American
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Environmental Partnership

AIR TOXICS EMISSION FACTORS FOR COMBUSTION SOURCES USING PETROLEUM-BASED FUELS

VOLUME 1
DEVELOPMENT OF EMISSION FACTORS USING API/WSPA APPROACH

Health and Environmental Affairs Department
Publication Number 348
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American Petroleum Institute

Strategies for Today's Environmental Partnership

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- To promote these principles and practices by sharing experiences and offering assistance to others who produce, handle, use, transport or dispose of similar raw materials, petroleum products and wastes.

Air Toxics Emission Factors for Combustion Sources Using Petroleum-Based Fuels

Volume 1
Development of Emission Factors Using API/WSPA Approach

Health and Environmental Affairs Department

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ABSTRACT

The Western States Petroleum Association (WSPA) and American Petroleum Institute (API) sponsored a program to develop air toxics emission factors for combustion devices using petroleum-based fuels from source test data collected under California Assembly Bill 2588 (AB2588), entitled the Air Toxics Hot Spots Information and Assessment Act of 1987. The California Air Resources Board (CARB) provided WSPA and API with access to more than 161 petroleum industry combustion source reports, from which data were extracted to derive emission factors. The types of devices represented include process heaters, boilers, reciprocating internal combustion engines, gas turbines, steam generators, asphalt blowers, and coke calciners. The substances quantified include: trace metals; polychlorinated dibenzo[*p*]dioxins and dibenzofurans; polycyclic aromatic hydrocarbons and other semivolatile organic compounds; benzene, toluene and other volatile organic compounds; formaldehyde and other aldehydes; and hydrochloric acid.

Procedures developed in a separate CARB-sponsored program were used to screen and validate data, eliminating those data points or sets with significant problems and/or reporting deficiencies. Through this process, the best data sets were selected for emission factor development. Emission factors were developed encompassing all industries in California, and petroleum-industry-specific emission factors.

As a result of this study, air toxics emission factors for combustion devices have been developed using the best available source testing information. These emission factors can be used by environmental health and safety engineers to develop more accurate and complete emission inventories without additional source testing.

This report consists of three volumes: Volume 1 presents emission factors derived specifically for petroleum industry combustion devices. Volume 2, which presents emission factors derived for inclusion in the CARB database, and Volume 3, providing detailed results of data validation and statistical comparisons are available from API's web site: ***http://www.api.org/ehs/Publications/348.htm***.

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ACRONYMS

2S	two stroke reciprocating internal combustion engine
4S	four stroke reciprocating internal combustion engine
AB2588	Air Toxics "Hot Spots" Information and Assessment Act of 1987
Aldehyde Total	acetaldehyde, formaldehyde
APC	air pollution control
API	American Petroleum Institute
BTX	benzene, toluene, xylene
CAAA	Clean Air Act Amendments of 1990
CARB	California Air Resources Board
CATEF	California Air Toxics Emission Factors
CO	carbon monoxide
COCCO	catalyst
CVRG	casing vapor recovery gas
DeNOx (SNCR)	selective non-catalytic NOx reduction
DL	detection limit
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
HAP	hazardous air pollutants
HCHO	formula for formaldehyde
HRMS	high-resolution mass spectrometry
LNB	low-NOx burner
LRMS	low-resolution mass spectrometry
LS	low sensitivity data
MACT	maximum achievable control technology
Mgal	thousand gallons
MMBtu	million British thermal units
Mmcf	million cubic feet
NC	not used in statistical comparison

NOx	nitrogen oxides
PAH	polycyclic aromatic hydrocarbon
RICE	reciprocating internal combustion engine
S	small data set
SCC	source classification code
SCR	selective catalytic NOx reduction
SNCR (DeNOx)	selective non-catalytic NOx reduction
WSPA	Western States Petroleum Association

EXECUTIVE SUMMARY

This project was performed with the cooperation of the California Air Resources Board (CARB) to develop updated air toxics emission factors for combustion sources using petroleum-based fuels. The emission factors developed in this project will be integrated into CARB's California Air Toxics Emission Factor (CATEF) database. They also may be used by environmental health and safety engineers to develop air toxics emissions inventories in response to state and federal requirements. In addition, these emission factors provide an improved scientific basis for technical and policy decision-making related to the development of new environmental regulations such as federal National Emission Standards for Hazardous Air Pollutants (NESHAPs) for petroleum industry sources.

California Assembly Bill 2588 (AB2588), entitled "Air Toxics Hot Spots Information and Assessment Act of 1987," requires facilities to provide an inventory of their air emissions for the purpose of assessing the potential health risk to surrounding communities. Source testing to characterize air toxics emissions is required when recognized emission factors or reliable engineering estimating techniques do not exist. The results of the source testing performed to comply with AB2588 were used to develop emission factors, which relate the quantity of emissions of a substance to a process-related rate.

DATA VALIDATION

To develop emission factors based on the best available source test results, the petroleum industry AB2588 source test results were screened using a data validation procedure developed by CARB for the CATEF database (Hansell, 1996). Using initial screening, detailed validation, and outlier analysis, this procedure identifies data points and data sets with significant problems and/or reporting deficiencies. Initial screening identifies source tests without sufficient documentation for emission factor development and assessment of data quality. The results of 93 of the 161 source tests were eliminated during the screening procedure. Most of the 93 source tests were eliminated because process rates needed for emission factor derivation were not provided. The detailed validation step was conducted on the remaining 68 source tests. Detailed validation includes checking to ensure the use of correct sampling and analysis procedures, qualifying significant problems such as high field blanks, checking calculations, and evaluating the accuracy of the test results. The impact of problems identified in the detailed validation process is quantified by conducting an outlier analysis. Outliers are identified statistically using the Dixon method. Each outlier is examined to determine if a process and/or method problem occurred as documented in the results of the detailed validation. If a documented problem occurred, then the outlier is eliminated.

EMISSION FACTOR DEVELOPMENT

The validated source test data were separated into five groups: external combustion devices, reciprocating internal combustion engines, gas turbines, asphalt blowers, and coke calciners. In general, the emissions data for each substance in each group were observed to vary over several orders of magnitude. This variability is due to a combination of measurement uncertainty and differences in the design and operation of devices tested. The variability was reduced, if possible, by identifying design and operating parameters responsible for the variation and further dividing the group into subgroups, if warranted. Engineering judgment and statistical analysis were used to determine whether the design or operating parameters had a significant impact on emissions. Pooling of different system and fuel types within each of the five groups was allowed to increase the quality of the resultant emissions factors. Low sensitivity data also were eliminated from the subgroup evaluation process and emission factor calculations.

FINDINGS

Key observations and findings from the subgroup analysis are listed below.

External Combustion Devices (Boilers and Process Heaters)

- Hazardous air pollutant (HAP) emission factors for boilers and process heaters are similar;
- HAP emission factors for external combustion sources fired by natural gas and process gas are similar;

- Polycyclic aromatic hydrocarbon (PAH) emission factors for liquid-fired sources are higher than for gas-fired sources;
- Benzene, toluene, and xylene (BTX) and formaldehyde emission factors for liquid- and gas-fired sources are similar; and
- HAP emission factors for boilers and process heaters with and without NOx emission controls are similar.

Reciprocating Internal Combustion Engines

- HAP emission factors for gas- and diesel oil-fired sources are similar, except that formaldehyde emissions from diesel sources are lower;
- HAP emission factors for 2 and 4 stroke sources are similar, except that total BTX emissions from 2 stroke sources are higher; and
- Rich burn reciprocating internal combustion engines (RICE) have higher total BTX and lower formaldehyde emissions than lean burn RICE.

Based on these observations, external combustion devices and reciprocating internal combustion engines were divided into the subgroups shown in Tables ES-1 and ES-2, respectively. The arithmetic mean emission factor and EPA quality rating are provided in these tables for each substance. Gas turbines were divided into two subgroups—with and without duct burners (Table ES-3). Emission factors for direct-fired devices (asphalt blowing and coke calcining) are provided in Table ES-4. The gas turbine and asphalt blower subgroups were developed from small data sets and could not be evaluated statistically for significance. The coke calcining emission factors were developed from source testing results on a single unit, therefore, no subgroup development was possible.

The EPA ratings listed in Tables ES-1 through ES-4 are assigned on a scale of A to E:

EPA Quality Rating	Emission Factors
A - Excellent	28
B - Above Average	2
C - Average	12
D - Below Average	260
E - Poor	107
NR - Not Reported	25

As shown, most of the emission factors developed in this project have EPA ratings of D or E. The predominant reason for low EPA ratings is that emission factors were developed from tests of only one or two sources. Under the EPA rating system, these emission factors can only receive a D or E rating even though the measurement data may be of high quality as a result of the screening and validation procedures. With additional future testing, most of the D-rated emission factors would move to the A through C categories because these factors were collected using CARB or EPA source test methodologies. Emission factors with E ratings also were developed using sound source test methodologies and data points with significant problems have been identified and eliminated. The E rating was assigned because the source test methodologies used (mainly CARB Method 428, CARB Method 430, and EPA Method 29/CARB Method 436 results) have been significantly revised since tests were performed. CARB has not required any retesting for data collected using previous versions of test methods and still considers data collected using these methods to be valid.

