	22.9
200 - 249	321	5.3	73	22.7
250 - 299	502	8.3	136	27.1
300 - 349	196	3.2	51	26.0
350 - 399	144	2.4	54	37.5
400 - 449	94	1.6	20	21.3
450 - 499	267	4.4	54	20.2
500 - 549	316	5.2	91	28.9
550 - 999	167	2.8	37	22.2
1000 - 1050	4	0.1	2	50.0
TOTAL	6043		929	15.4
Temperature (°F)				
-267 - -1	998	16.5	140	14.0
0 - 49	1452	24.0	236	16.2
50°F - 99	2035	33.6	327	16.1
100°F - 149	1011	16.7	111	11.0
150°F - 199	373	6.2	72	19.3
200°F - 249	78	1.3	27	34.6
250°F - 299	32	0.5	8	25.0
300°F - 349	4	0.1	0	0.0
350°F - 399	19	0.3	7	36.8
400°F - 1570	48	0.8	4	8.3
TOTAL	6050		932	15.4

[1]See Figure 3-2 for explanation of groups.

TABLE B-5. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON PERCENT LEAKING FOR VALVES IN GAS SERVICE WITHIN HIGH LEAKING PROCESS UNITS BY CHEMICAL GROUP

Group[1]:	Group 3[1] PRIMARY CHEMICALS				Group 4[1] PRIMARY CHEMICALS			
Pressure (psig)	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking
-15 - -1	5	0.4	0	0.0	66	3.8	0	0.0
0 - 49	203	16.5	9	4.4	1201	68.3	7	0.6
50 - 99	282	23.0	31	11.0	141	8.0	2	1.4
100 - 149	267	21.7	30	11.2	136	7.7	12	8.8
150 - 199	53	4.3	6	11.3	34	1.9	1	2.9
200 - 249	87	7.1	9	10.3	18	1.0	0	0.0
250 - 299	136	11.1	13	9.5	20	1.1	0	0.0
300 - 349	10	0.8	0	0.0	84	4.8	0	0.0
350 - 399	15	1.2	4	26.7	13	0.7	0	0.0
400 - 449	0	0.0	-	-	13	0.7	0	0.0
450 - 499	80	6.5	21	26.2	6	0.3	0	0.0
500 - 549	37	3.0	9	24.3	18	1.0	0	0.0
550 - 999	53	4.3	14	26.4	8	0.5	0	0.0
1000 - 1050	0	0.0	-	-	0	0.0	-	-
TOTAL	1228		146	11.9	1758		22	1.2
Temperature (°F)								
-267 - -1	0	0.0	-	-	0	0.0	-	-
0 - 49	12	1.0	1	8.3	45	2.6	0	0.0
50°F - 99	243	19.8	27	11.1	335	19.1	4	1.2
100°F - 149	355	29.0	31	8.7	454	25.8	2	0.4
150°F - 199	127	10.4	9	7.1	369	21.0	0	0.0
200°F - 249	43	3.5	2	4.6	156	8.9	2	1.3
250°F - 299	77	6.3	8	10.4	113	6.4	1	0.9
300°F - 349	109	8.9	14	12.8	63	3.6	1	1.6
350°F - 399	113	9.2	22	19.5	7	0.4	0	0.0
400°F - 1570	146	11.9	31	21.2	216	12.3	12	5.6
TOTAL	1225		145	11.8	1758		22	1.2

[1]See Figure 3-2 for explanation of groups.

TABLE B-6. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON PERCENT LEAKING FOR VALVES IN LIGHT LIQUID SERVICE WITHIN ETHYLENE PROCESS UNITS BY CHEMICAL GROUP

	GROUP 3[1] PRIMARY CHEMICALS				GROUP 4 PRIMARY CHEMICALS			
Pressure (psig)	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking
-15 - -1	0	0.0	-	-	0	0.0	-	-
50 - 49	480	13.7	57	111.9	173	28.5	0	0.0
50 - 99	363	10.3	66	18.2	215	35.4	4	1.9
100 - 149	226	6.4	54	21.9	107	17.6	1	0.9
150 - 199	229	6.5	56	24.4	54	8.9	0	0.0
200 - 249	138	3.9	55	39.9	20	3.3	3	15.0
250 - 299	477	13.6	156	32.7	0	0.0	-	-
300 - 349	141	4.0	43	30.5	0	0.0	-	-
350 - 399	310	8.8	94	30.3	0	0.0	-	-
400 - 449	109	3.1	28	25.7	0	0.0	-	-
450 499	273	7.8	59	21.6	0	0.0	-	-
500 - 549	242	6.9	93	38.4	38	6.3	1	2.6
550 - 999	312	8.9	97	31.1	0	0.0	-	-
1000 - 1050	211	6.0	99	46.9	0	0.0	-	-
TOTAL	3511		957	27.3	607		9	1.5
Temperature (°F)								
-267 - -1	1349	38.4	265	19.6	0	0.0	-	-
0 - 49	724	20.6	207	28.6	29	4.8	0	0.0
50 - 99	829	23.6	287	34.6	127	20.9	2	1.6
100 - 149	500	14.2	177	35.4	252	41.5	3	1.2
150 - 199	108	3.1	21	19.4	89	14.7	3	3.4
200 - 249	0	0.0	-	-	110	18.1	1	0.9
250 - 299	0	0.0	-	-	0	0.0	-	-
300 - 349	0	0.0	-	-	0	0.0	-	-
350 - 399	0	0.0	-	-	0	0.0	-	-
400 - 1570	0	0.0	-	-	0	0.0	-	-
TOTAL	3510		957	27.3	607		9	1.5

[1]See Figure 3-2 for explanation of groups.

TABLE B-7. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON PERCENT LEAKING FOR VALVES IN LIGHT LIQUID SERVICE WITHIN HIGH LEAKING PROCESS UNITS BY CHEMICAL GROUP

	Group 7[1] PRIMARY CHEMICALS				Group 8[1] PRIMARY CHEMICALS			
Pressure (psig)	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking
-15 - -1	6	0.2	1	16.7	21	0.3	0	0.0
0 - 49	1075	32.6	20	1.9	2411	39.4	16	0.7
50 - 99	702	21.3	21	3.0	1567	25.6	5	0.3
100 - 149	383	11.6	20	5.2	1034	16.9	13	1.3
150 - 199	317	9.6	16	5.0	621	10.2	3	0.5
200 - 249	100	3.0	9	9.0	261	4.3	2	0.8
250 - 299	45	1.4	6	13.3	21	0.3	0	0.0
300 - 349	168	5.1	10	6.0	140	2.3	5	3.6
350 - 399	29	0.9	4	13.8	24	0.4	0	0.0
400 - 449	33	1.0	5	15.2	4	0.1	0	0.0
450 - 499	36	1.1	3	8.3	0	0.0	-	-
500 - 549	174	5.3	15	8.6	0	0.0	-	-
550 - 999	224	6.8	17	7.6	16	0.3	2	12.5
1000 - 1050								
TOTAL	3292		147	4.5	6120		46	0.8
Temperature (°F)								
-267 - -1	0	0.0	-	-	0	0.0	-	-
0 - 49	122	3.7	7	5.7	96	1.6	2	2.1
50°F - 99	1039	31.7	38	3.7	1912	31.1	11	0.6
100°F - 149	819	25.0	36	4.4	1922	31.2	10	0.5
150°F - 199	287	8.8	22	7.7	661	10.7	6	0.9
200°F - 249	634	19.3	24	3.8	743	12.1	3	0.4
250°F - 299	89	2.7	3	3.4	512	8.3	9	1.8
300°F - 349	161	4.9	11	6.8	158	2.6	0	0.0
350°F - 399	15	0.5	1	6.7	68	1.1	0	0.0
400°F - 1570	112	3.4	2	1.8	82	1.3	5	6.1
TOTAL	3278		144	4.4	6154		46	0.8

[1]See Figure 3-2 for explanation of groups.

