RADIAN CORPORATION

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ASSESSMENT OF FUGITIVE EMISSIONS OF PROC FROM PETROLEUM REFINING OPERATIONS

Executive Summary

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1.0 INTRODUCTION

Fugitive emissions of photochemically reactive organic compounds (PROC) are emitted from a variety of equipment component types at petroleum refineries. These component types include valves, flanges, pumps, compressors, and pressure relief valves (PRVs). In order to promote attainment of federal and state ambient air quality standards for ozone (oxidant), these emissions have been reduced through the requirement of inspection/maintenance (I/M) programs. Suggested control measures (SCMs) for the control of PROC emissions from refinery valves, flanges, pumps, compressors, and PRVs were approved by the California Air Resources Board (ARB) in 1978, 1981, and 1982. Subsequently, air quality management and air pollution control districts adopted rules or rule elements partially based on the SCMs.

The typical air pollution control rule for refinery fugitive emissions in California has the following elements:

- Requirements for annual inspection of valves, flanges, and pumps. Requirements for quarterly inspection of compressors and PRVs.
- Use of a hydrocarbon detection instrument held at 1 cm from the source.
- Repair of any component screening greater than 10,000 parts per million by volume (ppmv).
- Reinspection of components after repair.
- Exemptions for component types with certain characteristics.

Radian Corporation conducted a study for the ARB to evaluate emissions of PROC from California petroleum refineries. There were several major objectives of the study: 1) to evaluate refinery fugitive emissions for each California refinery by process unit, component type, service type, and category of exemption, 2) to identify, and where possible quantify, those factors which contribute most significantly to differences in fugitive emission rates between refineries, 3) to compare post-rule vs pre-rule emissions, and 4) to evaluate the impact of rule exemptions on emissions.

In order to meet these objectives, an approach for estimating fugitive emissions was developed. This approach calculates fugitive emissions on the basis of four variables: 1) the number of components (component populations); 2) the fraction of components with screening values above 10,000 ppmv (fraction of components leaking); 3) the distribution of screening values for both leaking and nonleaking components (screening value distributions); and 4) the correlation between screening values and emission rates developed in previous fugitive emission studies. The first two variables are used in the process directly, the third and fourth variables are used to develop average emission rates (AERs) for leaking and nonleaking components.

Using this emission calculation approach as a cornerstone, an overall study approach was developed. This approach is summarized below.

- Questionnaires and data requests were sent to the refineries to obtain component population data and the I/M data that they have collected while complying with the rules.

- A consistent database was developed and all available data were entered.

- An extrapolation approach was developed and implemented to fill all gaps in the database.

- Average emission rates for leaking and nonleaking components were developed.

- Emissions were estimated from nonexempt and exempt components.

- A detailed evaluation of differences in component populations, fraction of components leaking, and emission estimates between refineries, and between air quality management and air pollution control districts was made.

As part of the work to improve the database, a small field sampling/data collection effort was conducted. This effort drew upon a small portion of the overall project budget and did not result in a significant amount of data being added to the database. Therefore, the study was almost solely based on data collected by refineries during implementation of I/M programs.

2.0 RESULTS AND CONCLUSIONS

2.1 General

The most significant result of this study was the creation of an extensive fugitive emission database for all refineries in California. This database was developed using LOTUS'123® software and can be used on any personal computer compatible with an IBM PC®. The database is very large; in hard copy format it consists of several thousand pages. Copies of the database in both magnetic and hard copy format have been made available to the ARB. The database contains component populations, fraction of components leaking, estimated average emission rates, and emission estimates by component type (e.g., valves, flanges, pumps, etc.) and by process unit for each refinery.

The database is made up of fugitive emission inspection/maintenance (I/M) data collected by California refineries. These data were collected by refineries solely for the purpose of complying with fugitive emission control rules. These data were submitted in response to requests for this study, and were provided with varying degrees of detail and documentation. The most recent year of usable data submitted by each refinery was included in the database.

Within the database, the source of each individual data point is documented. This allows future users to easily evaluate the source of the data and the level of confidence that can be placed on individual data points. It also facilitates updating the database. If actual data are obtained to replace extrapolated data, these data can easily be entered and the data source code changed.

There are three types of data or results that represent the most significant outcome of this study: component populations, fraction of components leaking, and emission estimates. The component populations represent a significant result of this study. These component populations are based on actual data submitted by the refineries for the majority of refineries. The fraction of components leaking is also a significant result. The amount of data collected on the fraction of components leaking in this study far exceeds the total amount of data on the fraction of components leaking in all previous studies. The final result of this study was emission estimates. While the development of detailed and accurate emission estimates was perhaps the most important objective of this study, it was not possible to develop one set of emission estimates for nonexempt valves and flanges that were certain enough to be presented as the sole results of this study. Therefore, two sets of valve and flange emission estimates were developed for nonexempt components. These two emission estimates differ by approximately an order of magnitude. Neither of these emission estimates can be stated with certainty to be accurate.

2.1.1 Component Populations

This study obtained the most comprehensive and detailed set of component populations ever developed for California refineries. Probably the most important information that these data provide is on the relative proportion of total components that are exempt from the rules. The percent of total components that are claimed as exempt for all refineries in California is presented below:

- Valves - gas service: 34.9 percent
- Valves - liquid service: 43.4 percent
- Flanges: 43.9 percent
- Pumps: 59.3 percent
- Compressors: 29.0 percent
- PRVs - gas service: 61.3 percent
- PRVs - liquid service: 61.8 percent

Another important conclusion about component populations relates to the consistency of component populations for a given process unit. A previous fugitive emission study entitled Assessment of Atmospheric Emissions from Petroleum Refining concluded that component populations were primarily a function of the type of process unit, not the size or capacity of that unit (Radian, 1980). This result was used in developing the component population extrapolation scheme that was used in this study. However, the data collected in this study show that there is a great deal of variability in component populations for a given process unit. For example, Table 2-1 presents information on the range of component populations by process unit for refineries in one example district, the South Coast Air Quality Management District (SCAQMD). Similar tables could be prepared for other air pollution control districts from the fugitive emission database.