Some discussion of the gas turbine and oil-fired external combustion metals data is warranted because these data were collected using versions of EPA Method 29/CARB Method 436 which have been significantly revised to reduce contamination. Specifically, Manganese emission factors for the oil-fired external combustion sources and gas turbines are suspect because of possible cross-contamination between the HNO_3/H_2O_2 and $KMnO_4/H_2SO_4$ impingers. Arsenic, Chromium, Copper, Lead and Zinc for oil-fired external combustion sources were detected in levels of significance in field blanks compared to the sample. A significant level is defined as one where the ratio of the blank to sample is greater than 0.10. The gas turbine trip blanks indicated significant levels of Mercury and Zinc for the sources with duct burners. A complete assessment of contamination was not possible for the gas turbine data sets because field blanks were not collected.

REPORT ORGANIZATION

Only Volume 1 is presented here; Volumes 2 and 3 are available from API's web site: ***http://www.api.org/ehs/Publications/348.htm***. Volumes 1 and 2 describe emission factors developed specifically for combustion sources using petroleum-based fuels and for CATEF, respectively. Data collection and validation procedures are summarized in Volume 1 and a detailed description is provided in Volume 2. Volume 3 provides supporting information, including detailed procedures used for validation of source test data, validation results, and detailed statistical comparison results.

This volume (Volume 1), which presents petroleum-industry-specific emission factors, is divided into three sections:

Section 1 - Introduction.

Section 2 - Data Validation. This section summarizes the data validation process to which the emission test data were subjected in calculating emission factors of known quality. A more complete discussion of the data validation procedures can be found in Volume 2.

Section 3 - Emission Factors. This section presents the results of analyses of the impact of design and operating parameters on HAP emissions from petroleum industry combustion sources.

TABLE ES-1. EXTERNAL COMBUSTION EMISSION FACTORS (lb/MMBtu)

Category	Substance	Crude/Pipeline Oil - Fired		Fuel Oil No. 6 - Fired		Gas - Fired	
		EPA Rating	Emission Factor	EPA Rating	Emission Factor	EPA Rating	Emission Factor
Dioxin/Furan	Dioxin:4D 2378	E	3.5E-12	E	4.3E-12	-	-
	Dioxin:5D 12378	E	1.7E-11	E	2.5E-12	-	-
	Dioxin:6D 123478	E	1.5E-11	E	2.5E-12	-	-
	Dioxin:6D 123678	E	2.1E-11	E	2.5E-12	-	-
	Dioxin:6D 123789	E	3.3E-11	E	2.5E-12	-	-
	Dioxin:7D 1234678	E	9.3E-11	E	2.1E-11	-	-
	Dioxin:8D	E	3.3E-10	E	5.1E-10	-	-
	Furan:4F 2378	E	6.2E-10	E	5.5E-12	-	-
	Furan:5F 12378	E	6.0E-11	E	3.1E-12	-	-
	Furan:5F 23478	E	1.1E-10	E	3.1E-12	-	-
	Furan:6F 123478	E	1.3E-10	E	2.5E-12	-	-
	Furan:6F 123678	E	4.3E-11	E	1.9E-12	-	-
	Furan:6F 123789	E	3.5E-12	E	2.5E-12	-	-
	Furan:6F 234678	E	6.1E-11	E	3.7E-12	-	-
	Furan:7F 1234678	E	1.4E-10	E	9.8E-12	-	-
	Furan:7F 1234789	E	8.3E-12	E	3.2E-12	-	-
	Furan:8F	E	7.3E-11	E	4.9E-11	-	-
Halogens	HCl	D	1.3E-06	-	-	-	-
Metals	Antimony	-	-	-	-	D	5.2E-07
	Arsenic	NA	6.7E-06	-	-	E	7.2E-07
	Barium	-	-	-	-	D	5.8E-06
	Beryllium	E	1.9E-06	E	4.3E-07	E	1.3E-07
	Cadmium	NA	2.2E-06	-	-	E	1.5E-06
	Chromium (Hex)	NA	1.1E-06	-	-	-	-
	Chromium (Total)	NA	8.7E-06	E	3.3E-05	D	5.7E-06
	Copper	NA	9.5E-06	E	2.6E-05	D	4.7E-06
	Lead	NA	1.9E-06	-	-	D	3.8E-06
	Manganese	NA	1.8E-05	E	3.9E-05	D	4.9E-06
	Mercury	NA	1.0E-05	E	7.0E-08	D	1.8E-07
	Nickel	NA	2.4E-03	E	2.3E-03	D	7.5E-06
	Phosphorus	E	1.8E-04	-	-	D	6.4E-07
	Selenium	NA	7.9E-06	E	2.0E-05	E	8.8E-07
	Silver	-	-	-	-	D	1.6E-06
	Thallium	-	-	-	-	D	5.8E-06
	Zinc	NA	4.2E-04	E	1.1E-04	E	1.4E-03
PAH	Acenaphthene	C	1.7E-07	D	6.0E-09	A	2.4E-09
	Acenaphthylene	C	2.3E-08	D	2.1E-09	A	6.5E-09
	Anthracene	C	3.7E-08	D	2.1E-09	A	4.7E-09
	Benzo(a)anthracene	C	3.2E-08	D	1.3E-09	A	2.2E-08
	Benzo(a)pyrene	D	1.4E-08	D	1.4E-09	A	5.7E-08

TABLE ES-1. EXTERNAL COMBUSTION EMISSION FACTORS (lb/MMBtu)

Category	Substance	Crude/Pipeline Oil - Fired		Fuel Oil No. 6 - Fired		Gas - Fired	
		EPA Rating	Emission Factor	EPA Rating	Emission Factor	EPA Rating	Emission Factor
	Benzo(b)fluoranthene	D	5.5E-09	D	8.1E-09	A	2.7E-08
	Benzo(b+k)fluoranthene	D	8.1E-08	-	-	-	-
	Benzo(e)pyrene	D	3.9E-09	D	5.8E-09	-	-
	Benzo(g,h,i)perylene	D	1.9E-08	D	6.7E-09	A	1.3E-09
	Benzo(k)fluoranthene	D	2.3E-10	D	4.6E-10	A	1.7E-08
	Chrysene	C	7.5E-08	D	2.6E-08	A	1.6E-09
	Dibenz(a,h)anthracene	D	1.2E-08	-	-	A	1.5E-09
	Fluoranthene	C	6.9E-08	D	5.3E-08	A	8.7E-09
	Fluorene	C	2.0E-07	D	3.1E-08	A	4.8E-08
	Indeno(1,2,3-cd)pyrene	D	1.9E-08	D	3.1E-09	A	7.1E-08
	Naphthalene	C	5.5E-06	D	4.0E-07	A	3.9E-07
	Phenanthrene	C	1.7E-07	D	7.4E-08	A	3.2E-08
	Pyrene	C	1.2E-07	D	2.7E-08	A	9.8E-09
	PAH Total	C	7.2E-06	D	6.5E-07	A	5.1E-07
SVOC	2-Chloronaphthalene	D	8.2E-08	D	1.5E-10	-	-
	2-Methylnaphthalene	D	2.5E-07	D	7.4E-08	-	-
	Benzaldehyde	E	4.7E-05	-	-	-	-
	Ethylbenzene	-	-	-	-	A	1.6E-05
	Perylene	D	5.2E-10	D	7.4E-10	-	-
	Phenol	-	-	-	-	NA	4.0E-06
VOC	Acetaldehyde	E	1.1E-05	D	7.0E-06	NA	1.2E-05
	Formaldehyde	NA	1.1E-05	D	1.7E-05	NA	5.2E-05
	Aldehyde Total	NA	2.6E-05	D	5.2E-05	NA	6.6E-05
	Benzene	D	4.1E-06	-	-	NA	6.0E-05
	Toluene	B	3.5E-05	D	3.9E-05	NA	1.5E-04
	Xylene (Total)	D	2.9E-06	-	-	A	2.5E-05
	BTX Total	D	5.0E-05	-	-	A	5.4E-05
	1,3-Butadiene	D	1.4E-04	-	-	-	-
	Acrolein	E	3.3E-06	-	-	A	1.7E-05
	Chloroform	D	6.0E-05	D	3.4E-05	-	-
	Hydrogen Sulfide	-	-	-	-	B	8.5E-05
	Propylene	D	4.4E-05	-	-	A	1.5E-04