TABLE B-8. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON PERCENT LEAKING FOR PUMP SEALS IN LIGHT LIQUID SERVICE

Pressure (psig)	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking
-15 - -1	0	0.0	-	-
0 - 49	146	33.0	10	6.8
50 - 99	115	26.0	19	16.5
100 - 149	66	14.9	3	4.5
150 - 199	44	9.9	8	18.2
200 - 249	6	1.4	0	0.0
250 - 299	8	1.8	3	37.5
300 - 349	15	3.4	0	0.0
350 - 399	9	2.0	1	11.1
400 - 449	6	1.4	3	50.0
450 - 499	8	1.8	1	12.5
500 - 549	6	1.4	2	33.3
550 - 999	13	2.9	2	15.4
1000 - 1050	0	0.0	-	-
TOTAL	442		52	11.8
Temperature (°F)				
-267 - -1	26	5.8	8	30.8
0 - 49	27	6.0	4	14.8
50 - 99	148	33.1	14	9.5
100 - 149	112	25.1	11	9.8
150 - 199	34	7.6	2	5.9
200 - 249	73	16.3	8	11.0
250 - 299	21	4.7	1	4.8
300 - 349	4	0.9	0	0.0
350 - 399	0	0.0	-	-
400 - 1570	2	0.4	0	0.0
TOTAL	447		48	10.7

TABLE B-9. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE FOR FLANGES IN GAS SERVICE FROM ETHYLENE PROCESS UNITS

	GROUP 1[1] PRIMARY MATERIALS			
Pressure (psig)	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking
-15 - -1	0	0.0	-	-
0 - 49	145	25.7	3	2.1
50 - 99	102	18.1	4	3.9
100 - 149	36	6.4	2	5.6
150 - 199	34	6.0	4	11.8
200 - 249	65	11.5	2	3.1
250 - 299	66	11.7	13	19.7
300 - 349	30	5.3	4	13.3
350 - 399	22	3.9	3	13.6
400 - 449	6	1.1	1	16.7
450 - 499	18	3.2	1	5.6
500 - 549	29	5.1	2	6.9
550 - 999	11	2.0	0	0.0
1000 - 1050	0	0.0	-	-
TOTAL	564		39	6.9
Temperature (°F)				
-267 - -1	71	12.5	7	9.9
0 - 49	58	10.2	10	17.2
50 - 99	270	47.7	15	5.6
100 - 149	117	20.7	4	3.4
150 - 199	35	6.2	1	2.9
200 - 249	8	1.4	1	12.5
250 - 299	0	0.0	-	-
300 - 349	1	0.2	0	0.0
350 - 399	1	0.2	0	0.0
400 - 1570	5	0.9	1	20.0
TOTAL	566		39	6.9

[1]See Figure 3-2 for explanation of groups.

TABLE B-10. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE FOR FLANGES WITH GAS SERVICE FROM HIGH LEAKING PROCESS UNITS BY CHEMICAL GROUP

	GROUP 5[1] PRIMARY CHEMICALS				GROUP 6[1] PRIMARY CHEMICALS			
Pressure (psig)	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking
-15 - -1	1	0.3	0	0.0	17	5.4	0	0.0
0 - 49	34	8.7	1	2.9	245	77.5	5	2.0
50 - 99	53	13.6	1	1.9	23	7.3	1	4.4
100 - 149	46	11.8	1	2.2	7	2.2	0	0.0
150 - 199	5	1.3	0	0.0	6	1.9	0	0.0
200 - 249	52	13.3	1	1.9	1	0.3	0	0.0
250 - 299	72	18.4	2	2.8	2	0.6	0	0.0
300 - 349	10	2.6	0	0.0	11	3.5	1	9.1
350 - 399	2	0.5	0	0.0	0	0.0	-	-
400 - 449	0	0.0	-	-	0	0.0	-	-
450 - 499	52	13.3	6	11.5	0	0.0	-	-
500 - 549	33	8.4	5	15.2	0	0.0	-	-
550 - 999	31	7.9	1	3.2	4	1.3	2	0.0
1000 - 1050	0	0.0	-	-	0	0.0	-	-
TOTAL	391		18	4.6	316		9	2.8
Temperature (°F)								
-267 - -1	0	0.0	0	0.0	0	0.0	-	-
0 - 49	1	0.3	0	0.0	15	4.8	0	0.0
50 - 99	44	11.2	1	2.3	51	16.1	0	0.0
100 - 149	75	19.2	2	2.7	95	30.1	2	2.1
150 - 199	36	9.2	0	0.0	62	19.6	0	0.0
200 - 249	11	2.8	0	0.0	22	7.0	3	13.6
250 - 299	22	5.6	0	0.0	5	1.6	0	0.0
300 - 349	68	17.4	3	4.4	15	4.8	2	13.3
350 - 399	51	13.0	5	9.8	3	1.0	0	0.0
400 - 1570	83	21.2	7	8.4	48	15.2	2	4.2
TOTAL	391		18	4.6	316		9	2.8

[1]See Figure 3-2 for explanation of groups.

TABLE B-11. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE FOR FLANGES IN LIGHT LIQUID SERVICE WITHIN ETHYLENE PROCESS UNITS BY CHEMICAL GROUP

	GROUP 3[1] PRIMARY CHEMICALS				GROUP 4[1] PRIMARY CHEMICALS			
Pressure (psig)	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking
-15 - -1	0	0.0	-	-	0	0.0	-	-
0 - 49	39	12.0	1	2.6	31	44.3	0	0.0
50 - 99	32	9.9	0	0.0	19	27.1	0	0.0
100 - 149	24	7.4	2	8.3	10	14.3	0	0.0
150 - 199	16	4.9	3	18.7	5	7.1	0	0.0
200 - 249	15	4.6	0	0.0	4	5.7	0	0.0
250 - 299	42	13.0	1	2.4	0	0.0	-	-
300 - 349	19	5.9	2	10.5	0	0.0	-	-
350 - 399	32	9.9	2	6.2	0	0.0	-	-
400 - 449	4	1.2	0	0.0	0	0.0	-	-
450 - 499	32	9.9	6	18.7	0	0.0	-	-
500 - 549	21	6.5	4	19.0	1	1.4	0	0.0
550 - 999	23	7.1	0	0.0	0	0.0	-	-
1000 - 1050	25	7.7	4	16.0	0	0.0	-	-
TOTAL	324		25	7.7	70		0	0.0
Temperature (°F)								
-267 - -1	66	20.4	7	2.2	0	0.0	-	-
0 - 49	63	19.4	6	9.5	2	2.9	0	0.0
50 - 99	125	38.6	10	8.0	8	11.4	0	0.0
100 - 149	60	18.5	2	3.3	40	57.1	0	0.0
150 - 199	10	3.1	0	0.0	11	15.7	0	0.0
200 - 249	0	0.0	-	-	9	12.9	0	0.0
250 - 299	0	0.0	-	-	0	0.0	-	-
300 - 349	31	20.5	7	22.6	0	0.0	-	-
350 - 399	36	23.8	8	22.2	0	0.0	-	-
400 - 1570	44	29.1	13	29.5	0	0.0	-	-
TOTAL	324		25	7.7	70		0	0.0

[1]See Figure 3-2 for explanation of groups.

TABLE B-12. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON PERCENT LEAKING FOR FLANGES IN LIGHT LIQUID SERVICE WITHIN HIGH LEAKING PROCESS UNITS BY CHEMICAL GROUP

	GROUP 7[1] PRIMARY CHEMICALS				GROUP 8[1] PRIMARY CHEMICALS			
Pressure (psig)	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking
-15 - -1	1	0.2	0	0.0	6	0.6	0	0.0
0 - 49	116	20.4	0	0.0	446	45.0	0	0.0
50 - 99	82	14.4	0	0.0	282	28.5	0	0.0
100 - 149	63	11.1	2	3.2	117	11.8	0	0.0
150 - 199	30	5.3	0	0.0	61	6.2	0	0.0
200 - 249	35	6.2	0	0.0	40	4.0	0	0.0
250 - 299	36	6.3	1	2.8	10	1.0	0	0.0
300 - 349	30	5.3	3	10.0	23	2.3	0	0.0
350 - 399	16	2.8	0	0.0	4	0.4	0	0.0
400 - 449	13	2.3	0	0.0	0	0.0	-	-
450 - 499	22	3.9	0	0.0	0	0.0	-	-
500 - 549	70	12.3	2	2.9	0	0.0	-	-
550 - 999	54	9.5	2	3.7	1	0.1	0	0.0
1000 - 1050	0	0.0	-	-	0	0.0	-	-
TOTAL	568		10	1.8	990		0	0.0
Temperature (°F)								
-267 - -1	0	0.0	-	-	0	0.0	-	-
0 - 49	14	2.4	0	0.0	12	1.2	0	0.0
50 - 99	143	25.0	2	1.4	310	30.7	0	0.0
100 - 149	125	21.8	0	0.0	309	30.6	0	0.0
150 - 199	80	14.0	6	7.5	124	12.3	0	0.0
200 - 249	125	21.8	1	0.8	134	13.3	0	0.0
250 - 299	21	3.7	1	4.8	69	6.8	0	0.0
300 - 349	32	5.6	0	0.0	12	1.2	0	0.0
350 - 399	14	2.4	0	0.0	7	0.7	0	0.0
400 - 1570	18	3.2	0	0.0	33	3.3	0	0.0
TOTAL	572		10	1.8	1010		0	0.0

[1]See Figure 3-2 for explanation of groups.