Based on a more detailed review of component populations by process unit, there appear to be two primary reasons that variability in component populations exist: 1) it was not possible to define a discrete set of boundaries for a given process unit to ensure that these boundaries were consistently applied between refineries, 2) actual variability in component populations for a given process unit does exist due to process unit capacity, and 3) variability in the type and number of exemptions claimed by different refineries for similar process units.

Actual component population data provided by the refineries were grouped by process unit. As mentioned above, the boundaries of process units were not consistent in that each individual refinery providing data made the determination of which components belonged to particular units. The disparity in component populations is particularly evident in ancillary process units (those that serve in a supporting function) such as storage/blending/shipping and blowdown/flare/vapor recovery.

It was not possible within this study to perform a detailed evaluation of the relationship between process unit capacity and component populations. However, for many process units, there does appear to be a relationship between these two parameters.

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TABLE 2-1. NONEXEMPT COMPONENT POPULATIONS - SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

	VALVES															PRESSURE RELIEF VALVES					
	GAS			LIQUID			FLANGES			PUMPS			COMPRESSORS			GAS			LIQUID		
PROCESS UNIT	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX	AVG
Crude Distillation	33	357	110	30	1,113	362	14	2,237	895	0	20	10	0	8	1	0	13	2	0	18	3
Catalytic Cracking	258	1,096	594	693	2,330	1,561	2,031	7,764	5,189	6	47	31	0	9	4	0	30	9	0	30	10
Hydrocracking	53	67	60	480	604	542	338	1,960	1,299	3	11	6	0	2	1	0	13	3	0	5	1
Thermal Operations	215	507	362	188	1,218	685	979	4,299	2,356	4	21	13	0	5	1	1	7	5	0	26	9
Fluid Coking																					
Blowdown/VR/Flares	30	173	107	0	1,557	818	30	5,190	2,253	0	33	10	2	15	7	0	10	7	0	22	7
Wastewater Treating	0	0	0	175	280	228	372	840	606	4	8	6	0	0	0	0	0	0	0	4	2
Storage/Blend/Ship	0	376	131	95	6,560	1,966	0	20,598	7,288	8	118	49	0	8	2	0	82	28	0	520	87
Naphtha Hydrotreating	0	264	74	20	684	191	24	863	287	0	27	10	0	0	0	0	1	1	0	0	0
Catalytic Reforming	7	344	156	28	1,311	670	0	3,252	1,830	3	22	11	0	1	0	0	7	2	0	2	1
Aromatics Extraction																					
Fractionation	0	217	58	0	992	264	0	3,695	1,073	0	33	16	0	12	2	0	3	1	0	3	1
Alkylation	52	554	249	473	2,873	1,344	1,577	45,900	9,607	13	172	40	0	0	0	0	49	11	0	26	7
Polymerization	98	190	144	415	805	610	670	678	674	10	15	13	0	0	0	-	-	-	-	-	-
Isomerization																					
Gasoline Treating	0	21	14	40	191	144	50	636	344	0	27	7	0	2	0	0	0	0	0	7	3
Olefins Production																					
Boilers (Utilities)	40	902	401	0	176	78	20	3,763	1,438	0	45	10	0	2	1	0	5	1	0	0	0
Sulfur Plant	5	677	208	0	380	119	40	1,257	488	0	7	2	0	2	1	0	1	0	0	1	0
Mid Dist Hydrotreating	21	193	93	85	618	311	125	6,880	1,778	0	7	5	0	2	1	0	10	4	0	3	1
Lubes Process - Solvents																					
Hydrogen Production	335	853	554	0	316	152	97	1,005	584	0	6	3	0	0	0	0	15	5	0	0	0
Other Product Treating	0	0	0	140	164	152	207	220	214	0	2	1	0	0	0	0	0	0	0	0	0
Other Volatile Petro																					
Other Low Vol Petro	73	73	73	308	308	308	363	363	363	7	7	7	0	0	0	-	-	-	-	-	-
Vacuum Crude Dist	15	158	53	0	193	125	20	1,790	709	0	3	1	0	2	1	0	7	3	0	9	4
Gas Oil Hydrotreating	9	202	87	20	360	156	110	2,340	958	0	5	3	0	1	0	0	0	0	0	0	0
Vacuum Resid Hydro	215	297	256	129	239	184	200	6,180	3,190	3	8	6	0	1	1	0	0	0	0	0	0
Other Lube Oil Process																					
Asphalt Production																					

2.1.2 Fraction of Components Leaking

Data on the fraction of components leaking at the time of inspection were submitted by 17 refineries. The average fraction of components leaking for all of these data represents an average of post-rule conditions. An average of pre-rule conditions for refineries nationwide was obtained from the reference cited as Radian, 1980. The Radian, 1980 data were all collected using a TLV calibrated with hexane at 0 cm from the source. The post-rule data were collected using a variety of different detection instruments, calibration gases, and screening distances. The most common of the combinations used to collect post-rule data was an OVA calibrated with methane at 1 cm from the source. In order to compare the two data sets, it was assumed that all of the post-rule data were collected using an OVA calibrated with methane at 1 cm from the source. The pre-rule data were then converted to this same basis using information from the source cited as Radian, 1980. Table 2-2 presents a comparison of the pre-rule and post-rule data.

2.1.3 Screening Values

Screening value data are the actual nonmethane hydrocarbon (NMHC) concentrations measured during the implementation of I/M programs. They are not actual measurements of emission rates but can be related to emission rates. Screening value data that were usable for this study were submitted by the following refineries:

- Coastal Petroleum, Bakersfield
- Edgington Oil, Wilmington
- Exxon, Benicia
- Shell Oil, Carson
- Texaco, Bakersfield
- Tosco, Martinez

TABLE 2-2. COMPARISON OF PERCENT OF COMPONENTS LEAKING FOR PRE-RULE AND POST-RULE CONDITIONS

Component Type	Percent of Components Leaking OVA (1 cm) Methane	
	Pre-Rule	Post-Rule
Valves		
Gas Service	8.0	1.58
Liquid Service	8.0	1.05
Flanges	0.0	0.13
Pumps	15.0	4.60
Compressors	29.0	8.65
PRVs		
Gas Service	4.5[a]	0.71
Liquid Service	4.5[a]	0.00

[a] A breakdown of the percent leaking for gas and liquid service was not available.