TABLE ES-2. RECIPROCATING INTERNAL COMBUSTION ENGINE EMISSION FACTORS (lb/MMBtu)*

Category	Substance	RICE, Diesel/O2<13%		RICE, Diesel/O2>13%		RICE, Gas/2S/Lean**		RICE, Gas/4S/Lean**		RICE, Gas/4s/Rich**	
		EPA Rating	Emission Factor	EPA Rating	Emission Factor	EPA Rating	Emission Factor	EPA Rating	Emission Factor	EPA Rating	Emission Factor
PAH	Acenaphthene	D	4.5E-06	D	1.4E-06	D	7.1E-07	D	6.8E-07	-	-
	Acenaphthylene	D	9.0E-06	D	5.1E-06	D	1.1E-05	D	7.2E-06	-	-
	Anthracene	D	1.2E-06	D	1.9E-06	D	4.3E-06	D	2.4E-07	-	-
	Benzo(a)anthracene	D	6.1E-07	D	1.7E-06	D	8.5E-07	D	7.4E-08	-	-
	Benzo(a)pyrene	D	2.5E-07	D	1.0E-08	-	-	D	3.4E-08	-	-
	Benzo(b)fluoranthene	D	1.1E-06	D	1.9E-07	D	1.4E-07	D	3.1E-07	-	-
	Benzo(b+k)fluoranthene	-	-	D	1.0E-08	-	-	-	-	-	-
	Benzo(g,h,i)perylene	D	5.4E-07	D	4.1E-07	D	9.0E-08	D	9.8E-08	-	-
	Benzo(k)fluoranthene	D	2.1E-07	D	3.0E-07	D	4.3E-06	D	5.0E-07	-	-
	Chrysene	D	1.5E-06	D	3.5E-07	D	1.6E-06	D	9.2E-08	-	-
	Dibenz(a,h)anthracene	D	3.4E-07	D	4.1E-07	-	-	D	1.0E-08	-	-
	Fluoranthene	D	3.9E-06	D	7.6E-06	D	1.6E-07	D	2.4E-07	-	-
	Fluorene	D	1.2E-05	D	2.9E-05	D	2.3E-06	D	4.4E-07	-	-
	Indeno(1,2,3-cd)pyrene	D	4.0E-07	D	2.7E-07	-	-	D	1.1E-07	-	-
	Naphthalene	D	1.3E-04	D	8.5E-05	D	2.1E-04	D	1.2E-04	-	-
	Phenanthrene	D	4.0E-05	D	2.9E-05	D	4.7E-06	D	8.5E-07	-	-
	Pyrene	D	3.6E-06	D	4.8E-06	D	2.3E-07	D	1.2E-07	-	-
	PAH Total	D	2.1E-04	D	1.7E-04	D	2.4E-04	D	1.3E-04	-	-
SVOC	Benzaldehyde	-	-	E	9.0E-05	-	-	-	-	-	-
VOC	Acetaldehyde	E	2.4E-05	E	7.6E-04	E	8.4E-03	NA	3.8E-03	E	1.6E-03
	Formaldehyde	E	7.7E-05	E	1.2E-03	E	4.8E-02	NA	3.1E-02	C	5.0E-03
	Aldehyde Total	E	1.0E-04	E	2.0E-03	E	3.3E-02	NA	3.1E-02	E	1.1E-02
	Benzene	D	7.1E-04	D	8.8E-04	D	7.5E-03	A	1.3E-03	D	9.9E-03
	Toluene	D	2.6E-04	D	4.0E-04	D	2.7E-03	A	4.9E-04	D	2.8E-03
	Xylene (m,p)	-	-	D	1.5E-04	D	5.8E-04	A	1.4E-04	D	4.7E-04
	Xylene (o)	-	-	D	1.5E-04	D	2.7E-04	A	5.9E-05	D	2.3E-04
	Xylene (Total)	D	1.9E-04	D	2.6E-04	-	-	-	-	-	-
	BTX Total	D	1.2E-03	D	1.6E-03	D	1.1E-02	A	2.0E-03	D	1.3E-02
	1,3-Butadiene	-	-	D	3.9E-05	-	-	-	-	-	-
	Acrolein	E	7.6E-06	E	9.4E-05	E	1.9E-03	NA	1.6E-03	D	5.1E-04
	Propylene	D	2.7E-03	D	2.6E-03	D	2.4E-02	A	1.7E-02	D	2.0E-02

* Assume average Brake-specific fuel consumption (BSFC) value of $7*10^{-3}$ MMBtu/hp-hr to convert from lb/MMBtu to lb/hp-hr (See Section 3.4 of AP-42)

** Formaldehyde measured by CARB 430 Method, which is under review for NO_2 interference (emissions may be under-reported)

TABLE ES-3. GAS TURBINE EMISSION FACTORS (lb/MMBtu)

Category	Substance	Turbine, Gas/DB=N		Turbine, Gas/DB=Y	
		EPA Rating	Emission Factor	EPA Rating	Emission Factor
Metals	Cadmium	E	5.3E-06	E	2.9E-06
	Chromium (Hex)	E	1.5E-06	E	1.7E-06
	Chromium (Total)	E	1.3E-05	E	5.0E-05
	Copper	E	4.1E-05	D	1.2E-05
	Lead	E	2.8E-05	E	3.6E-05
	Manganese	E	1.3E-04	D	4.8E-05
	Mercury	D	1.5E-05	D	4.4E-06
	Nickel	E	1.7E-04	E	7.7E-05
	Zinc	E	5.0E-03	D	1.2E-04
PAH	Acenaphthene	D	3.3E-09	D	2.2E-08
	Acenaphthylene	D	2.9E-09	D	1.1E-08
	Anthracene	D	3.4E-08	D	2.5E-08
	Benzo(a)anthracene	D	2.8E-09	D	1.5E-08
	Benzo(b)fluoranthene	D	3.3E-09	D	2.5E-08
	Benzo(g,h,i)perylene	D	1.9E-09	-	-
	Benzo(k)fluoranthene	D	2.3E-09	-	-
	Chrysene	D	4.9E-09	D	1.1E-07
	Fluoranthene	D	1.2E-08	D	9.9E-08
	Fluorene	D	1.5E-08	D	1.8E-07
	Indeno(1,2,3-cd)pyrene	D	1.8E-09	-	-
	Naphthalene	D	7.3E-07	D	3.7E-05
	PAH Total	D	9.1E-07	D	3.9E-05
	Phenanthrene	D	6.5E-08	D	6.4E-07
	Pyrene	D	2.3E-08	D	1.2E-07
SVOC	Phenol	D	6.7E-06	D	2.2E-05
VOC	Acetaldehyde	D	2.7E-05	E	4.1E-06
	Formaldehyde	D	3.1E-04	E	3.1E-03
	Aldehyde Total	D	3.4E-04	E	1.6E-04
	Toluene	NA	3.1E-04	E	1.6E-04
	Xylene (Total)	NA	7.7E-04	E	3.7E-04
	BTX Total	D	1.2E-04	-	-
	Acrolein	D	1.7E-05	-	-
	Propylene	D	1.6E-03	-	-

TABLE ES-4. ASPHALT BLOWING AND COKE CALCINING EMISSION FACTORS
(lb/MMBtu)

Category	Substance	Asphalt, Blow Cycle		Asphalt, No Blow Cycle		Coke Calcining	
		EPA Rating	Emission Factor	EPA Rating	Emission Factor	EPA Rating	Emission Factor
Dioxin/Furan	Dioxin:4D 2378	-	-	-	-	D	3.7E-11
	Dioxin:4D Other	-	-	-	-	D	4.4E-10
	Dioxin:5D 12378	-	-	-	-	D	2.9E-11
	Dioxin:5D Other	-	-	-	-	D	2.7E-10
	Dioxin:6D 123478	-	-	-	-	D	3.5E-11
	Dioxin:6D 123678	-	-	-	-	D	4.4E-11
	Dioxin:6D 123789	-	-	-	-	D	4.2E-11
	Dioxin:6D Other	-	-	-	-	D	2.1E-10
	Dioxin:7D 1234678	-	-	-	-	D	4.2E-10
	Dioxin:7D Other	-	-	-	-	D	4.1E-10
	Dioxin:8D	-	-	-	-	D	5.3E-09
	Furan:4F 2378	-	-	-	-	D	4.2E-11
	Furan:4F Other	-	-	-	-	D	4.3E-10
	Furan:5F 12378	-	-	-	-	D	4.4E-11
	Furan:5F 23478	-	-	-	-	D	4.1E-11
	Furan:5F Other	-	-	-	-	D	3.8E-10
	Furan:6F 123478	-	-	-	-	D	7.9E-11
	Furan:6F 123678	-	-	-	-	D	7.1E-11
	Furan:6F 123789	-	-	-	-	D	2.9E-11
	Furan:6F 234678	-	-	-	-	D	6.5E-11
	Furan:6F Other	-	-	-	-	D	4.8E-10
	Furan:7F 1234678	-	-	-	-	D	4.8E-10
	Furan:7F 1234789	-	-	-	-	D	8.0E-11
	Furan:7F Other	-	-	-	-	D	1.8E-10
	Furan:8F	-	-	-	-	D	4.1E-10
Halogens	HCl	E	2.1E-06	E	7.7E-07	-	-
Metals	Antimony	-	-	-	-	D	1.4E-04
	Arsenic	-	-	-	-	D	1.5E-05
	Barium	-	-	-	-	D	6.1E-05
	Beryllium	E	2.5E-06	E	2.2E-06	D	6.0E-06
	Cadmium	-	-	-	-	D	2.9E-05
	Chromium (Hex)	-	-	-	-	D	2.1E-06
	Chromium (Total)	E	3.9E-05	E	1.3E-05	D	6.9E-05
	Copper	E	4.5E-05	E	3.6E-05	D	2.9E-05
	Lead	-	-	-	-	D	1.9E-04
	Manganese	E	1.2E-04	E	1.9E-04	D	1.4E-04
	Mercury	D	8.5E-06	D	8.0E-06	D	1.5E-04
	Nickel	-	-	-	-	D	2.9E-04
	Phosphorus	-	-	-	-	D	1.5E-03