TABLE B-13. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON PERCENT LEAKING FOR OPEN-ENDED LINES IN GAS SERVICE WITHIN ETHYLENE PROCESS UNITS

	GROUP 1[1] PRIMARY CHEMICALS			
Pressure (psig)	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking
-15 - -1	0	0.0	-	-
0 - 49	139	49.3	6	4.3
50 - 99	53	18.8	7	13.2
100 - 149	12	4.3	3	25.0
150 - 199	3	1.1	0	0.0
200 - 249	20	7.1	0	0.0
250 - 299	20	7.1	5	25.0
300 - 349	5	1.8	3	60.0
350 - 399	2	0.7	0	0.0
400 - 449	2	0.7	1	50.0
450 - 499	12	4.3	5	41.7
500 - 549	2	0.7	2	100.0
550 - 999	12	4.3	4	33.3
1000 - 1050	0	0.0	-	-
TOTAL	282		36	12.8
Temperature (°F)				
-267 - -1	42	14.8	8	19.0
0 - 49	131	46.1	8	6.1
50 - 99	77	27.1	17	22.1
100 - 149	17	6.0	3	17.6
150 - 199	12	4.2	1	8.3
200 - 249	3	1.1	0	0.0
250 - 299	0	0.0	-	-
300 - 349	1	0.4	0	0.0
350 - 399	0	0.0	-	-
400 - 1570	1	0.4	0	0.0
TOTAL	284		37	13.0

[1]See Figure 3-2 for explanation of groups.

TABLE B-14. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON PERCENT LEAKING FOR OPEN-ENDED LINES IN GAS SERVICE WITHIN HIGH LEAKING PROCESS UNITS BY CHEMICAL GROUP

	GROUP 5[1] PRIMARY CHEMICALS				GROUP 6[1] PRIMARY CHEMICALS			
	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking
Pressure (psig)								
-15 - -1	0	0.0	-	-	16	4.8	0	0.0
0 - 49	29	23.8	3	10.3	227	68.0	2	0.9
50 - 99	28	23.0	3	10.7	31	9.3	1	3.2
100 - 149	42	34.4	1	2.4	5	1.5	0	0.0
150 - 199	5	4.0	0	0.0	12	3.6	0	0.0
200 - 249	3	2.5	0	0.0	7	2.1	0	0.0
250 - 299	7	5.0	2	28.6	2	0.6	0	0.0
300 - 349	0	0.0	-	-	29	8.7	0	0.0
350 - 399	4	3.3	0	0	1	0.3	0	0.0
400 - 449	0	0.0	-	-	3	0.9	0	0.0
450 - 499	0	0.0	-	-	1	0.3	0	0.0
500 - 549	0	0.0	-	-	0	0.0	-	-
550 - 999	4	3.3	2	50.0	0	0.0	-	-
1000 - 1050	0	0.0	-	-	0	0.0	-	-
TOTAL	122		11	9.0	334		3	0.9
Temperature (°F)								
-267 - -1	0	0.0	-	-	0	0.0	-	-
0 - 49	2	1.6	0	0.0	11	3.3	0	0.0
50 - 99	37	30.6	8	21.6	46	13.8	0	0.0
100 - 149	49	40.5	2	4.1	84	25.2	2	2.4
150 - 199	13	10.7	0	0.0	79	23.6	1	1.3
200 - 249	6	5.0	1	16.7	36	10.8	0	0.0
250 - 299	4	3.3	0	0.0	21	6.3	0	0.0
300 - 349	1	0.8	0	0.0	17	5.1	0	0.0
350 - 399	9	7.4	0	0.0	0	0.0	-	-
400 - 1570	0	0.0	-	-	40	12.0	0	0.0
TOTAL	121		11	9.09	334		3	0.9

[1]See Figure 3-2 for explanation of groups.

TABLE B-15. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON PERCENT LEAKAGE FOR OPEN-ENDED LINES IN LIGHT LIQUID SERVICE WITHIN ETHYLENE PROCESS UNITS BY CHEMICAL GROUP

	GROUP 3[1] PRIMARY CHEMICALS				GROUP 4[1] PRIMARY CHEMICALS			
	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking
Pressure (psig)								
-15 - -1	0	0.0	-	-	0	0.0	-	-
0 - 49	18	11.9	0	0.0	12	19.0	0	0.0
50 - 99	9	6.0	0	0.0	39	61.9	2	5.1
100 - 149	16	10.6	3	18.7	6	9.5	0	0.0
150 - 199	7	4.6	2	28.6	3	4.8	0	0.0
200 - 249	6	4.0	2	33.3	0	0.0	-	-
250 - 299	14	9.3	6	42.9	0	0.0	-	-
300 - 349	12	8.0	6	50.0	0	0.0	-	-
350 - 399	23	15.2	5	21.7	0	0.0	-	-
400 - 449	1	0.7	0	0.0	0	0.0	-	-
450 - 499	12	8.0	1	8.3	0	0.0	-	-
500 - 549	12	8.0	2	16.7	3	4.8	0	0.0
550 - 999	7	4.6	5	71.4	0	0.0	-	-
1000 - 1050	14	9.3	7	50.0	0	0.0	-	-
TOTAL	151		39	25.8	63		2	3.2
Temperature (°F)								
-267 - -1	31	20.5	7	22.6	0	0.0	-	-
0 - 49	36	23.8	8	22.2	8	12.7	0	0.0
50 - 99	44	29.1	13	29.5	12	19.0	0	0.0
100 - 149	36	23.8	11	30.6	12	19.0	0	0.0
150 - 199	4	2.6	0	0.0	10	15.9	0	0.0
200 - 249	0	0.0	-	-	21	33.3	2	9.5
250 - 299	0	0.0	-	-	0	0.0	-	-
300 - 349	0	0.0	-	-	0	0.0	-	-
350 - 399	0	0.0	-	-	0	0.0	-	-
400 - 1570	0	0.0	-	-	0	0.0	-	-
TOTAL	151		39	25.8	63		2	3.2

[1]See Figure 3-2 for explanation of groups.

TABLE B-16. EFFECTS OF LINE TEMPERATURE AND LINE PRESSURE ON PERCENT LEAKING FOR OPEN-ENDED LINES IN LIGHT LIQUID SERVICE WITHIN HIGH PROCESS UNITS BY CHEMICAL GROUP

	GROUP 7[1] PRIMARY CHEMICALS				GROUP 8[1] PRIMARY CHEMICALS			
	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking	Number Screened	Percent of Total Screened	Number Leaking	Percent Leaking
Pressure (psig)								
-15 - -1	0	0.0	-	-	5	0.4	0	0.0
0 - 49	289	42.7	12	4.2	519	42.8	15	2.9
50 - 99	140	20.7	10	7.1	339	27.9	12	3.5
100 - 149	54	8.0	2	3.7	174	14.3	7	4.0
150 - 199	86	12.7	3	3.5	138	11.4	1	0.7
200 - 249	12	1.8	1	8.3	10	0.8	0	0.0
250 - 299	2	0.3	0	0.0	0	0.0	-	-
300 - 349	28	4.1	1	3.6	23	1.9	0	0.0
350 - 399	1	2.0	0	0.0	4	0.3	0	0.0
400 - 449	5	0.7	0	20.0	1	0.1	0	0.0
450 - 499	5	0.7	0	0.0	0	0.0	-	-
500 - 549	19	2.8	1	5.3	0	0.0	-	-
550 - 999	36	5.3	0	0.0	1	0.1	0	0.0
1000 - 1050	0	0.0	-	-	0	0.0	-	-
TOTAL	677		31	4.6	1214		35	2.9
Temperature (°F)								
-267 - -1	0	0.0	-	-	0	0.0	-	-
0 - 49	41	6.1	0	0.0	15	1.2	0	0.0
50 - 99	228	33.9	13	5.7	440	35.9	15	3.4
100 - 149	154	22.9	6	3.9	330	26.9	12	3.6
150 - 199	40	6.0	2	5.0	161	13.1	4	2.5
200 - 249	133	19.8	7	5.3	178	14.5	2	1.1
250 - 299	15	2.2	1	6.7	74	6.0	1	1.4
300 - 349	40	6.0	2	5.0	15	1.2	0	0.0
350 - 399	0	0.0	-	-	3	0.2	0	0.0
400 - 1570	21	3.1	0	0.0	9	0.7	1	11.1
TOTAL	672		31	4.6	1225		35	2.9

[1]See Figure 3-2 for explanation of groups.