NOTES:

- The post-rule percent of components leaking (i.e., with screening values greater than 10,000 ppm) represents the maximum number of leaking components at the end of the inspection cycle. If you assume that almost all of these components are repaired promptly and leak occurs/recurs linearly over time, then the average percent of components leaking is slightly more than one-half of the percentage shown.

- The fraction of components leaking in the pre-rule case have been adjusted to be on the basis of an OVA calibrated with methane at 1 cm from the source. Post-rule data were collected using a variety of different detection instruments, calibration gases, and screening distances. The most common of the combinations used to collect post-rule data was an OVA calibrated with methane at 1 cm from the source.

As was the case for the fraction of components leaking, the screening value distributions were variable between refineries. This variability may be the result of the following possible factors:

- Real differences in the leak rates for components in different refineries. These differences could result from: 1) differences in district rules, 2) differences in enforcement practices between districts, or 3) differences in the practices followed by different operators in order to comply with the rules.

- Differences in the hydrocarbon detection instrument, calibration gas, and screening distance.

- Differences in the methods used to conduct component screening.

Because limited data were available and it was not clear that the variability in screening values represented real differences in leak rates, average emission rates (emission factors) were not developed for individual refineries. Instead, one set of average emission rates was developed for the South Coast Air Quality Management District (SCAQMD) and the Bay Area Air Quality Management District (BAAQMD), and one set was developed for the Kern County Air Pollution Control District (KCAPCD) and miscellaneous air pollution control districts.

2.1.4 Emission Estimates

In this study, average emission rates were estimated from screening values. Significant difficulties were encountered in the development of average emission rates from the screening value distributions for nonexempt valves and flanges obtained from the refineries. The difficulties arose in converting screening values between different detection instruments and correlating screening values to emission rates. As a result, two complete sets of nonexempt emission estimates were developed using two different sets of average emission rates for valves and flanges. These two emission estimates differ by approximately an order of magnitude. Neither of these sets of emission estimates can be stated with certainty to be accurate.

Table 2-3 presents a summary of controlled (i.e., post-rule) emissions from nonexempt and exempt components by district for the entire state. Tables 2-4, 2-5, 2-6, and 2-7 present this same information by refinery for SCAQMD, BAAQMD, KCAPCD, and other districts, respectively. Emissions from threaded connections were assumed to be negligible and were not included in this study.

2.1.4.1 Nonexempt Component Emission Estimates

As stated in the previous section, two different sets of post-rule nonexempt component emission estimates were developed. Both sets of average emission rates were developed through the following process of conversion and correlation.

- Screening values provided by refineries were obtained using a variety of different detection instruments, calibration gases, and distances from the source. These screening values were converted to a common basis (i.e., TLV®, calibrated with hexane, at the source).

- These TLV® screening values were then correlated to emission rates.

The two sets of average emission rates, referred to as Method 1 and Method 2, differ in the way that these conversions and correlations were made. This difference is described below.

TABLE 2-3. SUMMARY OF EMISSION ESTIMATES FOR REFINERIES IN CALIFORNIA (ton/yr)

	SCAQMD		BAAQMD		KCAPCD		Misc. Districts		Statewide	
	Total	% of Total	Total	% of Total	Total	% of Total	Total	% of Total	Total	% of Total
METHOD 1 -										
Nonexempt Components										
Valves	9600	34.3	6700	60.9	350	18.4	36	11.6	17,000	41.5
Flanges	3400	12.1	220	2.0	28	1.5	10	3.2	3700	9.0
Pumps	540	1.9	350	3.2	37	1.9	12	3.9	940	2.3
Compressors	130	0.5	110	1.0	2.9	0.2	5.8	1.9	250	0.6
PRVs	880	3.1	270	2.5	65	3.4	17	5.5	1200	2.9
Subtotal	15,000	53.6	7700	70.0	480	25.3	81	26.0	23,000	56.1
METHOD 2 -										
Nonexempt Components										
Valves	1000	6.3	660	12.9	40	2.5	5.1	1.9	1700	7.4
Flanges	470	2.9	26	0.5	12	0.8	4.2	1.6	500	2.2
Pumps	540	3.4	350	6.9	37	2.3	12	4.4	940	4.1
Compressors	130	0.8	110	2.2	2.9	0.2	5.8	2.2	250	1.1
PRVs	880	5.5	270	5.3	65	4.1	17	6.3	1200	5.2
Subtotal	3000	18.8	1400	27.5	160	10.0	44	16.3	4600	20.0
Exempt Components										
Low PROC	420	1.5/2.6	280	2.5/5.5	26	1.4/1.6	5.0	1.6/1.9	730	1.8/3.2
Low RVP	2600	9.3/16.3	1100	10.0/21.6	560	29.5/35.0	97	31.2/35.9	4400	10.7/19.1
Inaccess	9300	33.2/58.1	2300	20.9/45.1	810	42.6/50.6	130	41.8/48.1	13,000	31.7/56.5
High Temp	170	0.6/1.1	43	0.4/0.8	3.1	0.2/0.2	1.2	0.4/0.4	220	0.5/1.0
Subtotal	13,000	46.4/81.3	3700	33.6/72.5	1400	73.7/87.5	230	74.0/85.2	18,000	43.9/78.3
METHOD 1 - Total Exempt and Nonexempt	28,000	100	11,000	100	1900	100	300	100	41,000	100
METHOD 2 - Total Exempt and Nonexempt	16,000	100	5100	100	1600	100	270	100	23,000	100