TABLE ES-4. ASPHALT BLOWING AND COKE CALCINING EMISSION FACTORS
(lb/MMBtu)

Category	Substance	Asphalt, Blow Cycle		Asphalt, No Blow Cycle		Coke Calcining	
		EPA Rating	Emission Factor	EPA Rating	Emission Factor	EPA Rating	Emission Factor
Metals (Cont'd.)	Selenium	-	-	-	-	D	1.5E-05
	Silver	-	-	-	-	D	5.1E-05
	Thallium	-	-	-	-	D	2.2E-04
	Zinc	E	7.9E-04	E	5.0E-04	D	3.7E-04
PAH	Acenaphthene	-	-	-	-	D	4.4E-08
	Acenaphthylene	-	-	-	-	D	5.6E-08
	Anthracene	-	-	-	-	D	5.4E-08
	Benzo(a)anthracene	-	-	-	-	D	2.6E-08
	Benzo(a)pyrene	-	-	-	-	D	2.4E-08
	Benzo(b)fluoranthene	-	-	-	-	D	2.4E-08
	Benzo(g,h,i)perylene	-	-	-	-	D	2.4E-08
	Benzo(k)fluoranthene	-	-	-	-	D	2.4E-08
	Chrysene	-	-	-	-	D	3.7E-08
	Dibenz(a,h)anthracene	-	-	-	-	D	2.4E-08
	Fluoranthene	-	-	-	-	D	1.1E-07
	Fluorene	-	-	-	-	D	1.7E-07
	Indeno(1,2,3-cd)pyrene	-	-	-	-	D	2.4E-08
	Naphthalene	-	-	-	-	D	7.3E-06
	PAH Total	-	-	-	-	D	8.6E-06
	Phenanthrene	-	-	-	-	D	5.7E-07
	Pyrene	-	-	-	-	D	7.9E-08
SVOC	Ethylbenzene	E	8.1E-04	E	7.2E-04	-	-
	Phenol	D	7.1E-05	D	4.4E-05	-	-
VOC	Acetaldehyde	E	1.7E-06	E	4.1E-06	D	3.1E-03
	Formaldehyde	E	3.3E-06	E	1.2E-05	D	1.0E-03
	Aldehyde Total	E	5.0E-06	E	1.6E-05	D	4.2E-03
	Benzene	-	-	-	-	D	1.0E-03
	Toluene	-	-	-	-	D	1.6E-04
	Xylene (m,p)	-	-	-	-	D	8.9E-05
	Xylene (o)	-	-	-	-	D	1.3E-04
	Xylene (Total)	E	8.1E-04	E	7.2E-04	-	-
	BTX Total	-	-	-	-	D	1.4E-03
	Acrolein	-	-	-	-	D	1.0E-03
	Hydrogen Sulfide	D	1.9E-03	D	1.7E-03	-	-

Section 1
INTRODUCTION

This report presents the results of a project to develop air emission factors for combustion devices using petroleum-based fuels. The project was performed by Energy and Environmental Research Corporation (EER) with funding from the American Petroleum Institute (API) and the Western States Petroleum Association (WSPA). The goal was to provide scientifically sound emission factors using procedures recognized by state and federal regulatory agencies for the purposes of developing air emission inventories. These emission factors can be utilized by environmental health and safety engineers to develop more accurate and complete air emission inventories to comply with state and federal requirements. They also can be used to support scientifically-sound technical and policy decision-making related to development of National Emission Standards for Hazardous Air Pollutants (NESHAPs) for petroleum industry sources.

In 1987, the California state legislature passed Assembly Bill 2588 (AB2588), entitled the "Air Toxics Hot Spots Information and Assessment Act of 1987." This California law required industry to inventory air emissions of more than 300 substances (later expanded to more than 700) to assess the potential human health risk to communities surrounding emission sources. Substances include known and potential carcinogens and acutely toxic substances, collectively known as air toxics. Source testing to characterize air toxics emissions was required when recognized emission factors or reliable engineering estimating techniques did not exist. AB2588 allowed source test results for representative sources to be applied to other similar sources through the use of emission factors, or "pooled" source testing. In 1989, the Western States Petroleum Association (WSPA) initiated development of air toxics emission factors specific to petroleum industry combustion sources with a pooled testing program. Two rounds of testing were performed in 1990 and 1992. All source testing was performed under strict guidelines for test methodology specified by the California Air Resources Board (CARB). The results of this testing program were organized into a common database of air toxics emission factors. This database, which has become known as the WSPA database, provides common and consistent emission factors for petroleum industry combustion devices [Hansell *et al.*, 1992]. The source types included in the database are

- Boilers, process heaters, steam generators, internal combustion engines (gas turbines and reciprocating) with and without NOx and other air emissions controls; and
- Asphalt blowers and coke calciners.

The database includes sources fired with a variety of gaseous and liquid fuels, including natural gas and petroleum industry process gases (e.g., refinery gas, field gas, casing vapor recovery gas). The database includes information on sources located in California only. The data may not be representative of emission factors for sources outside of California. Since California generally has more stringent air pollutant emission regulations than other states, California sources probably have more controls for criteria pollutants (e.g., NO_X, SO_2, particulate, etc.) than those in the rest of the nation.

A key feature of this database is the emphasis placed on the evaluation of data quality. Significant variations in test and quality assurance/quality control procedures were observed among the various tests, particularly in the first round of pooled source testing. Recognizing the need for more reliable emission factors, WSPA developed a guidance manual for performing air toxics tests to ensure high quality data in the second round of pooled source tests as well as any subsequent tests performed by its individual member companies (Soelberg *et al.*, 1994). As additional tests were performed by industry over the ensuing years, the database has been periodically updated to provide more reliable and representative emission factors.

CARB recently completed a project to compile air toxics emission factors from source test data generated in response to AB2588. Through surveys and visits to local air quality management districts throughout the state, source test reports describing 799 air toxics emissions tests for a wide variety of combustion and non-combustion sources were assembled and used to develop air toxics emission factors (Hansell, 1996). CARB did not develop air toxics emission factors for petroleum industry combustion sources under this effort. Instead, CARB agreed to provide the American Petroleum Institute (API) and WSPA access to results from 161 petroleum industry air toxics source tests for derivation of combustion device emission factors. Many of these source tests had already been evaluated and incorporated into the WSPA database described above. In return for the additional source test data, API and WSPA agreed to use the CARB data validation procedures and provide the validated information to CARB for inclusion in the California Air Toxics Emission Factors (CATEF) database. In response to this agreement, API and WSPA agreed to use the same rigorous data validation and emission factor development procedures described in the CATEF report (Hansell, 1996) to develop petroleum industry emission factors. The results of this effort are described in Volume 2 of this report. The information in Volume 2 will be submitted to CARB for inclusion in the next version of the CATEF report and database.

In addition to developing emission factors for CATEF, API and WSPA conducted a separate analysis which is described in this volume. The data review and validation procedures are identical to those used for CATEF. To improve the quality of emission factors specific to petroleum industry combustion sources, the CATEF emission factor derivation procedure was modified:

- Emission factors from selected CATEF source categories were pooled together to increase the robustness of the emission factors for selected petroleum industry sources;
- Statistical comparisons were conducted assuming the data are log-normally distributed; and
- Undetected test results collected using low sensitivity analytical techniques were excluded.

Section 2
DATA VALIDATION

Results from the validation process are summarized below. The validation process included screening and detailed validation steps, and an outlier analysis. A complete discussion of the validation process is provided in Volume 2.

2.1 SCREENING

The objective of the screening analysis was to eliminate test reports with insufficient process information to develop emission factors or documentation to evaluate the accuracy of test results. Supporting documentation included device and method descriptions, sample, lab, and blank data. Some tests were accepted without all of the supporting documentation to increase the size of the source pools. Test results for non-combustion sources and tests without air toxic emission results were excluded. Of the 161 tests screened, 68 were selected for detailed data validation and extraction. The 68 tests were comprised of 33 "old" tests evaluated in a previous CARB project to develop emission factors and 35 "new" tests.

2.2 DETAILED VALIDATION

Data validation procedures unique to each test method were used to evaluate the quality of emissions data. Data validation included checking to ensure that the correct sampling and analysis procedures were used, identifying significant problems such as high field blanks, checking calculations, and evaluating the accuracy of the test results. Major problems encountered during the method validation are documented in Table 2-1 for each test. The most common problem was the lack of a full set of internal standards used during Method 429 (PAH) analyses. PAH data from 15 tests in document 2599 were eliminated from the emission factor development process because none of the required internal standards were used in the analytical procedures, high levels of contaminants were found in many of the samples, and LRMS was used yielding high detection limits. Five Method 430 (HCHO) calculation check failures were documented; these data were either corrected or eliminated.