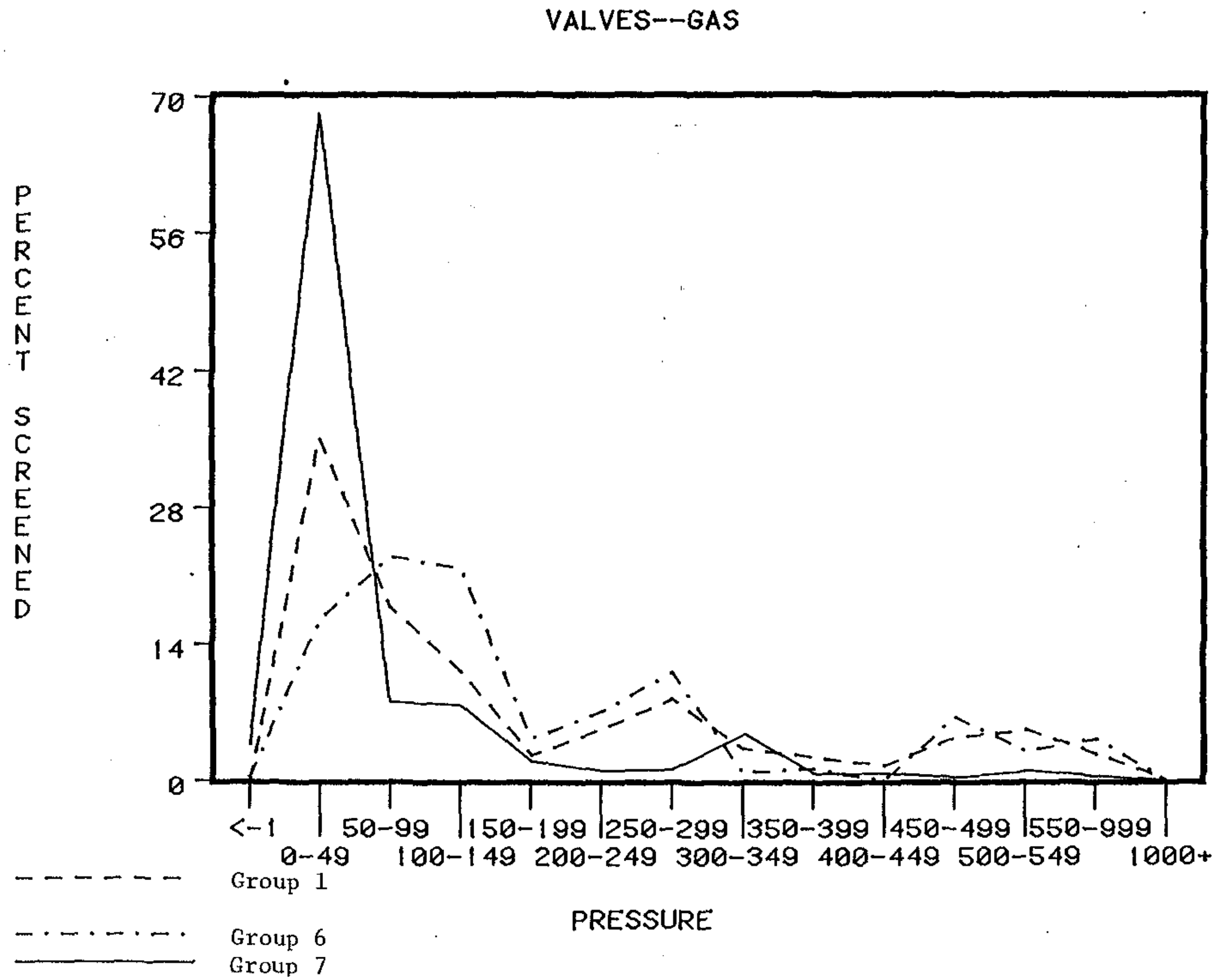


Figure B-1. Distribution of Sources Screened by Line Pressure for Ethylene and High Leaking Process Units by Chemical Group for Valves with Gas Service

*See Figure 3-2 for explanation of groups.

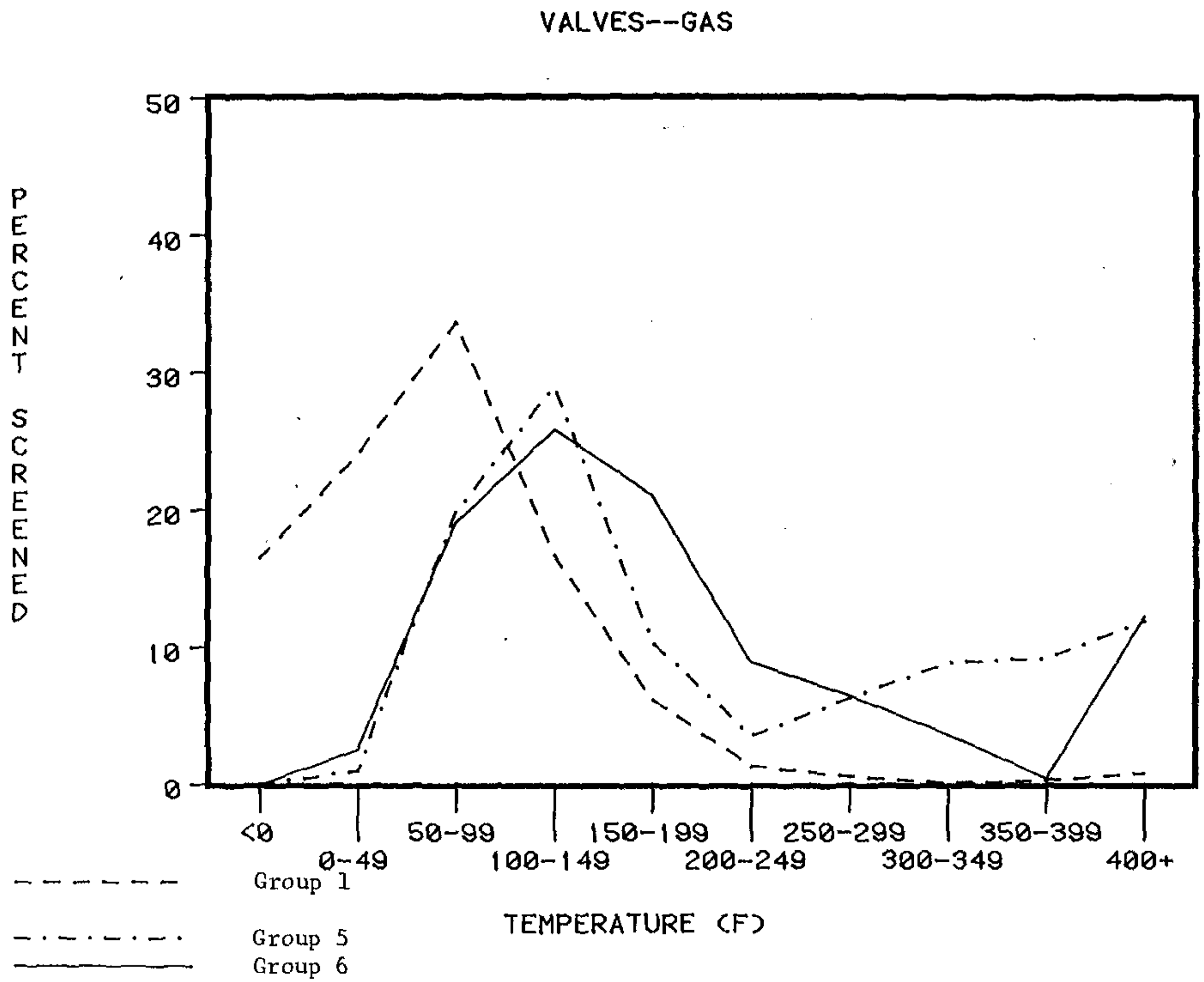


Figure B-2. Distribution of Sources Screened by Line Temperature for Ethylene and High Leaking Process Units by Chemical Group for Valves with Gas Service

*See Figure 3-2 for explanation of groups.