Table 2-4. Summary of Emission Estimates (ton/yr) for Refineries in the SCAQMD

	ARCO, Carson	Champlin, Wilmington	Chevron, El Segundo	Edgington, Wilmington	Fletcher Oil, Wilmington	Golden West, Santa Fe Springs	Huntway, Wilmington	Macmillan, Signal Hill	Mobil Oil, Torrance	Newhall, Newhall	Paramount, Paramount	Shell Oil, Carson	Texaco, Wilmington	Union Oil, Los Angeles	Total SCAQMD
METHOD 1 –															
Nonexempt Components															
Valves	1100	980	4400	180	210	450	110	17	410	210	31	350	1100	120	9800
Flanges	740	420	320	5.1	190	160	88	1.5	410	14	20	810	430	48	3400
Pumps	75	58	80	4.8	28	39	13	4.4	48	8.9	12	77	52	35	540
Compressors	12	10	13	0.9	6.0	35	3.7	0.8	13	6.5	1.1	6.8	17	1.1	130
PRVs	210	84	44	19	41	39	37	38	60	0.0	29	160	94	23	880
Subtotal Nonexempt	2100	1500	4900	210	470	710	230	82	940	240	83	1200	1700	230	15000
METHOD 2 –															
Nonexempt Components															
Valves	140	100	420	17	23	54	18	1.7	50	20	7.5	47	110	26	1000
Flanges	100	58	44	0.7	28	21	9.0	0.2	56	1.9	2.5	83	59	5.8	470
Pumps	76	59	80	4.8	28	39	13	4.4	48	8.9	12	77	52	35	540
Compressors	12	10	13	0.9	6.0	36	3.7	0.8	13	6.5	1.1	6.8	17	1.1	130
PRVs	210	84	44	19	41	39	37	38	60	0.0	29	160	94	23	880
Subtotal Nonexempt	540	310	610	42	120	190	79	45	230	37	52	370	330	91	3000
Exempt Components															
Low PROC	40	17	61	5.5	8.4	25	8.4	0.2	11	30	13	18	24	180	420
Low RVP	740	270	300	97	110	120	19	1.0	58	9.4	130	390	280	110	2800
Inaccess	2500	900	840	15	170	480	0.0	7.9	420	40	240	480	980	2500	9300
High Temp	16	13	48	22	4.3	5.0	0.0	7.7	4.2	0.0	21	0.0	12	20	170
Subtotal Exempt	3300	1200	1100	140	290	630	27	17	490	79	400	870	1300	2800	13000
METHOD 1 – Total Exempt and Nonexempt	5400	2700	6000	350	760	1300	260	79	1400	320	490	2100	3000	3000	28000
METHOD 2 – Total Exempt and Nonexempt	3800	1500	1710	180	410	820	110	62	720	120	450	1200	1600	2900	16000

Table 2-5. Summary of Emission Estimates (ton/yr) for Refineries in the BAAQMD

	Chevron, Richmond	Exxon, Benicia	Huntway, Benicia	Pacific Refining, Hercules	Shell Oil, Martinez	Tosco, Martinez	Union Oil, Rodeo	Total BAAQMD
METHOD 1 -								
Nonexempt Components								
Valves	1800	880	260	420	790	2500	210	6700
Flanges	50	23	15	22	42	37	28	220
Pumps	81	30	21	26	48	120	19	350
Compressors	43	1.4	5.9	8.8	31	15	6.8	110
PRVs	79	31	19	25	45	48	21	270
Subtotal Nonexempt	2100	770	320	500	960	2700	290	7700
METHOD 2 -								
Nonexempt Components								
Valves	180	76	28	44	81	220	26	660
Flanges	6.0	2.8	1.8	2.6	5.1	4.5	3.3	26
Pumps	81	30	21	26	48	120	19	350
Compressors	43	1.4	5.9	8.8	31	15	6.8	110
PRVs	79	31	19	25	45	48	21	270
Subtotal Nonexempt	390	140	76	110	210	410	76	1400
Exempt Components								
Low PROC	68	84	3.9	11	83	5.6	24	280
Low RVP	330	130	61	73	280	160	38	1100
Inacess	570	220	100	180	610	500	130	2300
High Temp	42	0.0	0.0	0.0	1.4	0.0	0.0	43
Subtotal Exempt	1000	430	170	260	980	670	190	3700
METHOD 1 - Total Exempt and Nonexempt	3100	1200	490	760	1900	3400	480	11000
METHOD 2 - Total Exempt and Nonexempt	1400	570	250	370	1200	1100	270	5100

Table 2-6. Summary of Emission Estimates (ton/yr) for Refineries in the KCAPCD

	Chevron, Bakersfield	Coastal Petroleum, Bakersfield	Kern Oil and Refining, Bakersfield	Paramount, Bakersfield	San Joaquin Refining, Bakersfield	Texaco, Bakersfield	Witco Golden Bear, Bakersfield	Total KCAPCD
METHOD 1 -								
Nonexempt Components								
Valves	27	82	43	62	0.0	140	0.0	350
Flanges	0.4	3.3	1.8	6.6	0.0	16	0.0	28
Pumps	3.1	3.2	8.7	7.3	0.0	15	0.0	37
Compressors	0.2	0.2	0.7	0.3	0.0	1.5	0.0	2.9
PRVs	5.3	8.0	2.0	16	0.0	34	0.0	65
Subtotal Nonexempt	36	97	56	92	0.0	210	0.0	480
METHOD 2 -								
Nonexempt Components								
Valves	4.1	7.3	5.4	6.5	0.0	17	0.0	40
Flanges	0.2	1.4	0.6	2.7	0.0	6.6	0.0	12
Pumps	3.1	3.2	8.7	7.3	0.0	15	0.0	37
Compressors	0.2	0.2	0.7	0.3	0.0	1.5	0.0	2.9
PRVs	5.3	8.0	2.0	16	0.0	34	0.0	65
Subtotal Nonexempt	13	20	17	33	0.0	74	0.0	480
Exempt Components								
Low PROC	7.7	0.2	5.7	4.3	0.3	6.6	1.5	26
Low RVP	37	71	95	99	99	78	82	560
Inacess	56	7.1	180	140	28	260	140	810
High Temp	0.6	0.0	1.2	0.7	0.0	0.6	0.0	3.1
Subtotal Exempt	100	79	280	240	130	350	220	1400
METHOD 1 - Total Exempt and Nonexempt	140	175	340	270	130	560	220	1900
METHOD 2 - Total Exempt and Nonexempt	110	99	300	130	130	420	220	1600

Table 2-7. Summary of Emission Estimates (ton/yr) for Refineries in Kings County APCD, San Luis Obispo County APCD, and Ventura County APCD