TABLE 2-1. SUMMARY OF MAJOR VALIDATION AND EXTRACTION PROBLEMS

Report ID	Device ID*	Number of Tests	Contractor ID	Device Type	Material Used	Review Date	Comment	Calculation Check Status
2599L	160	2[a]	A	Asphalt blowing with blow/no blow cycle	Asphalt fumes	1/31/95	5	P
2444B	177	1	A	Turbine	Natural gas	3/17/95		P
2444A	178	1	A	Steam generator	Natural/CVR gas	3/17/95		P
2599A	437	1	A	Heater	Refinery fuel gas	12/21/95	5	P
2599N	438	1	A	Heater	Refinery fuel gas	12/22/95	5	P
2599A	444	2[a]	A	Heater	Refinery fuel gas	12/22/95	5	P
2599K	451	1	A	Turbine	Refinery fuel gas	1/10/96		P
2599K	452	1	A	Turbine	Refinery fuel gas	1/10/96		P
2599B	505	1	A	Boiler	Refinery fuel gas	12/20/95	5	P
2599C	506	1	A	Heater	Refinery fuel gas	12/21/95	5	P
2599D	507	1	A	Heater	Refinery fuel gas	12/21/95	5	P
2599E	508	1	A	Boiler	Refinery fuel gas	12/21/95	5	P
2599B	509	1	A	Heater	Refinery fuel gas	12/21/95	5	P
2599J	510	2[a]	A	Turbine	NG/Liquid petroleum gas/RFG	12/22/95	5	P
2599G	642	1	A	Boiler	Refinery fuel gas	12/20/95	5	P
2599H	643	1	A	Boiler	Refinery fuel gas	12/21/95	5	P
2599I	644	1	A	Turbine	Refinery fuel gas	12/22/95	5	P
2599F	646	1	A	Boiler	Refinery fuel gas	1/8/96		P
2599M	**	1	A	Sulfur recovery unit			1	
2124A	445	3[a]	B	Heater	Refinery fuel gas	1/4/96		P
2536A	435	1	C	Steam generator	Crude oil	4/21/95		ND-430
2355A	448	1	D	Internal combustion engine	Natural gas	1/11/96		ND-430
2513C	637	1	E	Internal combustion engine	Diesel	3/9/95	5	P
2513A	638	1	E	Steam generator	Crude oil	3/14/95	5	P
2598A	436	1	F	Heater	Refinery fuel gas	12/20/95	5	P
2460B	168	1	G	Internal combustion engine	Natural gas	3/1/95		F-430
2460B	169	1	G	Internal combustion engine	Natural gas	3/1/95		F-430
2460B	170	1	G	Internal combustion engine	Natural gas	3/1/95		F-430
2460B	171	1	G	Internal combustion engine	Natural gas	3/1/95		F-430
2459A	449	1	G	Turbine	Natural gas	1/12/96		ND-430
2511A	**	1	G	Turbine			1	
2375A	110	1	H	Steam generator	Natural gas	12/6/94		P
2375B	111	1	H	Steam generator	Crude oil	12/6/94	4,5	P
2375C	112	1	H	Internal combustion engine	Diesel	12/6/94	4,5	NR
2375C	113	1	H	Internal combustion engine	Diesel	12/6/94	4,5	NR
2409A	114	1	H	Internal combustion engine	Field gas	12/8/94	3	P
2409A	115	1	H	Internal combustion engine	Field gas	12/8/94	3	NR
2409A	116	1	H	Internal combustion engine	Natural gas	12/8/94	3	NR
2409A	117	1	H	Internal combustion engine	Natural gas	12/8/94	3	NR

TABLE 2-1. SUMMARY OF MAJOR VALIDATION AND EXTRACTION PROBLEMS

Report ID	Device ID*	Number of Tests	Contractor ID	Device Type	Material Used	Review Date	Comment	Calculation Check Status
2409A	118	1	H	Internal combustion engine	Field gas	12/8/94	3	NR
2409A	119	1	H	Internal combustion engine	Field gas	12/8/94	3	NR
2409A	120	1	H	Internal combustion engine	Field gas	12/8/94	3	NR
2409A	121	1	H	Internal combustion engine	Natural gas	12/8/94	3	NR
2409A	122	1	H	Internal combustion engine	Natural gas	12/8/94	3	NR
2409A	123	1	H	Internal combustion engine	Natural gas	12/8/94	3	NR
2409A	124	1	H	Internal combustion engine	Natural gas	12/8/94	3	NR
2409A	125	1	H	Internal combustion engine	Natural gas	12/8/94	3	NR
2409A	126	1	H	Internal combustion engine	Natural gas	12/8/94	3	NR
2409A	127	1	H	Internal combustion engine	Field gas	12/8/94	3	NR
<u>2492A</u>	446	1	H	Reboiler	Glycol	1/9/96		ND-430
<u>2492B</u>	447	1	H	Reboiler	Glycol	1/9/96		ND-430
<u>2407A</u>	511	2	H	Steam generator	Natural/CVR gas, Natural gas	1/2/96		P
<u>2407A</u>	512	1	H	Steam generator	Natural/CVR gas	1/2/96		P
<u>2407A</u>	513	1	H	Steam generator	Natural/CVR gas	1/2/96		P
2007A	425	1	I	Kiln, calcining coke to petroleum products	Coke, natural gas	4/3/95		F-430
2484A	142	1	J	Boiler	No. 6 fuel oil	1/11/95	2	P
2541A	146	1	J	Heater	Pipeline oil	1/17/95	2	P
2405A	107	1	K	Heater	Natural gas	12/5/94		P
2405B	108	1	K	Steam generator	Natural/CVR gas	12/5/94		NR
2405C	109	1	K	Turbine	Natural gas	12/5/94		NR
<u>2300A</u>	439	1	K	Heater	Refinery fuel gas	1/3/96		P
<u>2300A</u>	440	1	K	Heater	Refinery fuel gas	1/3/96		P
<u>2300A</u>	441	1	K	Heater	Refinery fuel gas	1/3/96		P
<u>2300A</u>	442	1	K	Heater	Refinery fuel gas	1/3/96		P
<u>2300A</u>	443	1	K	Heater	Refinery fuel gas	1/3/96		P
2481A	411	1	L	Heater	Natural/Refinery fuel gas	3/15/95		P
<u>2487A</u>	645	1	L	Boiler	Crude oil	1/2/96		P

<u>Underlined</u> Report IDs extracted and validated using WSPA funding
* Device ID assigned on entry
** Data not extracted for this device
a = Number of conditions tested
b = Number of locations tested
F = Failed calculation check
P = Passed calculation check
NR = Calculation check not required because calculations checked for another device in report
ND = Not enough data to check calculations

1. Emission factor cannot be calculated (data not validated or extracted)
2. Dioxin/PAH sampled using a single train (data extracted and noted in the database)
3. Naphthalene analyzed by method 410 (data not extracted)
4. 4. Non-isokinetic sampling method 429
5. Full set of internal standards not used for method 429

2.3 OUTLIER ANALYSIS

Before developing emission factors, outliers were identified and evaluated. For this study, the Dixon test was used to identify outliers per substance per test and per substance per major group. To use the Dixon test, a group of data was selected and sorted from lowest to highest emissions. Then the high and low points were examined statistically in relation to the other points in the data set. The test identified if the high and low points were outliers at a 95 percent level of confidence. Outliers were evaluated to determine if sampling problems, calculation errors, or process upsets occurred. Outliers with calculation errors were corrected; those with sampling problems were rejected. Twenty-two outliers were identified in the analysis by device and substance, and four in the analysis by major group and substance. These results were excluded from the emission factor calculations.

Section 3
EMISSION FACTORS

CARB developed a procedure to provide emission factors of known quality for a wide range of air toxics and source types (Hansell, 1996). This procedure considers the design and operation of the sources, process stream characteristics, data quality, source population size, and emission factor variability. The steps of the procedure and corresponding sections in this study are:

Emission Factor Procedure	Volume 1	Volume 2
1.) Identify design and operating parameters	3.1	6.1
2.) Identify normalizing units	3.4	6.2
3.) Assign run-specific method ratings	-	6.3
4.) Calculate run-specific emission factor	3.4	6.4
5.) Identify major and subgroup evaluation parameters	3.1, 3.2	6.5
6.) Compile detailed data listing	3.5	6.6
7.) Conduct outlier analysis	2.3	6.7
8.) Identify subgroups	3.7	6.8
9.) Calculate emission factors for each subgroup	3.8	6.9
10.) Assign subgroup method and population ratings	-	6.10
11.) Assign CARB overall quality rating	-	6.11
12.) Assign EPA overall quality rating	-	6.12

- See Volume 2 for a detailed description

The data pool remaining after the screening and detailed validation described in Section 2 were evaluated using the CARB emission factor development procedure. This analysis and the subsequent emission factors are provided in Volume 2. Reference sections in Volume 2 for each step are listed above.

The emission factor analysis provided here in Volume 1 includes several revisions to the CARB procedures including:

- Emission factors from different major groups as identified in Volume 2 Section 6.5 were pooled together to increase the robustness of the emission factors (see Section 3.2);
- Statistical comparisons were conducted assuming the data are log normally distributed as opposed to normally distributed; and
- Nondetect data collected using low sensitivity analytical techniques were also excluded when higher quality data was available.