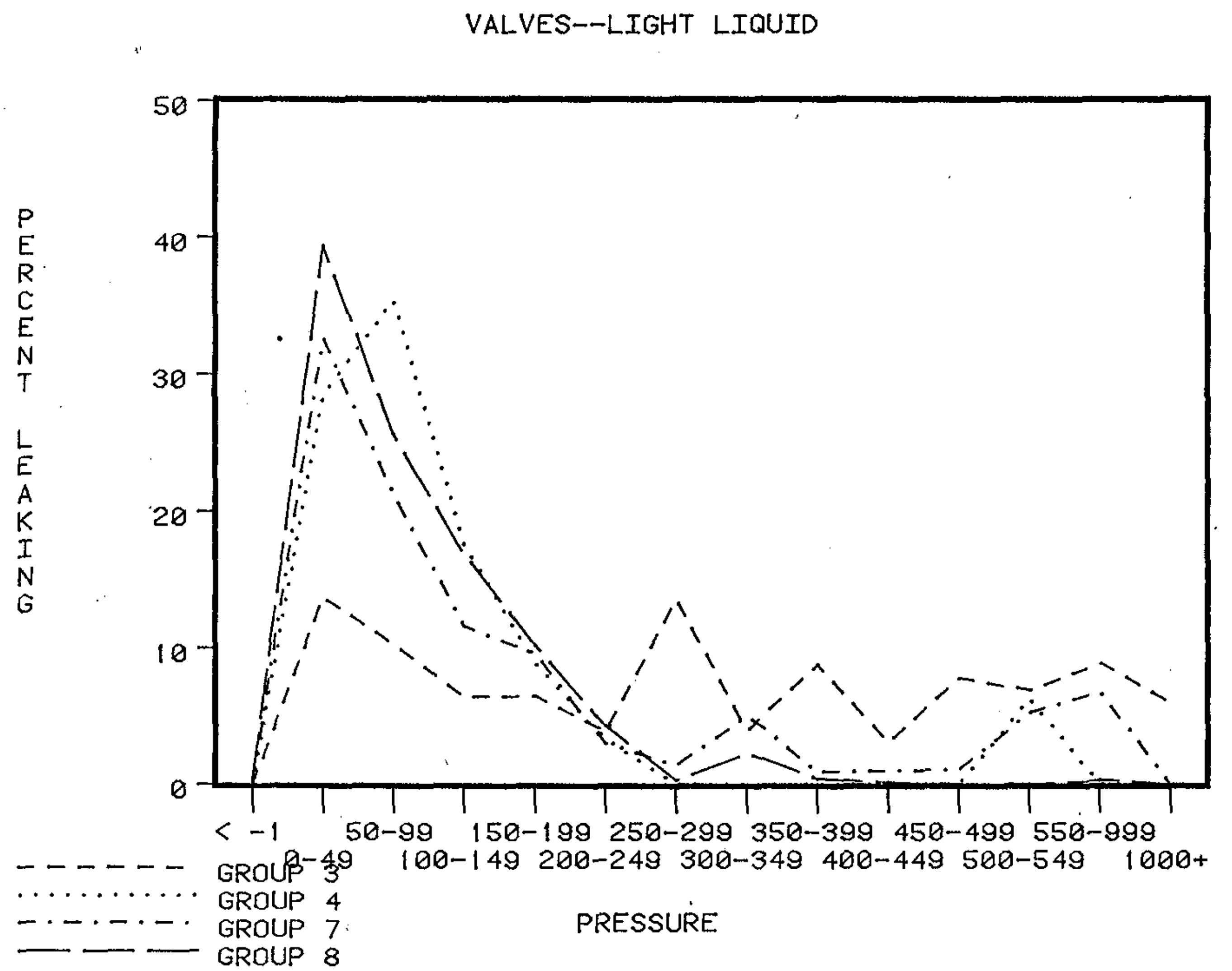


Figure B-3. Distribution of Sources Screened by Line Pressure for Ethylene and High Leaking Process Units by Chemical Group for Valves with Light Liquid Service

*See Figure 3-2 for explanation of groups.

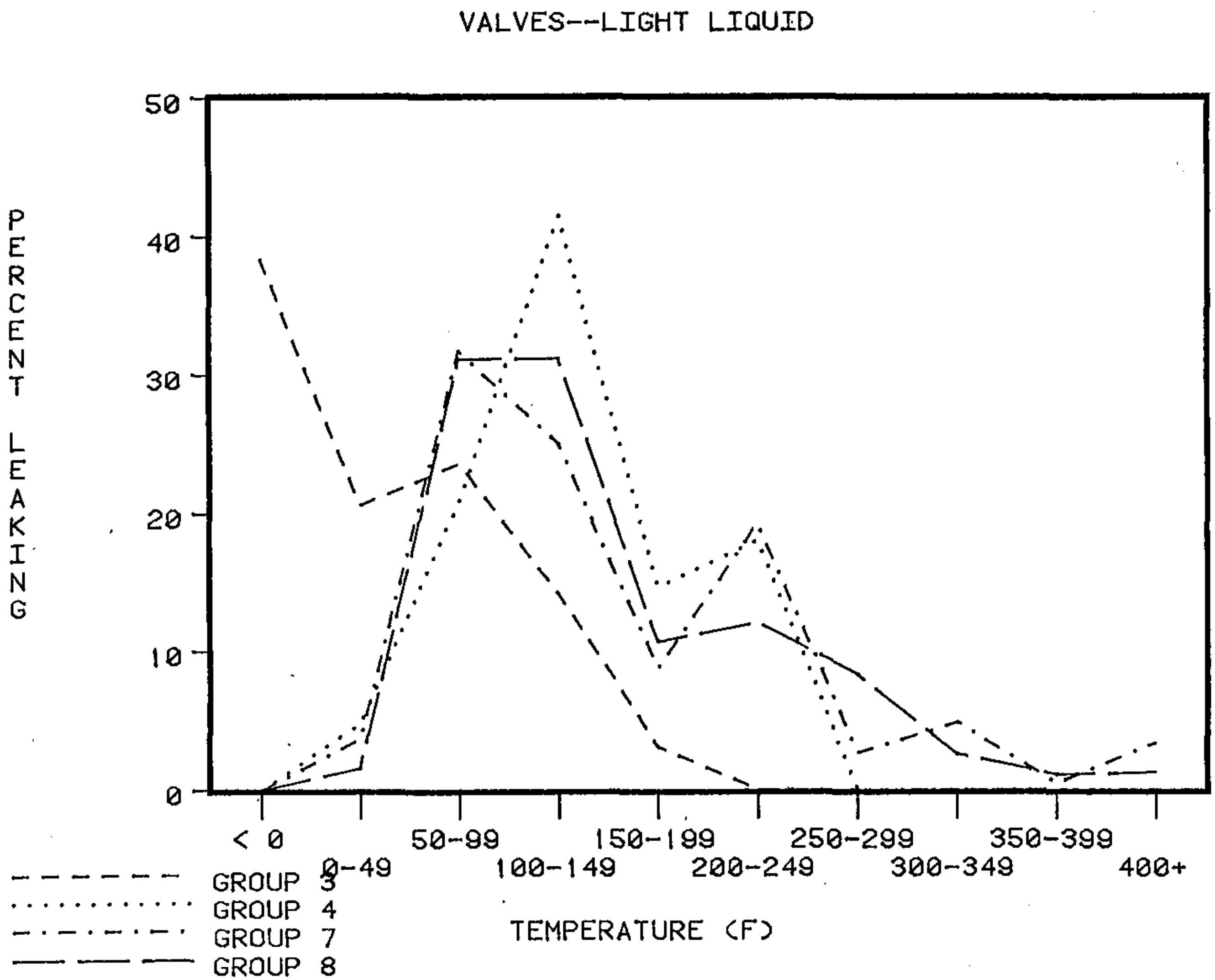


Figure B-4. Distribution of Sources Screened by Line Temperature for Ethylene and High Leaking Process Units by Chemical Group for Valves with Light Liquid Service

*See Figure 3-2 for explanation of groups.

APPENDIX C

SUMMARY STATISTICS AND DETAILED INFORMATION ON THE EFFECTS OF AMBIENT TEMPERATURE AND ELEVATION ON LEAK FREQUENCY

This appendix contains detailed information on the effects of ambient temperature and source elevation on leak frequency. Tables C-1 and C-2 contain summary statistics for ambient temperature for the groupings of sources described in Section 3.

Ambient temperature was measured as a continuous variable, but to evaluate its effect on leak frequency, it was grouped as less than 70°F or greater than or equal to 70°F. Tables C-3 and C-4 give the number of sources screened, number leaking and percent leaking for both of the groups of ambient temperatures. The statistics are categorized by source type, stream service, the type of process unit, and the primary material group. Table C-3 contains the data for ethylene process units and Table C-4 contains the data for high leaking process units.

Chi-square tests were performed on each group to determine if there was a significant difference in leak frequencies between the two categories of ambient temperatures. The results are given in Tables C-3 and C-4. For the ehtylene process units (Table C-3), the leak frequencies of valves are significantly different in all categories. For both gas and light liquid service in the high leaking primary material group, higher leak frequencies were found at the higher levels of ambient temperature. For the low leaking primary material group, the higher leak frequencies occurred at the lower ambient temperature level. The only other group in the ethylene process units that showed a significant effect of the ambient temperature is open-ended lines in gas stream service in the high leaking primary material group.

Table C-4 contains the same information for the high leaking process units. Valves in group 7 showed the only significant effect on leak frequencies of ambient temperature. The higher level of ambient temperature was associated with the higher leak frequency.

Tables C-5 and C-6 contain the data on the effects of elevation on leak frequency for ethylene and high leaking process units, respectively. Chi-square tests were performed to determine differences in percent leaking for the two levels. There were no significant differences in leak frequencies for any source types in the ethylene process units. The high leaking process units showed a few significant effects of elevation on leak frequencies. These effects were seen for valves and open-ended lines in light liquid stream service and with high leaking primary materials in the line. For the even numbered groups only valves in gas stream service were significantly affected. In each of these cases the higher leak frequency occurred at the ground level.