	Beacon Oil, Hanford KCAPCD	Conoco, Santa Maria SLOCAPCD	Oxnard Refining, Oxnard VCAPCD	Total Miscellaneous Districts
METHOD 1 –				
Nonexempt Components				
Valves	32	1.8	2.1	36
Flanges	5.5	4.7	0.2	10
Pumps	9.5	0.0	2.6	12
Compressors	5.8	0.0	0.0	5.8
PRVs	16	0.1	0.7	17
Subtotal Nonexempt	69	6.6	5.6	81
METHOD 2 –				
Nonexempt Components				
Valves	4.2	0.4	0.5	5.1
Flanges	2.2	1.9	0.1	4.2
Pumps	9.5	0.0	2.6	12
Compressors	5.8	0.0	0.0	5.8
PRVs	16	0.1	0.7	17
Subtotal Nonexempt	38	2.4	3.9	44
Exempt Components				
Low PROC	2.2	0.0	2.8	5.0
Low RVP	26	0.3	71	97
Inacess	79	14	37	130
High Temp	0.6	0.0	0.6	1.2
Subtotal Exempt	110	14	110	233
METHOD 1 – Total Exempt and Nonexempt	180	21	120	310
METHOD 2 – Total Exempt and Nonexempt	150	16	110	280

- For Method 1, the conversions and correlations were made taking into account the uncertainty in these relationships. Therefore, a given value could be converted or correlated to a variety of possible values within the range of uncertainty for that conversion or correlation.

- For Method 2, the conversions and correlations were made on the basis of the mean values of these relationships.

There is one significant shortcoming for each of these methods.

- For Method 1, the resulting average emission rates are higher than appears reasonable when compared to actual data from the measurement of leak rates. For example, for leaking gas service values, the Method 1 average emission rate for BAAQMD/SCAQMD is 6.6 lb/hr-source. However, in the report cited as Radian, 1980, the highest measured leak rate for a gas service valve was 2.5 lb/hr. This was the highest measured value from over 100 data points on leaking gas service valves.

- The shortcoming of Method 2 is that it does not account for the uncertainty that exists in converting screening values for different detection instrument, calibration gas, and screening distance combinations or the uncertainty that exists in correlating screening values to emission rates. For example, when a mean screening value is obtained through the conversion process, the actual screening value that would have been measured with a TLV, calibrated with hexane, at the source might be significantly higher or lower. Because the screening values are approximately lognormally distributed, the exclusion of these uncertainties results in lower average emission rates.

2.1.4.2 Exempt Component Emission Estimates

One set of exempt component emission factors was developed for use in estimating exempt component emissions. These emission factors were developed using uncontrolled AP-42 emission factors (EPA, 1985) in conjunction with engineering judgement. The basis for these exempt component emission factors is described in Section 4.4.2. The use of these emission factors may lead to the overestimation or underestimation of emissions for different exemption types. Table 2-8 presents exempt component emissions as a percent of total emissions. Although there are only one set of exempt component emission estimates, the percent of total emissions varies depending on whether nonexempt component emissions were estimated using Method 1 or Method 2.

In either case, emissions from inaccessible components are significant, over 30 percent of the total emissions. Low RVP component emissions are also significant, over 10 percent of total emissions. Emissions from low PROC components and high temperature components appear to be less significant, with less than 5 percent of total emissions in both cases.

2.1.4.3 Pre-Rule Emission Estimates

Pre-rule emission estimates are presented in Table 2-9. The emission estimates are presented on a statewide basis for nonexempt components only. Pre-rule emission estimates for nonexempt components were developed using uncontrolled AP-42 emissions factors (EPA, 1985) in conjunction with component population data provided by refineries in response to survey questionnaires.

Comparison of pre-rule emissions to post-rule emissions for both Method 1 and Method 2 indicate a decrease in emissions for nearly all component types. The total emission reductions due to implementation of fugitive emission control rules was estimated to be 56 percent for Method 1 and 91 percent for Method 2.

TABLE 2-8. EXEMPT EMISSIONS AS A PERCENT OF TOTAL EMISSIONS ON A STATEWIDE BASIS

COMPONENT EXEMPTION TYPE	PERCENT OF TOTAL EMISSIONS METHOD 1 (ton/yr)	PERCENT OF TOTAL EMISSIONS METHOD 2 (ton/yr)
Nonexempt Components	56.1	20.0
Exempt Components	43.9	78.3
Exemption Type		
Low PROC	1.8	3.2
Low RVP	10.7	19.1
Inaccessible	31.7	56.5
High Temperature	0.5	1.0

TABLE 2-9. COMPARISON OF PRE-RULE VS POST-RULE EMISSIONS FOR NONEXEMPT COMPONENTS ON A STATEWIDE BASIS

	Post-Rule Emissions (ton/yr)		Pre-Rule Emissions (ton/yr)	Estimated Emission Reduction (%)	
	Method 1	Method 2		Method 1	Method 2
Nonexempt Components					
Valves	17,000	1,700	37,000	54	95
Flanges	3,700	500	1,400	—[a]	64
Pumps	940	940	5,100	82	82
Compressors	250	250	2,700	91	91
PRVs	1,200	1,200	4,600	74	74
Subtotal Nonexempt Components	23,000	46,000	52,000	56	91
Exempt Components	18,000	18,000	18,000	0	0
TOTAL All Components	41,000	22,600	70,000	41	68

[a] The post-rule emissions for flanges calculated using Method 1 are greater than the pre-rule emissions for flanges.

2.2 Differences in Fugitive Emissions and Inspection/Maintenance Programs Between Districts

2.2.1 Component Populations

Table 2-10 presents the percentage of components that are exempt in each district by type of exemption. The following observations can be made from reviewing this information.

- While the percentage of components that are claimed as exempt varies by district, there are no trends to indicate that significantly more components are being claimed as exempt in one district relative to another.

- It was expected that refineries in KCAPCD would have a significantly greater percentage of components that are exempt as low RVP because these refineries primarily process heavy crudes. However, this was not the case.