Aside from these changes, all other procedures are identical to those developed by CARB. The next sections provide details on the API/WSPA emission factor procedure. Where the CARB and API/WSPA procedures are the same, the reader is referred to the appropriate sections of Volume 2 (see above list). API/WSPA emission factors are listed in Appendices and described in Section 3.8. A comparison of the API/WSPA and CARB emission factors is provided in Section 3.9.

3.1 DESIGN AND OPERATING PARAMETERS

For this study, petroleum industry combustion devices have been divided into six groups: boilers, heaters, reciprocating internal combustion engines, gas turbines, coke calcining, and asphalt blowing. The boiler group includes steam generators. Various design and operating parameters can impact air toxic emissions from each of these groups. Parameters which may have a significant impact on emissions and were described in the test reports are listed in Table 3-1. This table also lists the number of tests for each system and design parameter. For example, 16 of the 19 tests for heaters were conducted while firing refinery gas. The table also shows that most of the sources tested, except for the gas turbines, did not have post-combustion APC systems. There is an equal split between sources with low-NOx burners and conventional burners. In ten of the 36 tests on boilers and heaters, the burner type was not listed in the test report.

TABLE 3-1. SUMMARY OF TESTING INFORMATION AVAILABLE BY SYSTEM TYPE AND KEY DESIGN PARAMETERS

Description		Number of Tests					
		Boiler (16)	Heater (16)	Reciprocating ICE (22)	Turbine (7)	Asphalt Blowing (1)	Coke Calcining (1)
Total Tests		17	19	22	8	2	1
Fuel Type	Asphalt fumes	-	-	-	-	2	-
	Natural/CVR gas	5	0	0	-	-	0
	Natural gas	2	1	13	3	-	1
	Crude oil	3	0	-	-	-	-
	No. 6 fuel oil	2	0	-	-	-	-
	Refinery gas	5	16	0	1	-	0
	Natural/Refinery gas	0	1	0	3	-	0
	Pipeline oil	0	1	-	-	-	-
	Diesel	0	0	3	0	-	0
	Field gas	0	0	6	0	-	0
	Natural/LP/Refinery gas	0	0	-	1	-	0
Post Combustion APC System	TO	0	0	0	0	2	0
	None	14	16	22	1	0	0
	SO2 Scrub	2	0	-	-	0	0
	SCR	1	2	0	1	0	0
	SD/FF	0	0	-	-	0	1
	DeNOx	0	1	-	-	-	-
	SCR/COC	0	0	0	5	0	0
	COC	0	0	0	1	0	0
2 or 4 Stroke	4S	-	-	19	-	-	-
	2S	-	-	3	-	-	-
Rich or Lean	Lean	-	-	19	-	-	-
	Rich	-	-	3	-	-	-
Capacity	>650 Hp	-	-	3	-	-	-
	<650 Hp	-	-	19	-	-	-
Duct Burners	No	-	-	-	3	-	-
	Yes	-	-	-	5	-	-
Load	Unknown	9	3	-	-	-	-
	>80%	3	7	-	-	-	-
	<80%	5	9	-	-	-	-
Burner Type	Unknown	7	3	-	-	-	-
	Low NOx	5	8	-	-	-	-
	Conventional	5	8	-	-	-	-

SCR: Selective Catalytic Reduction
COC: CO Catalyst
CVR gas: Casing Vapor Recovery Gas
SD: Spray Dryer
FF: Fabric Filter
-: Not applicable
(): Number of devices

3.2 MAJOR GROUPS

Under the CARB emission factor development procedures, emissions data from tests conducted on sources with different types of fuels (i.e. refinery gas, natural gas, field gas, etc.) and system classifications (process heaters, steam generators, and boilers) cannot be combined, as described in Section 6.5 of Volume 2. These guidelines yield emission factor groups containing results from one to two tests. Due to the inherent uncertainty of the measurement techniques, the robustness of the emission factors can be increased by combining fuel types and system types. Using the API/WSPA emission factor procedures, emissions from sources with different fuel types and system classifications are compared and combined when significant differences are not found. For this study the following major groups have been identified:

- External combustion
- Reciprocating internal combustion engines
- Gas turbines
- Coke calcining
- Asphalt blowing

Emissions data from these major groups will not be combined. For example, data from external combustion sources will not be combined with data from gas turbines. However, it is possible that data from process heaters and data from boilers will be combined, even though this is not allowed under the CARB procedures.

3.3 AIR TOXICS

To evaluate emission factor groupings, several representative air toxics were selected from the database described in Volume 2. In addition, total aldehyde, total BTX (benzene, toluene, and xylene), and total PAH (polycyclic aromatic hydrocarbons) emissions were calculated and evaluated. Table 3-2 shows the air toxics considered and the air toxics included in the totals. The table also shows the number of tests conducted for each air toxic and the total for each system type. The metals represent low volatility (arsenic, chromium and nickel), medium volatility

TABLE 3-2. SUMMARY OF TESTING INFORMATION AVAILABLE BY SYSTEM TYPE AND SUBSTANCE

Description		Number of Tests					
		Boiler [16]	Heater [16]	Reciprocating ICE [22]	Turbine [7]	Asphalt Blowing [1]	Coke Calcining [1]
Aldehydes	Formaldehyde	15	10	18 (4)	4	2	1
	Aldehyde Total	14	10	10	3	2	1
VOC	Benzene	15	14	17 (3)	5	2	1
	BTX Total	10	7	17 (3)	3	0	1
Metals	Arsenic	5	2	0	2	2	1
	Cadmium	5	2	0	3	2	1
	Chromium (Hex)	5	2	0	3	2	1
	Chromium (Total)	5	2	0	3	2	1
	Lead	5	2	0	2	2	1
	Mercury	5	2	0	3	2	1
	Nickel	5	2	0	3	2	1
	Selenium	5	2	0	2	2	1
PAH	Anthracene	8 (4)	7 (7)	5	3 (2)	0 (2)	1
	Benzo(a)pyrene	7 (4)	12 (7)	5	3 (2)	0 (2)	1
	PAH Total	7 (4)	7 (7)	5	3 (2)	0 (2)	1

(#): Number of tests rejected as a result of quality problems

[#]: Number of devices

Aldehyde Tot Acetaldehyde, Formaldehyde

BTX Total: Benzene, Toluene, Xylene

POM Total: Acenaphthene, Acenaphthylene, Anthracene, Benzo(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(e)pyrene, Benzo(g,h,i)perylene, Benzo(k)fluoranthene, Chrysene, Dibenz(a,h)anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-cd)pyrene, Naphthalene, Phenanthrene, Pyrene (cadmium and lead), and high volatility (mercury and selenium) groups. Benzo(a)pyrene was selected because of its toxicity. Since benzo(a)pyrene was not detected for most tests, a second PAH, anthracene, was selected.

3.4 NORMALIZING UNITS

An emission factor characterizes air toxic emissions as a ratio of the amount of pollutant released to a process-related parameter such as fuel feed rate. Using CARB emission factor procedures, the process parameter was based on the Source Classification Code (SCC) as described in Section 6.2 of Volume 2. For example, the SCC for natural gas-fired internal combustion engines is 20200202 and the process unit assigned to this code is million cubic feet (MMcf) of fuel burned. Thus, emission factors for natural gas-fired internal combustion engines were expressed as pounds per MMcf. The process unit for refinery gas-fired heaters also is MMcf. Because of the highly variable composition of refinery gas, the fuel heat input expressed as million British thermal units (MMBtu) is a more appropriate normalizing unit. Fuel-specific heating values measured during the test programs were used to convert all of the emissions data from lb/MMcf or lb/Mgal to lb/MMBtu. The emission factor calculation procedure used to convert the source test data to lb/MMcf and lb/Mgal is described in Section 6.4 of Volume 2.

The variability of fuel composition as indicated by heating value is illustrated in Figure 3-1. The typical range of heating values for refinery fuels (800 to 1500 Btu/scf) also is included on the figure. Most of the fuels fall within this range, as shown in Figure 3-1. The natural gases, field gases, and mixtures of natural gas and casing vapor recovery gas (CVRG) all have heating values of approximately 1000 Btu/scf. The refinery gas fuels or mixtures of refinery gas and other fuels have heating values ranging from 900 to 2000 Btu/scf.