TABLE C-1. SUMMARY OF AMBIENT TEMPERATURE DURING SCREENING OF VARIOUS SOURCE TYPES IN GAS SERVICE

			HIGH LEAKING PROCESS		ETHYLENE
VARIABLE	SOURCE TYPE	SUMMARY STATISTICS FOR AMBIENT AIR TEMPERATURE	HIGH LEAKING PRIMARY MATERIALS	LOW LEAKING PRIMARY MATERIALS	HIGH LEAKING PRIMARY MATERIALS
	VALVES	Average (°F)	73.1	63.6	58.3
		Standard Deviation	18.5	19.5	20.6
		Minimum	33	30	11
		Maximum	104	100	187
	FLANGES	Average (°F)	86.2	79.8	73.2
		Standard Deviation	13.0	16.4	14.5
		Minimum	33	33	20
		Maximum	102	100	120
	OPEN-ENDED LINES	Average (°F)	69.5	66.0	48.2
		Standard Deviation	17.5	20.4	20.1
		Minimum	33	30	20
		Maximum	100	100	90

TABLE C-2. SUMMARY OF AMBIENT TEMPERATURE DURING SCREENING OF VARIOUS SOURCE TYPES IN LIGHT LIQUID SERVICE

		HIGH LEAKING PROCESS		ETHYLENE	
SOURCE TYPE	SUMMARY STATISTICS FOR AMBIENT AIR TEMPERATURE	HIGH LEAKING PRIMARY MATERIALS	LOW LEAKING PRIMARY MATERIALS	HIGH LEAKING PRIMARY MATERIALS	LOW LEAKING PRIMARY MATERIALS
VALVES	Average (°F)	57.8	72.4	62.8	65.5
	Standard Deviation	19.0	17.7	19.9	20.7
	Minimum	29	29	21	22
	Maximum	100	104	91	91
PUMP SEALS	Average (°F)	54.5	74.2	56.6	62.9
	Standard Deviation	15.1	17.6	21.2	21.2
	Minimum	32	32	22	36
	Maximum	98	100	85	88
FLANGES	Average (°F)	77.6	82.0	74.1	78.1
	Standard Deviation	19.0	15.4	13.6	14.7
	Minimum	29	29	24	30
	Maximum	100	102	91	91
OPEN-ENDED LINES	Average (°F)	52.2	77.6	51.3	48.2
	Standard Deviation	13.5	17.4	21.1	19.4
	Minimum	29	29	24	22
	Maximum	98	104	91	90

TABLE C-3. EFFECT OF AMBIENT TEMPERATURE ON PERCENT OF SOURCES LEAKING IN ETHYLENE PROCESS UNITS AS A FUNCTION OF THE PRIMARY CHEMICAL GROUPS

SOURCE TYPE	STREAM SERVICE	AMBIENT TEMPERATURE, °F	PRIMARY CHEMICAL Group 1 and Group 3[1]					PRIMARY CHEMICAL Group 4[1]				
			NUMBER SCREENED	NUMBER LEAKING	PERCENT LEAKING	CHI-SQUARE	p[2]	NUMBER SCREENED	NUMBER LEAKING	PERCENT LEAKING	CHI-SQUARE	p[2]
VALVES	Gas	<70°	3760	474	12.6	36.8	<0.001					
		70°+	2534	460	18.2							
	Light Liquid	<70°	1666	446	26.8	0.34	>0.05	240	2	0.8	1.1	>0.05
		70°+	1848	511	27.6			367	7	1.9		
PUMP SEALS	Light Liquid	<70°	29	7	24.1	0.4	>0.05	7	0	0.0	2.1	>0.05
		70°+	32	11	34.4			8	2	25.0		
FLANGES	Gas	<70°	165	10	6.1	0.01	>0.05					
		70°+	469	29	6.2							
	Light Liquid	<70°	68	6	8.8	0.16	>0.05	9	0	0.0	*	
		70°+	259	19	7.3			61	0	0.0		
OPEN-ENDED LINES	Gas	<70°	223	19	8.5	10.1	<0.01					
		70°+	82	18	22.0							
	Light Liquid	<70°	110	30	27.3	0.04	>0.05	50	2	4.0	0.54	>0.05
		70°+	41	9	21.9			13	0	0.0		

[1]See Figure 3-2 for explanation of groups.

[2]Probability of no significant difference in leak frequency due to ambient temperature.

*Expected values were too low for Chi-square test.

TABLE C-4. EFFECTS OF AMBIENT TEMPERATURE ON PERCENT OF SOURCES LEAKING IN HIGH LEAKING PROCESS UNITS AS A FUNCTION OF THE PRIMARY CHEMICAL GROUPS

			PRIMARY CHEMICAL Group 5 and Group 7[1]					PRIMARY CHEMICAL Group 6 and Group 8[1]				
SOURCE TYPE	STREAM SERVICE	AMBIENT TEMPERATURE, °F	NUMBER SCREENED	NUMBER LEAKING	PERCENT LEAKING	CHI-SQUARE	P[2]	NUMBER SCREENED	NUMBER LEAKING	PERCENT LEAKING	CHI-SQUARE	P[2]
VALVES	Gas	<70°	499	50	10.0	2.8	>0.05	1090	17	1.6	2.2	>0.05
		70°+	729	96	13.2			668	5	0.8		
	Light Liquid	<70°	2435	52	2.1	135.6	<0.001	2861	17	0.6	1.7	>0.05
		70°+	803	95	11.8			3293	29	0.9		
PUMP SEALS	Light Liquid	<70°	108	11	10.2	0.7	>0.05	101	3	3.0	2.5	>0.05
		70°+	18	3	16.7			142	11	7.8		
FLANGES	Gas	<70°	46	1	2.2	0.7	>0.05	77	3	3.9	0.4	>0.05
		70°+	345	17	4.9			239	6	2.5		
	Light Liquid	<70°	161	1	0.6	0.6	>0.05	219	0	0.0	*	
		70°+	417	9	2.2			791	0	0.0		
OPEN-ENDED LINES	Gas	<70°	71	4	5.6	1.8	>0.05	204	1	.5	1.9	>0.05
		70°+	75	9	12.0			143	3	2.1		
	Light Liquid	<70°	713	45	6.3	2.1	>0.05	415	7	1.7	3.3	>0.05
		70°+	85	2	2.4			876	31	3.5		

[1]See Figure 3-2 for explanation of groups.

[2]Probability of no significant difference in leak frequency due to ambient temperature.

*Expected values were too low for Chi-square test.

TABLE C-5. EFFECTS OF SOURCE ELEVATION ON PERCENT LEAKING FOR ETHYLENE PROCESS UNITS AS A FUNCTION OF PRIMARY CHEMICAL GROUPS

			PRIMARY CHEMICAL Group 1 and Group 3[1]					PRIMARY CHEMICAL Group 2[1]				
SOURCE TYPE	SERVICE	ELEVATION	NUMBER SCREENED	NUMBER LEAKING	PERCENT LEAKING	CHI-SQUARE	p[2]	NUMBER SCREENED	NUMBER LEAKING	PERCENT LEAKING	CHI-SQUARE	p[2]
VALVES	Gas	Ground	3298	475	14.9	1.2	>0.05					
		Above	2844	452	15.9							
	Light Liquid	Ground	2578	716	27.8	1.6	>0.05	494	8	1.6	0.34	>0.05
		Above	926	237	25.6			113	1	0.9		
PUMP SEALS	Light Liquid	Ground	61	18	29.5	*		15	2	13.3	*	
		Above	0	—	—			0	—	—		
FLANGES	Gas	Ground	246	13	5.3	0.53	>0.05					
		Above	387	26	6.7							
	Light Liquid	Ground	234	16	6.8	0.37	>0.05	55	0	0.0	*	
		Above	91	8	8.8			15	0	0.0		
OPEN-ENDED LINES	Gas	Ground	235	25	10.6	2.3	>0.05					
		Above	69	12	17.4	2.0						
	Light Liquid	Ground	109	29	26.6	0.12	>0.05	54	2	3.7	0.3	>0.05
		Above	42	10	23.8			9	0	0.0		

[1]See Figure 3-2 for explanation of groups.

[2]Probability of no significant difference in leak frequency due to source elevation.