2.2.2 Fraction of Components Leaking

Table 2-11 summarizes the percent of components leaking at time of inspection for each district. These results were compared to determine whether, for a given component type, a statistically significant difference exists for the percent of leaking components between districts. This comparison takes into account both the number of data points and the magnitude of the differences between results. The comparison assumes a binomial distribution and is made with 95 percent confidence. For each component type, the only differences between districts that were determined to be statistically significant are indicated below.

- Valves-gas service: SCAQMD vs BAAQMD
- Valves-liquid service: SCAQMD vs KCAPCD vs BAAQMD

TABLE 2-10. PERCENT OF TOTAL COMPONENT POPULATIONS THAT ARE EXEMPT BY DISTRICT

	VALVES					PRVS	
DISTRICT	GAS	LIQUID	FLANGES	PUMPS	COMPRESSORS	GAS	LIQUID
SCAQMD							
Percent Nonexempt	57.7	58.8	57.0	42.6	69.4	37.4	42.8
Percent Exempt							
Low PROC	20.3	4.3	6.9	15.3	30.3	13.9	0.9
Low RVP	0.0	29.9	22.5	41.0	0.0	0.0	24.3
Inaccessible	22.0	6.9	10.0	0.0	0.0	48.4	31.9
High Temperature	0.0	0.1	3.6	1.1	0.3	0.3	0.0
BAAQMD							
Percent Nonexempt	73.2	53.6	52.0	38.0	77.2	28.0	17.9
Percent Exempt							
Low PROC	17.6	1.4	9.0	10.9	22.8	38.0	1.6
Low RVP	0.0	40.3	28.4	51.0	0.0	0.0	63.6
Inaccessible	9.2	4.7	10.3	0.0	0.0	33.9	16.9
High Temperature	0.0	0.0	0.3	0.0	0.0	0.0	0.0
KCAPCD							
Percent Nonexempt	69.0	48.4	67.5	37.5	57.1	84.6	23.3
Percent Exempt							
Low PROC	4.7	3.1	2.2	3.1	42.9	5.1	0.7
Low RVP	0.0	35.9	24.2	54.0	0.0	4.3	65.7
Inaccessible	26.2	12.6	6.0	5.4	0.0	6.0	10.2
High Temperature	0.0	0.1	0.1	0.0	0.0	0.0	0.0
ALL DISTRICTS							
Percent Nonexempt	65.1	56.6	56.1	40.7	71.0	38.7	38.2
Percent Exempt							
Low PROC	16.1	3.3	7.3	13.0	28.8	18.6	1.0
Low RVP	0.0	33.5	24.2	45.2	0.0	0.0	32.5
Inaccessible	18.7	6.5	9.9	0.4	0.0	42.5	28.3
High Temperature	0.0	0.1	2.6	0.6	0.2	0.2	0.0

NOTE: The numbers in these tables were compiled for refineries that provided relatively complete sets of component populations for both nonexempt and exempt components. These refineries are listed below by district.

SCAQMD - ARCO, Chevron, Edgington, Huntway, MacMillan, Newhall, Shell, and Union.

BAAQMD - Exxon, Shell, Tosco, and Union.

KCAPCD - Coastal, Paramount, Texaco, and Witco Golden Bear.

Misc. Districts - No complete data sets were available.

TABLE 2-11. SUMMARY OF ACTUAL DATA BY DISTRICT - FRACTION AND PERCENT OF COMPONENTS LEAKING AT TIME OF INSPECTION

	SCAQMD		BAAQMD		KCAPCD		Misc. Districts[a]	
Component	Fraction	Percent	Fraction	Percent	Fraction	Percent	Fraction	Percent
Valves								
Gas	316/14417	2.19	162/19750	0.82	43/2741	1.57	3/1178	0.25
Liquid	543/37181	1.46	97/27970	0.35	34/5427	0.63	9/2412	0.36
Flanges	11/2979	0.37	0/0	ND[b]	17/15299	0.11	4/6278	0.06
Pumps	62/1233	5.03	67/1260	5.32	1/212	0.47	0/113	0.00
Compressors	7/46	15.2	34/393	8.65	0/12	0.0	0/7	0.0
PRVs								
Gas	1/41	2.44	0/0	ND	0/72	0.0	0/29	0.0
Liquid	0/1	0.0	0/0	ND	0/46	0.0	0/7	0.0

[a] Miscellaneous districts are Kings County Air Pollution Control District, San Luis Obispo County Air Pollution Control District, and Ventura County Air Pollution Control District. There is one petroleum refinery in each of these districts.

[b] ND = No data available.

- Flanges: SCAQMD vs KCAPCD
- Pumps: SCAQMD and BAAQMD vs KCAPCD

In all cases where there is a statistically significant difference between the SCAQMD and another district, the data indicate that the SCAQMD has the higher percent of leaking components.

Table 2-12 summarizes the fraction and the percent of components leaking 15 days after inspection for each district. These results were also compared to determine whether statistically significant differences exist between districts. Partly because there are fewer data points 15 days after inspection, there were fewer differences that were determined to be statistically significant. The differences between districts that were determined to be statistically significant are indicated below.

- Valves-gas service: BAAQMD vs SCAQMD and KCAPCD
- Valves-liquid service: BAAQMD vs KCAPCD

2.2.3 Differences in District Rules

A detailed comparison of the district rules is presented in Section 5. This comparison demonstrates that there are few significant differences in the refinery fugitive I/M rules between districts. An example of the difference between district rules are the requirements to calibrate hydrocarbon detection instruments with hexane in the SCAQMD and methane in the BAAQMD.

While there are few significant differences between the rules themselves, there are differences in how the rules are implemented. For example, the BAAQMD must be more rigorous than the SCAQMD in promoting that complete usable I/M records be kept. This is seen in the fact that BAAQMD refineries were able to provide more than five times the actual I/M screening measurements than SCAQMD refineries.