3.5 DETAILED DATA LISTING

The impact of the design and operating parameters identified in Table 3-1 is illustrated graphically in Section 9 of Volume 3. One figure is presented for each system (boiler, heater, RICE, and gas turbine) and air toxic. One data set is provided per test condition. A data set includes three or

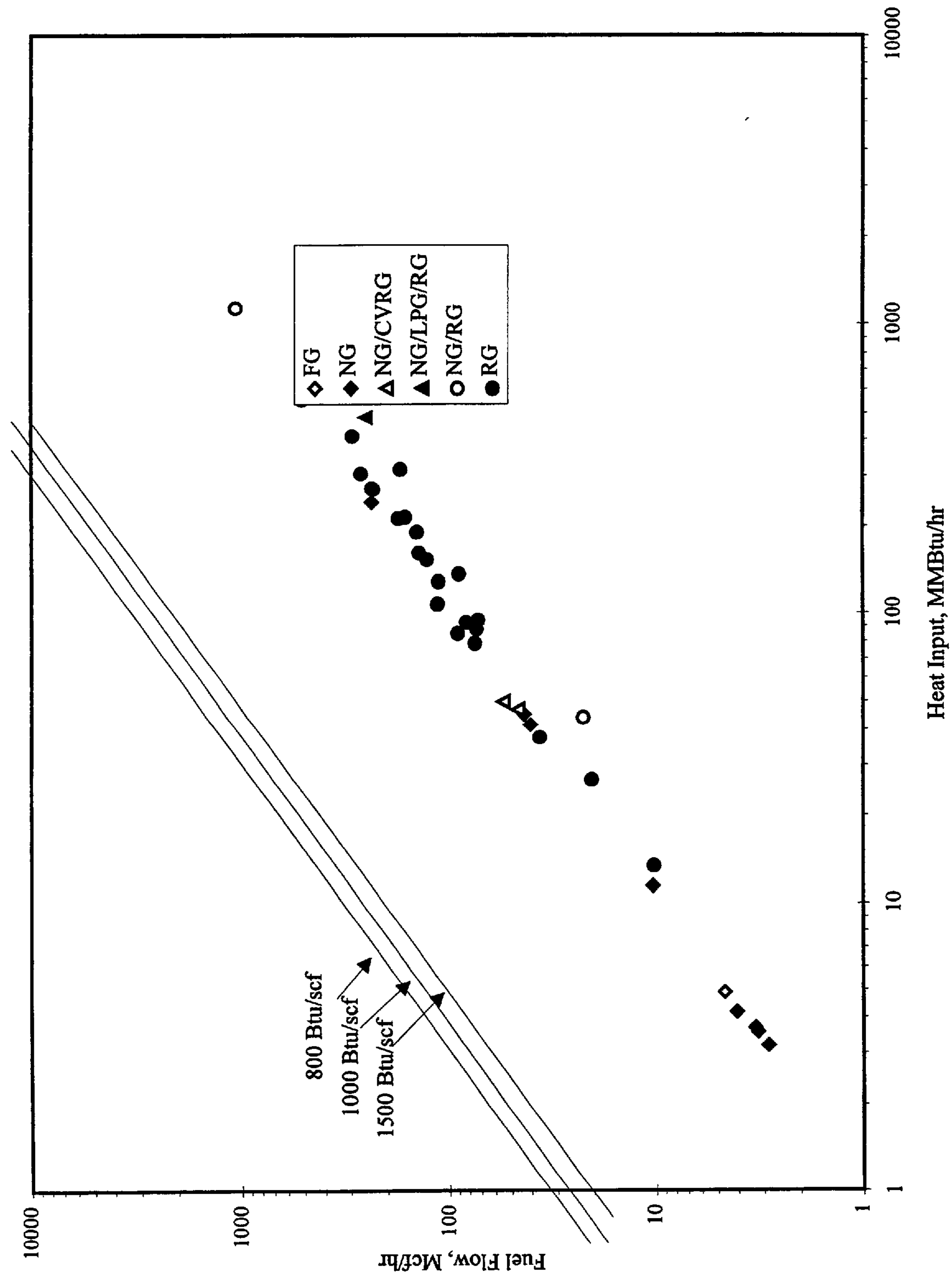


Figure 3-1. Normalizing Unit Comparison

more sampling runs conducted under a defined set of conditions. The minimum, mean, and maximum emission factor expressed in pounds per million Btu (lb/MMBtu) is shown for each data set. A detection ratio also is provided for each data set. The detection ratio is the ratio of the detected emission factors to the total of detected and not detected emission factors in a data set. Thus, a detection ratio of 1 indicates that all of the emissions data in a data set was detected and a detection ratio of zero indicates that all of the data in a data set was not detected. When an emission result was not detected, the full analytical detection limit was used to calculate the emission factor. The label on the x-axis describes the test condition. Data sets are sorted from low to high by fuel type.

3.6 TREATMENT OF NONDETECTS

Data generated from the chemical analysis of samples generated during a source test may fall below the detection limit (DL) of the analytical procedure. These data are referred to as not detected or nondetects. There are several ways to report nondetected levels of air toxic substances including using zero, the full detection limit, or a number between zero and the detection limit (usually one-half the detection limit). If similar sampling and analytical techniques are used, the DLs for nondetect values should be lower than the detected values. However, DLs for nondetect values also can be mixed with the detect values and in some cases DLs for nondetect values can be higher than any of the detect values. Nondetect values with DLs higher than any of the detect values for a group of data are referred to as low sensitivity data. In general, low sensitivity data is collected using short sampling times and/or low sensitivity analytical techniques such as low resolution mass spectrometry (LRMS) as opposed to high resolution mass spectrometry (HRMS).

Low sensitivity data is treated in the same manner as other data in the CARB procedures described in Volume 2. That is, low sensitivity data is used to evaluate the impact of design and operating parameters on emissions and it is used to develop emission factors. Under the WSPA/API procedures described in this volume, low sensitivity data is not used for statistical comparisons or emission factor development. A similar approach was used by the Electric Power

Research Institute (EPRI) to remove low sensitivity data (EPRI, 1995). Low sensitivity data also was eliminated in the development of proposed MACT standards for Hazardous Waste Incinerators (USEPA, 1996).

A graphical analysis was used to identify low sensitivity data for the WSPA/API analysis. For each air toxic, groups of data were defined by system type (boiler, heater, gas turbine, or RICE) and fuel phase (liquid or gas). For example one group of data would be formaldehyde emissions from boilers fired on liquid fuels and another would be boilers fired on gaseous fuels. The data were then sorted from low to high in each group. If the range included nondetects at the upper end of the distribution, these nondetects were labeled low sensitivity data and excluded from the analysis and emission factor development. It should be noted that the comparison was performed on a test condition basis using the arithmetic mean of all test runs. For a test condition to be characterized as low sensitivity, all of the runs had to be nondetect. Table 3-3 lists the number of low sensitivity tests by air toxic and system.

The treatment of nondetects described above eliminated nondetects from the upper end of the frequency distribution for each air toxic and group. However, nondetects are still present at the low end of the frequency distribution and mixed in with detected values. Various approaches have been formulated to handle these nondetects (EPA, 1996). Unfortunately, most approaches require that the DLs be the same or that the nondetects only occur at the lower end of the frequency distribution. Neither of these conditions are satisfied with the source test results presented in this study. To handle nondetects for this study, the full DL was substituted for nondetects. The actual value ranges from zero to the DL. Since the low sensitivity data were eliminated, it is likely that the actual value of emissions will be close to the DL. Thus the DL were used to calculate emission factors for nondetect source test results. This is the same approach used in the CARB procedures described in Volume 2.

TABLE 3-3. LISTING OF LOW SENSITIVITY TESTS BY SYSTEM TYPE AND SUBSTANCE

Category	Substance	RICE		Turbine		Boiler		Heater	
		Number of Low Sensitivity Tests	Total Number of Tests	Number of Low Sensitivity Tests	Total Number of Tests	Number of Low Sensitivity Tests	Total Number of Tests	Number of Low Sensitivity Tests	Total Number of Tests
Metals	Arsenic	-	-	2	2	1	5	1	2
	Beryllium	-	-	2	2	0	4	2	2
	Cadmium	-	-	0	3	[illegible]	5	0	2
	Chromium (Hex)	-	-	[illegible]	3	2	5	2	2
	Chromium (Total)	-	-	0	3	[illegible]	5	0	2
	Copper	-	-	0	3	0	5	0	2
	Lead	-	-	0	2	1	5	0	2
	Manganese	-	-	0	3	0	5	0	2
	Mercury	-	-	0	3	[illegible]	5	0	2
	Nickel	-	-	0	3	0	5	0	2
	Phosphorus	-	-	-	-	0	2	-	-
	Selenium	-	-	2	2	[illegible]	5	[illegible]	2
	Zinc	-	-	0	3	[illegible]	5	[illegible]	2
PAH	Acenaphthene	[illegible]	5	0	3	[illegible]	7	[illegible]	7
	Acenaphthylene	[illegible]	5	0	3	[illegible]	8	[illegible]	7
	Anthracene	[illegible]	5	0	3	0	8	[illegible]	7
	Benzo(a)anthracene	[illegible]	5	[illegible]	3	[illegible]	8	[illegible]	12
	Benzo(a)pyrene	2	5	3	3	[illegible]	7	0	12
	Benzo(b)fluoranthene	[illegible]	4	0	3	[illegible]	6	0	12
	Benzo(g,h,i)perylene	[illegible]	5	2	3	[illegible]	7	0	7
	Benzo(k)fluoranthene	0	4	2	3	[illegible]	6	0	12
	Chrysene	[illegible]	5	0	3	0	8	0	7
	Dibenz(a,h)anthracene	2	5	3	3	[illegible]	7	2	12
	Fluoranthene	0	5	0	3	0	8	0	7
	Fluorene	0	5	0	3	0	8	0	7
	Indeno(1,2,3-cd)pyrene	2	5	2	3	2	7	0	12
	Naphthalene	0	5	[illegible]	-	0	8	0	7
	Phenanthrene	0	5	0	3	0	8	0	7
	Pyrene	0	5	0	3	0	8	0	7
	Total PAH	0	5	0	3	0	7	0	7
SVOC	Ethylbenzene	-	-	2	2	0	2	1	5
	Phenol	-	-	0	3	0	4	0	8
VOC	Acetaldehyde	0	10	0	3	1	14	0	11
	Formaldehyde	0	18	0	4	1	15	0	10
	Total Aldehyde	0	10	0	3	0	14	0	10
	Benzene	0	17	5	5	1	15	10	14
	Toluene	0	17	0	4	0	13	0	14
	Xylene (m,p)	0	15	-	-	-	-	-	-
	Xylene (o)	0	15	-	-	-	-	-	-
	Xylene (Total)	0	2	0	4	7	10	2	7
	Total BTX	0	17	1	3	1	10	2	7
	1,3-Butadiene	-	-	-	-	2	2	-	-
	Acrolein	0	11	-	-	2	8	3	3
	Hydrogen Sulfide	-	-	2	2	3	6	7	7
	Propylene	0	17	-	-	2	8	0	6
Totals:		7	232	29	113	43	308	33	275

3.7 SUBGROUP EVALUATION

Subgroups may be developed for major groups (external combustion, reciprocating internal combustion engines, gas turbines, coke calcining, and asphalt blowing) with two or more sources. As the number of sources increases, the potential for subgroup development also increases.