*Insufficient data for Chi-square test

TABLE C-6. EFFECTS OF SOURCE ELEVATION ON PERCENT LEAKING IN HIGH LEAKING PROCESS UNITS AS A FUNCTION OF PRIMARY CHEMICAL GROUPS

			PRIMARY CHEMICAL Group 5 and Group 7[1]					PRIMARY CHEMICAL Group 6 and Group 8				
SOURCE TYPE	SERVICE	ELEVATION	NUMBER SCREENED	NUMBER LEAKING	PERCENT LEAKING	CHI-SQUARE	p[2]	NUMBER SCREENED	NUMBER LEAKING	PERCENT LEAKING	CHI-SQUARE	p[2]
VALVES	Gas	Ground	479	54	11.3	0.3	>0.05	423	12	2.8	11.3	<0.001
		Above	749	92	12.3			1333	10	0.7		
	Light Liquid	Ground	2494	121	4.8	4.1	<0.05	4394	35	0.8	0.8	>0.05
		Above	795	25	3.1			1743	10	0.6		
PUMP SEALS	Light Liquid	Ground	122	14	11.5	*		237	14	5.9	*	
		Above	4	0				6	0			
FLANGE	Gas	Ground	155	5	3.2	1.0	>0.05	76	4	5.3	2.1	>0.05
		Above	236	13	5.5			240	5	2.0		
	Light Liquid	Ground	417	9	2.2	1.6	>0.05	662	0		*	
		Above	160	1	0.6			343	0			
OPEN-ENDED LINE	Gas	Ground	59	6	10.2	0.2	>0.05	72	2	2.8	2.1	>0.05
		Above	87	7	8.0			274	2	0.7		
	Light Liquid	Ground	623	45	7.2	8.9	<0.01	949	29	3.1	0.1	>0.05
		Above	172	2	1.2			340	9	2.6		

[1]See Figure 3-2 for explanation of groups.

[2]Probability of no significant difference in leak frequency due to source elevation.

*Insufficient data for Chi-squares test

APPENDIX D

CORRECTIONS TO SCREENING DATA

During the SOCMI fugitive emission screening project (Reference 1), occasional corrections were required on the original data sheets. These corrections were subsequently documented along with an explanation of why they were necessary.

One clarification that affected almost all of the units screened was due to the decision to exclude water when calculating the primary chemical concentration. To make this adjustment all primary material concentrations that were below thirty percent (30%) were changed to reflect ninety to one-hundred percent (90-100%), if no secondary material other than water existed. That is, if the primary chemical was twenty percent (20%) of the stream and water made up the other eighty percent (80%), then the primary chemical concentration was adjusted to one hundred percent (100%). So, the concentration number was adjusted to reflect the percent of total VOC's.

Table D-1 and D-2 summarize all adjustments and corrections made to the original data sheets. Table D-1 is a summary of the detailed corrections listed in Table D-2 which affected the overall number screened, the number not screened and the number screened greater than or equal to 10,000, as reported earlier (Reference 1). After the corrections described in this appendix were made, the data reported in this reference were used for the analyses in Section 3 of this report.

Other clarifications, mostly due to miscoding by the recorder, are listed in Table D-2, by unit, then source identification sequence. Coding corrections covered a wide range of source identification codes and few were changed from the same code number. Therefore, it was not feasible to list all the old codes along with their corrections.

TABLE D-1. CORRECTIONS AFFECTING RESULTS ON PREVIOUS REPORTS

SOURCE/SERVICE	NUMBER SCREENED OLD	NUMBER SCREENED NEW	NUMBER NOT SCREENED OLD	NUMBER NOT SCREENED NEW	NUMBER SCREENED >=10000 OLD	NUMBER SCREENED >=10000 NEW	EXPLANATION
Flanges							
Gas	1443	1450	No Change		No Change		Unit 2 had 4 sources and Unit 4 had 3 sources which were reclassified from compressors.
Light Liquid	2897	2833	76	142	No Change		Unit 60 had 64 sources in which the values were changed from Ø to missing. Unit 4 had 2 sources which were reclassified from pumps and their values changed from Ø to missing. Unit 60 had 2 sources which should have been recorded with Unit 61.
Open-Ended Lines							
Light Liquid	3603	3605	417	415	No Change		Unit 29 had 2 sources in which the values were changed from missing to Ø. Unit 60 had 2 sources which should have been recorded with Unit 61.
Relief Valves							
Gas	85	84	226	227	No Change		Unit 20 had 1 source in which the value was changed from Ø to missing.
Light Liquid	69	68	47	48	No Change		Unit 20 had 1 source in which the value was changed from Ø to missing.

TABLE D-1 (continued)

SOURCE/SERVICE	NUMBER SCREENED OLD	NUMBER SCREENED NEW	NUMBER NOT SCREENED OLD	NUMBER NOT SCREENED NEW	NUMBER SCREENED >=10000 OLD	NUMBER SCREENED >=10000 NEW	EXPLANATION
Valves/							
Gas	9668	9669	2047	2046	No Change		Unit 29 had 1 source in which the valve was changed from missing to Ø.
Light Liquid	18294	18300	2553	2548	1174	1183	Unit 29 had 6 sources in *which the values were changed* from missing to Ø. Unit 20 had 1 source in which the value was changed from Ø to missing. Unit 3 had 1 source in which the value was changed from missing to Ø. Unit 60 had 9 sources which had values of 10,000 that were not included in the number screen-*ed over 10,000. Unit 60 had 8* sources which should have been recorded with Unit 61, 1 of which had a value of 10,000.
Pumps							
Light Liquid	647	646	29	28	No Change		Unit 29 had 1 source in which the value was changed from missing to Ø. Unit 4 had 2 sources which were reclassified as flanges.
Compressors							
Gas	29	22	3	2	No Change		Unit 2 had 4 sources and Unit 4 had 3 sources which were reclassi-fied to flanges. Unit 64 had 1 source in which the value was changed from missing to Ø. Unit 4 had 1 source which was reclassi-fied to other.
Other							
Light Liquid	33	34	No Change		No Change		Unit 4 had 1 source which was *reclassified from compressors.*

TABLE D-2. CORRECTIONS TO SCREENING DATA SHEETS

Unit	Source ID	Change
1	33	Elevation to 1 Comment to missing
	133-140	Secondary material concentration to 4
	534, 1052, 1355-1356, 1393	Comment to 1
	365	Deleted
	1552	Source type to 54 Line temperature to 140
	1580-1581	Service to 2
2	918	Screening value to missing Comment to 1 (inaccessible)
	1574-1576, 1594-1596, 1606-1608, 1624, 1633, 1646, 1723	Source type to 2
	1756	Source type to 1 Line temperature to 143 Line pressure to 525
	1757	Source type to 1
	1758, 1822	Source type to 52 Line temperature to 143 Line pressure to 525
	1873, 1895	Source type to 1 Line temperature to 188 Line pressure to 155
	2215-2219	Screening value to missing Comment to 1 (inaccessible)
	2440, 2487	Source type to 2
	3004	Line temperature to 300 Line pressure to 6
	3005-3020	Line pressure to 6
	3021-3024	Primary material to 3 Primary material concentration to 3 Secondary material to 1 Secondary material concentration to 2
	3025	Screening value to missing Comment to 1 (inaccessible)

(continued)

TABLE D-2. CORRECTIONS TO SCREENING DATA SHEETS (CONTINUED)

Unit	Source ID	Change
2	3028-3030	Primary material to 3 Primary material concentration to 3 Secondary material to 1 Secondary material concentration to 2 Line temperature to 260
	3031-3033	Line temperature to 260
	3034-3038, 3121	Primary material to 3 Primary material concentration to 3 Secondary material to 1 Secondary material concentration to 2
	3236-3298	Line temperature to 5
	3239	Source type to 40 Line temperature to 260
	3240	Line temperature to 5
	3241-3243	Line temperature to 5
	3289	Screening value to missing Comment to 1 (inaccessible)
	3300, 3309-3317, 3332-3347, 3350-3373	Service to 1
	3378-3388	Service to 1 Line pressure to 2
	3447	Screening value to missing Comment to 1 (inaccessible)
	3463-3469, 3473-3477	Primary material to 1
	3478-3498	Primary material concentration to 7
	3552-3578	Line temperature to 25
	3604	Service to 1 Line pressure to 500
	3605-3607	Service to 2
	3608-3630	Service to 1 Line pressure to 2
	3631-3634	Service to 2
	3635-3660	Service to 1 Line pressure to 2

(continued)

TABLE D-2. CORRECTIONS TO SCREENING DATA SHEETS (CONTINUED)

Unit	Source ID	Change
2	3683-3684	Service to 1
	3700-3714	Primary material concentration to 5
	3716, 3718	Primary material concentration to 5 Secondary material to 2 Secondary material concentration to 2
	3719-3720	Primary material concentration to 4 Secondary material to 2 Secondary material concentration to 2
	3721-3722	Primary material to 3 Primary material concentration to 5 Secondary material to 1 Secondary material concentration to 3
	3734-3740	Primary material concentration to 5 Secondary material concentration to 3
	3751-3754	Service to 2
	3755-3758	Service to 1
	3762-3783	Secondary material concentration to 1
	3801-3809	Service to 1
	3882	Source type to 42
	3901	Source type to 30
	3913-3917	Line temperature to 62 Line pressure to 480
	3968-3975, 3987	Service to 1
	4668, 5048	**Source Type to 35**
	5339	Screening value to 10,000
	5690	Source type to 52 Service to 1 Primary material to 5 Line temperature to 195 Line pressure to 225
3	1215-1216	Comment to 1
	1349	Secondary material concentration to 0
	1638	Source type to 32
	1639	Source type to 42