TABLE 2-12. SUMMARY OF ACTUAL DATA BY DISTRICT - FRACTION AND PERCENT OF COMPONENTS LEAKING 15 DAYS AFTER INSPECTION

	SCAQMD		BAAQMD		KCAPCD		Misc. Districts[a]	
Component	Fraction	Percent	Fraction	Percent	Fraction	Percent	Fraction	Percent
Valves								
Gas	2/3905	0.05	60/17493	0.34	0/2299	0.0	0/1131	0.0
Liquid	12/8342	0.14	31/22822	0.14	0/3501	0.0	0/1773	0.0
Flanges	0/1418	0.0	0/0	ND[b]	1/11834	0.01	0/5808	0.0
Pumps	7/553	1.27	50/1260	3.97	1/140	0.71	0/90	0.0
Compressors	5/40	12.5	20/393	5.09	0/10	0.0	0/70	0.0
PRVs								
Gas	0/9	0.0	0/0	ND[2]	0/72	0.0	0/28	0.0
Liquid	0/1	0.0	0/0	ND[2]	0/13	0.0	0/0	ND[2]

[a] Miscellaneous districts are Kings County Air Pollution Control District, San Luis Obispo County Air Pollution Control District, and Ventura County Air Pollution Control District. There is one petroleum refinery in each of these districts.

[b] ND = No data available.

2.3 Differences in Fugitive Emissions and Inspection/Maintenance Programs Between Refineries

2.3.1 Component Populations

Table 2-1, presented earlier in this section, shows the variability that exists in nonexempt component populations by process unit. In many cases the difference between the nonexempt component populations for the same process unit between two different refineries is an order of magnitude. In some cases, this difference is more than two orders of magnitude. As discussed earlier, this suggests that component populations for a given process unit are a function of both the type of process unit and the size of the unit.

There is even greater variability in exempt components populations by process unit. This variability is increased because of the flexibility that exists in interpreting the exemptions. For example, for a given process unit, one refinery might claim a large percentage of the components exempt due to low RVP, whereas another refinery in the same district might not claim any components exempt due to low RVP. There are numerous examples of this type of situation that can be identified by reviewing the database.

2.3.2 Fraction of Components Leaking

Table 2-13 presents the percent of components leaking at the time of inspection by component type for all refineries that submitted actual I/M data.

The differences that exists in the percent of components leaking is surprisingly large. The most significant example of these differences is the percent of gas service valves leaking for Shell Oil, Carson versus Chevron, El Segundo. Both refineries submitted over 5,000 data points for gas service values. The percent leaking was 0.08 percent for Shell and 3.91 percent for Chevron. This difference is statistically significant. It is not completely

TABLE 2-13. SUMMARY OF ACTUAL DATA SUBMITTED FOR FRACTION OF COMPONENTS LEAKING AT TIME OF INSPECTION

	VALVES										PRESSURE RELIEF VALVES			
	Gas		Liquid		Flanges		Pumps		Compressors		Gas		Liquid	
District/Refinery	Fraction	%	Fraction	%	Fraction	%	Fraction	%	Fraction	%	Fraction	%	Fraction	%
SCAQMD[a]														
ARCO, Carson							12/309	3.88						
Chevron, El Segundo	271/6,937	3.91	456/20,602	2.1			10/488	2.05	1/21	4.76	0/5	0.00		
Edgington, Wilmington	11/151	7.28	3/558	0.54	2/1,418	0.14	0/15	0.00	0/2	0.00	1/36	2.78	0/1	0.00
Golden West	16/1,485	1.08	44/3,205	1.37			18/56	32.1	6/17	29.4				
MacMillan, Signal Hill	1/127	0.79	0/232	0.00	1/91	1.10	0/29	0.00						
Newhall, Newhall	13/470	2.77	29/650	4.46	8/1,470	0.54	0/47	0.00	1/6	16.7				
Shell Oil, Carson	4/5,247	0.08	11/11,934	0.09			22/293	7.51						
SCAQMD Subtotal	316/14,417	2.19	543/37,181	1.46	11/2,979	0.37	62/1,237	5.01	7/46	15.2	1/41	2.44	0/1	0.00
BAAQMD[b]														
Chevron, Richmond							7/428	1.64	4/134	2.99				
Exxon, Benicia	27/5,191	0.52	58/9,709	0.60			5/188		0/14	0.00				
Shell, Martinez	14/2,250	0.62	18/6,148	0.35			11/187	5.82	13/41	31.7				
Tosco, Martinez	112/9,600	1.17	10/6,338	0.16			41/311	13.1	10/168	5.99				
Union Oil, Rodeo	9/2,709	0.33	11/6,775	0.16			3/145	1.15	7/36	19.4				
BAAQMD Subtotal	162/19,750	0.82	97/27,970	0.35			67/1,260	5.32	34/393	8.65				
KCAPCD[c]														
Coastal, Bakersfield	16/555	2.88	0/533	0.00	3/2,208	0.09	0/30	0.00	0/1	0.00	0/14	0.00	0/2	0.00
Kern Oil and Refining	5/390	1.03	5/1,738	0.29	0/2,981	0.00	0/66	0.00	0/3	0.00				
Texaco, Bakersfield	22/1,796	1.22	29/3,156	0.92	14/10,110	0.14	1/116	0.86	0/9	0.00	0/58	0.00	0/44	0.00
KCAPCD Subtotal	43/2,741	1.57	34/5,427	0.63	17/15,299	0.11	1/212	0.47	0/13	0.00	0/72	0.00	0/46	0.00
Misc. Districts[d]														
Beacon Oil, Hanford	3/1,131	0.27	8/1,773	0.45	4/5,808	0.07	0/90	0.00	0/7	0.00	0/28	0.00		
Conoco, Santa Maria	0/10	0.00	0/174	0.00									0/3	0.00
Oxnard, Oxnard	0/37	0.00	1/465	0.22	0/470	0.00	0/23	0.00			0/1	0.00	0/4	0.00
Misc. District Subtotal	3/1,178	0.25	9/2,412	0.36	4/6,278	0.06	0/113	0.00	0/7	0.00	0/29	0.00	0/7	0.00
TOTAL ALL DISTRICTS	524/38,086	1.38	683/72,990	0.94	32/24,556	0.13	130/2,822	4.61	41/459	8.93	1/142	0.70	0/54	0.00

Notes: Footnotes are defined on the continuation of this table on the following page.

TABLE 2-13. (Continued)

FOOTNOTES:

[a] The SCAQMD defines a leaking component as one that leaks greater than 10,000 ppm, measured in hexane at the source.