(continued)

TABLE D-2. CORRECTIONS TO SCREENING DATA SHEETS (CONTINUED)

Unit	Source ID	Change
4	97-98, 849, 956, 956-959	Comment to 1 (inaccessible)
	1120-1139	Deleted
	2161, 2173	Source type to 1
	3375	Source type to 32
	5192, 5837	Source type to 1
	6760	Service to 1 Source type to 1
5	If Service=missing	Service to 2
11	21-40	Day to 21
	607 (2nd)	Source id to 4105
	608 (2nd)	Source id to 4106
	613 (2nd)	Source id to 4107
	735 (2nd)	Source id to 4108
	885	Source type to 10
	1745	Unit to 11
	1953	Source type to 10
	2358-2359	Service to 10
	2426-2429	Comment to 3
	2566-2585, 2626-2641	Secondary material concentration to missing
	2731-2734	Comment to 3
	2889	Deleted
	3156	Service to 2
	3409, 3411, 3418, 3422	Comment to 3
12	If screening team=13 or 15	Source id to: id plus 1959
	If source type=* 81-100	Source type to 1 Month to 3

(continued)

TABLE D-2. CORRECTIONS TO SCREENING DATA SHEETS (CONTINUED)

Unit	Source ID	Change
12	87	Source type to 40
	221-240	Service to 2
	310, 338, 339, 362	Source type to 40
	561-562	Service to 2 Primary material to 40 Primary material concentration to 6 Secondary material to 45 Secondary material concentration to 3 Line temperature to 170 Line pressure to 100 Ambient air temperature to 60
	565-580	Service to 2
	2730-2739	Primary material to 42 Primary material concentration to 9 Secondary material to missing Secondary material concentration to missing
	2788-2791	Primary material to 41 Primary material concentration to 9 Secondary material to missing Secondary material concentration to missing
	3416	Source type to 3
20*	If screening value= missing	Comment to 1
	1049, 1081	Source type to 33
	1239, 1251, 1314	Screening value to missing
	3156	Service to 2
	3201	Screening value to missing
21*	947	Service to 2
22	154	Comment to 1 (inaccessible)
	221-240	Ambient air temperature

*Pedco used duplicate unit #'s, so the VMC unit screened between 2-14 and 2-20 was changed to unit 28 and the EDC unit screened between 2-12 and 2-15 was changed to unit 29.

(continued)

TABLE D-2. CORRECTIONS TO SCREENING DATA SHEETS (CONTINUED)

Unit	Source ID	Change
28 (20)*	If primary material=19	Primary material to 14 Primary material concentration to 9 Secondary material to missing Secondary material concentration to missing
	2710-2720	Secondary material to missing Secondary material concentration to missing
	2777	Screening value to missing
	2793	Source type to 45
	2855	Screening value to 30
	3257-3276	Line temperature to 355
29 (21)*	If screening value is blank	Screening value to 0
	19	Source type to 35
	359-360	Comment to 1
	432-440	Secondary material to missing Secondary material concentration to missing
	626-640	Secondary material to missing Secondary material concentration to missing
	808-809	Comment to 1 (inaccessible)
	865-880	Secondary material to missing Secondary material concentration to missing
	1017, 1025	Source type to 35
	2103-2120	Comment to missing
	2135-2140	Secondary material to missing Secondary material concentration to missing
	3116	Comment to 1
	3181-3200	Instrument to 2
	3239-3240	Secondary material to missing Secondary material concentration to missing

*Pedco used duplicate unit #'s, so the VMC unit screened between 2-14 and 2-20 was changed to unit 28 and the EDC unit screened between 2-12 and 2-15 was changed to unit 29.

TABLE D-2. CORRECTIONS TO SCREENING DATA SHEETS (CONTINUED)

Unit	Source ID	Change
32	435, 463	Comment to 2
	646-647	Secondary material concentration to 2
33	331, 337-338	Comment to 1
34	741-760	Elevation to 2
	1521	Service to 2
60	1-505 (excluding 361-364, 398-401, 425-428)	Primary material to 6
	39	Source type to 30
	506-696	Primary material to 6 Primary material concentration to 6 Secondary material to 14 Secondary material concentration to 2
	897-918	Service to 2
	1044-1057	Secondary material to 9 Elevation to 3
	1058-1068	Secondary material to 9
	1269-1278	Secondary material to 8
	1301-1720	Primary material to 6
	1810 (2nd)	Source id to 1811
	1829-1831	Secondary material to missing Secondary material concentration to missing
	1941-1960	Primary material to 6
	2005-2080	Primary material to 4 Secondary material to 15
	2081-2123	Primary material to 4 Secondary material to 15 Secondary material concentration to ∅
	2354-2406, 2421-2449, 2486-2500	Primary material to 5
	2591-2600	Secondary material to missing Secondary material concentration to missing

(continued)

TABLE D-2. CORRECTIONS TO SCREENING DATA SHEETS (CONTINUED)

Unit	Source ID	Change
60	2628	Source type to 1
	2743-2747, 2787-2800	Secondary material to missing Secondary material concentration to missing
	2890-2900	Secondary material to missing Secondary material concentration to missing
	4113-4130	Primary material to 5
	6970-6974	Secondary material to missing Secondary material concentration to missing
61	3021-3027, 3044-3060	Secondary material to 3
	3053	Source type to 1 Screening value to 3600
	3121-3127	Primary material to 6
	3188	Screening value to 200
	3233, 3235-3237	Screening value to Ø
	3246-3260	Secondary material to 6
	3261-3280	Secondary material to 3
	3281-3297	Primary material to 3
	3298-3305	Primary material to 3 Secondary material to 6
	3306-3328	Primary material to 6
	3329-3335	Primary material to 3 Secondary material to 6
	3521-3716	Primary material to 3
	3742-3760	Secondary material missing Secondary material concentration to missing
	3781-3830	Primary material to 3 Secondary material to 6
	3805-3806	Comment to 1

(continued)

TABLE D-2. CORRECTIONS TO SCREENING DATA SHEETS (CONTINUED)

Unit	Source ID	Change
62	3841-3860	Unit to 62
64	If service=2 and primary material is 2, 4, or 5	Service to 3
	3933	Service to 1 Primary material concentration to 1 Secondary material concentration to 0
	3941-3950	Secondary material to 3 Secondary material concentration to 2
	4357, 4362	Service to 3
	4604-4609, 4611-4612	Comment to 1 (inaccessible)
	4631-4640	Source id=id + 46
65	4801-4820	Ambient air temperature to 8
	4900 (2nd)	Source id to 6751
	5241-2	Service to 2
	5243	Service to 2 Elevation to 2
	5244-5280	Service to 2
	5286-5290, 5299-5300	Comment to 1 (inaccessible)
	5340	Source type to 1
	5354-5356, 5364-5367	Screening value to missing
	5393	Source type to 10
	5404, 5413-5414, 5464-5466	Screening value to missing
	5468	Service to 1
	5511	Comment to 2
	5521-5540	Line pressure to 45
	5979-5986, 5988-6000	Line pressure to -5
	6011-6013	Comment to 1 (inaccessible)
	6021-6039	Ambient air temperature to 84

(continued)

TABLE D-2. CORRECTIONS TO SCREENING DATA SHEETS (CONTINUED)

Unit	Source ID	Change
65	6040	Ambient air temperature to 84 Comment to 2
	6113-6114	Screening value to missing
	6221-6222, 6224-6225, 6243-6249	Comment to 1 (inaccessible)
	6601-6620	Line pressure to -5
66	7083	Source type to 30
	7141-7160	Unit to 66
	7173, 7249, 7264, 7336, 7354	Source type to 30
	8574, 8808-8810	Secondary material to missing Secondary material concentration to missing
	8850, 8862	Source type to 30

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES IERL-RTP project officer is Bruce A. Tichenor, Mail Drop 63, 919/541-2547.

16. ABSTRACT The report gives results of an examination of fugitive emission data from Synthetic Organic Chemical Manufacturing Industry (SOCMI) processing units (collected under earlier EPA studies) for correlations between process variables and leak frequency. Although line temperature did not have a consistent relationship with leak frequency, the data showed that leak frequency increased with increasing line pressure. Also, emission factors for three process types (vinyl acetate, cumene, and ethylene) were developed and presented. Increases in mass emissions due to occurrence and recurrence of leaks for these three process types are also estimated. Finally, the effect of adjusting portable hydrocarbon readings by chemical response factor curves on leakage frequency estimates is investigated. Despite the wide range of response factors encountered, the adjusted leak frequencies were essentially the same as the unadjusted frequencies.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Cumene	Pollution Control	13B
Volatility	Ethylene	Stationary Sources	20M
Organic Compounds		Volatile Organic Compounds	07C
Processing	Hydrocarbons		13H
Leakage		Fugitive Emissions	14G
Vinyl Acetate			

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