[b] The BAAQMD defines a leaking component as one that leaks greater than 10,000 ppm, measured in methane 1 cm from the source.

[c] The KCAPCD defines a leaking liquid component as one that leaks at a rate of more than 3 drops per minute. A leaking gas component is defined as one that leaks greater than 10,000 ppm, measured in methane 1 cm from the source.

[d] The Kings County APCD defines: 1) leaking valves and flanges as those that leak greater than 1,000 ppm, measured as hexane at the source; 2) leaking PRVs as those that leak greater than 10,000 ppm, measured as hexane at the source; and 3) leaking pumps and compressors as those that leak greater than 10,000 ppm, measured as methane 1 cm from the source. The Santa Barbara County APCD defines leaking valves and flanges as those that leak greater than 10,000 ppm, measured as methane 1 cm from the source. The Ventura County APCD defines a leaking liquid component as one that leaks at a rate of more than 3 drops per minute. A leaking gas component is defined as one that leaks greater than 10,000 ppm, measured as methane 1 cm from the source.

clear what could cause such significant differences in the percent of components leaking. However, differences in the I/M approach used may play a role here.

2.3.3 Difference in Inspection/Maintenance Approach

The three primary approaches to I/M program implementation are as follows:

- The program is conducted by each individual process unit operator.
- The program is conducted by a group of refinery personnel who perform the I/M activities for the entire refinery.
- The program is conducted by an outside contractor.

The most significant difference in these approaches is applicable to the use of process unit operators to conduct the I/M program. There are two views regarding use of process unit operators to conduct I/M programs. The fact that the process unit operator is involved in the I/M program may significantly improve their desire and ability to recognize leaks. However, the fact that a variety of process unit operators are conducting the component screening may result in the use of inconsistent procedures and a decrease in quality assurance/quality control. These inconsistencies may carry over to the recordkeeping associated with the I/M program.

3.0 RECOMMENDATIONS

There are a number of recommendations that are prompted by the results and conclusions of this study. These recommendations are presented in this section along with the primary result or conclusion that prompted the recommendation. The intent of these recommendations is to suggest actions that would improve consistency in the implementation of fugitive I/M programs and lead to a better understanding of the magnitude of refinery fugitive emissions. It is recognized that some of these recommendations would have a significant effect on industry and agency resources.

3.1 Possible Improvement to Inspection/Maintenance Procedures and Methods

This study found that inspection/maintenance procedures and methods are being applied inconsistently. As a result, the levels of emission control that are being achieved in the various districts and refineries are both variable and difficult to quantify. The following recommendations address this and other related issues.

- Emissions from inaccessible components were estimated to be greater than 30 percent of total emissions. The number of inaccessible components claimed as exempt varied significantly between refineries. It is recommended that distinct criteria be developed to define an inaccessible component. Consideration could also be given to requiring refineries to submit a detailed plan justifying exemption claims.

- The use of different combinations of detection instruments, calibration gas, and screening distance results in inconsistent levels of emission control. It also leads to significant difficulty in evaluating the relative effectiveness of a given

I/M program. It is recommended that a standard detection instrument, calibration gas, and screening distance be adopted statewide.

- The content and format of I/M records that are currently maintained are extremely inconsistent. Recordkeeping requirements are an important tool in assuring and monitoring compliance with rules. It is recommended that I/M records be submitted annually to the districts in a standard statewide format. These records should, at a minimum, include: the process unit, component/stream type, component ID number, inspection date, and screening value for all components inspected. For leaking components, these records should include: the repair date, repair method, reinspection date, and reinspection screening values.

3.2 Additional Studies and Analyses for Consideration

Several of the important results of this study lead to recommendations for further studies and analyses. These results and the related studies or analyses are described below.

- Statistically significant differences exist in the fraction of components leaking between refineries and districts. It would be valuable to further investigate these differences. Are they real differences in leak rates or a result of inconsistent measurement techniques? How much of the variability in the fraction of components leaking can be attributed to different I/M approaches?

- Emissions from exempt components were shown to be a significant percentage of total emissions. It is recommended that a review of the exemptions claimed by refineries be conducted to evaluate their appropriateness. It would also be valuable to conduct a field study of exempt components with particular emphasis on inaccessible and low RVP components. This field study should define leak frequencies, degrees of inaccessibility, and ranges of RVPs.

- The average emission rates developed in this study are uncertain because the only correlations that exist between screening values and leak rates are for a TLV, calibrated with hexane, at the source. In order to develop average emission rates with greater certainty, it will be necessary to conduct a field study to measure screening values and leak rates for different (or a future standard) instruments, calibration gases, and screening distances.

- The database that was developed in this study will be very useful and valuable in performing detailed evaluations of fugitive emissions. One possibility for improving the database would be to require each refinery to perform a complete component inventory for its refinery. This information could then be used for many years and would only need to be updated as refinery modifications occurred.

RADIAN CORPORATION

ABSTRACT

The primary objectives of this study were: (1) to evaluate fugitive emissions from various components (e.g., valves, flanges, pumps, etc.) at petroleum refineries, and (2) to evaluate factors which contribute to differences in these fugitive emissions between refineries and air pollution control districts. The technical approach for this study included: (1) collection of an extensive amount of data on the populations of these components by component type, process unit, and refinery, (2) collection of an extensive amount of hydrocarbon screening data that were obtained to comply with fugitive emission inspection/maintenance rules, (3) development of a database structure and extrapolation procedures and compilation of fugitive emissions data for all refineries in California, (4) a detailed evaluation of the effect on fugitive emissions of various provisions of air pollution control rules, and (5) a detailed evaluation of differences in fugitive emissions between refineries and air pollution control districts. The major conclusions of the study were: (1) significant uncertainty exists in estimating emissions from refinery fugitive emissions on the basis of hydrocarbon screening data obtained to comply with fugitive emission inspection/maintenance rules, (2) significant differences exist in the fraction of leaking components between individual refineries, (3) for components that are subject to the rule (nonexempt), there has been a reduction in emissions of between 56 and 91 percent as a result of fugitive emission control rules, and (4) between 44 and 78 percent of refinery fugitive emissions come from components which are exempt from the rules.