Subgroups are developed when a secondary design or operating parameter is identified that impacts emissions. Engineering judgement and statistical analysis can be used to determine whether the secondary parameters have a significant impact on emissions. If a secondary parameter does impact emissions, subgroups are established resulting in lower emission variability than present across the major group. If the statistical analysis contradicts commonly accepted knowledge about emissions behavior, subgroups should not be developed.

In cases where a secondary parameter impacts one substance but not another, the data for both substances could be segregated into different subgroups. Another approach would be to segregate the data for the impacted substance into different subgroups and combine the data for the substance that was not impacted. This approach can generate a large number of subgroups with high variability. To reduce the number of subgroups and the variability of emissions data in each subgroup, subgroups were identified in this project using the following two step process:

i) Identify which parameters (comparison parameters) identified in Table 3-1 impact the emissions data by reviewing the graphs in Section 9 of Volume 3 and using the t-test. The t-test uses the t-distribution to determine if two samples are from the same population when the variances are unknown but equal. The test is applicable to large and small samples. A sample with 30 or fewer data points is considered to be small. A sample is a group of data with a distinct value or range of values of the secondary parameter considered. If the t-test indicates that two samples are not from the same population, then the secondary parameter which the samples were grouped by has a significant impact on emissions. It should be noted that the t-test was only used to support the development of subgroups. In no case was the t-test used to blindly develop subgroups. Before developing subgroups, the results of the t-test were examined to ensure that they were reasonable based on engineering judgement.

ii) Segregate tests in each major group into subgroups based on those secondary parameters identified in Step i which impact the emissions data. Results from one device were not split into different subgroups. This approach is appropriate when a substance is impacted by the secondary parameter and when it is not impacted.

The t-test comparisons were conducted assuming the data is log normally distributed as opposed to normally distributed. For comparisons, the log normal distribution provides a better representation of typical emissions and is not impacted by outliers. The log normal distribution is a commonly used distribution for modeling environmental data (USEPA, 1996). Environmental data generally have frequency distributions that are non-negative and skewed with heavy or long right tails.

Subgroups are identified in the following subsections for external combustion, reciprocating internal combustion engines, and gas turbines. Subgroups were not developed for coke calcining since only one test is available. Subgroups for asphalt blowing include no blow cycle and blow cycle.

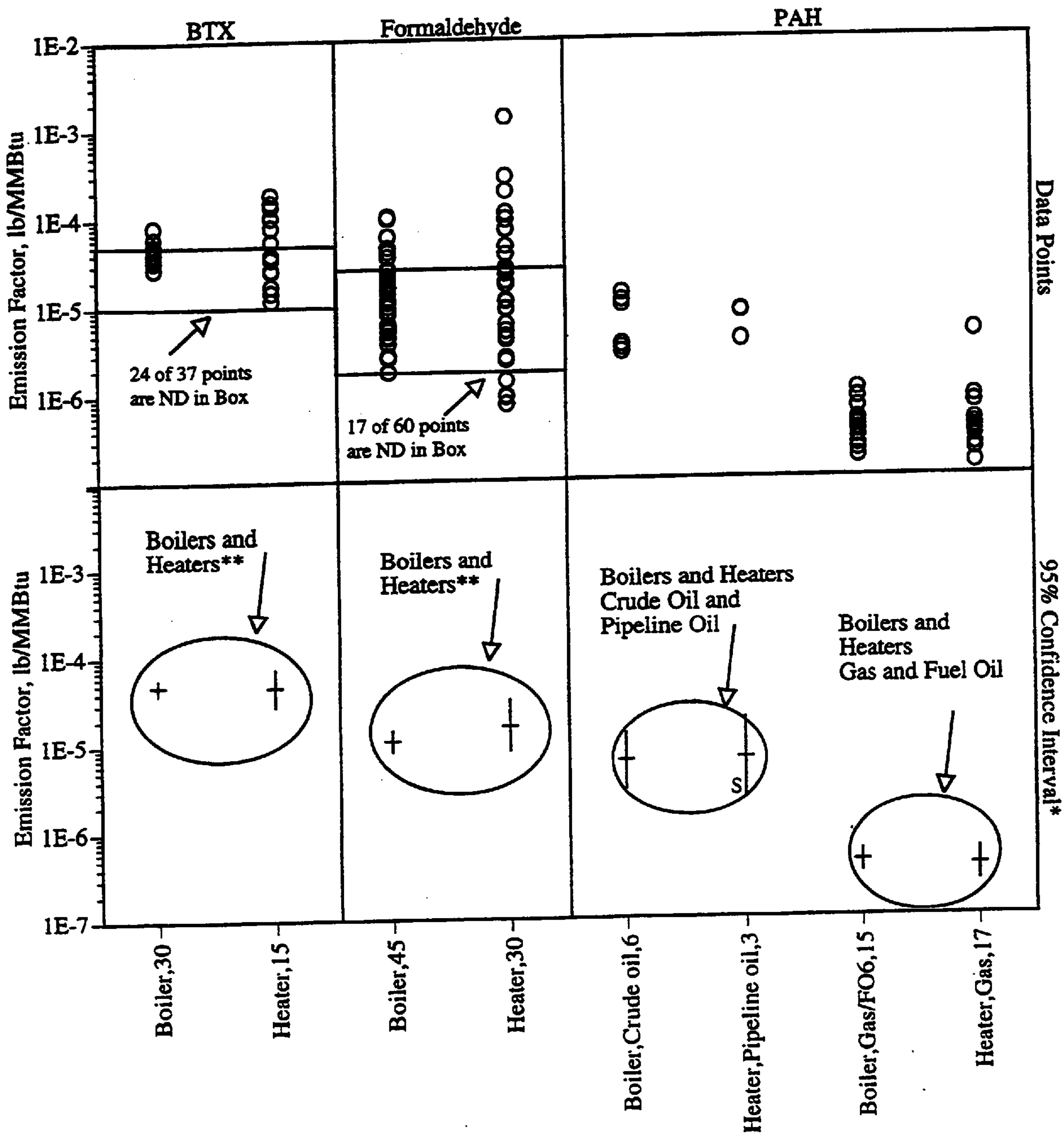
3.7.1 External combustion

Several possible subgroup parameters were identified in Table 3-1 for external combustion sources including fuel type, system type, post-combustion air pollution controls, load, and burner type. Based on an examination of the graphs in Section 9 of Volume 3 and the analysis presented in Section 6.8 of Volume 2, load and heating value were eliminated from the list of possible subgroup parameters. The impact of system type, fuel type, and NOx controls (post-combustion controls and burner type) are discussed below.

The results of fuel type, system type, and NOx control t-test comparisons are provided in Tables 8-1, 8-2, and 8-3 of Volume 3. Each of these tables includes a description of the data sets being compared, number of points, average, standard deviation, and detection limit ratio (detect ratio). The detect ratio is the ratio of the sum of detected values to the sum of detected and nondetected values. A detect ratio of one indicates that all of the data was detected. A detect ratio of zero indicates that all of the data was not detected. If the difference between the data sets is significant based on the t-test, a *Yes* is provided in the last column of the table. If the comparison includes more than three runs (two tests or more), the significantly higher data set is shaded. The higher data set is underlined for comparisons where the difference is not significant or the difference is significant but contains three or fewer runs. If the difference is significant but none of the data was detected, no shading or underlining is provided. If the lower data set includes all nondetect data and the higher data set includes detected data, then the higher data set is shaded, provided each data set in the comparison includes more than three runs. If the sample sizes are too small for statistical comparison (i.e., one run only), *NA* is given in the last column.

Figure 3-2 compares BTX, formaldehyde, and total PAH emission factors in pounds per million Btu (lb/MMBtu) for boilers and process heaters. The top part of the figure displays the data points included in each group. A data point is a single test run. Usually a test on a single unit operated under one condition is composed of three replicate runs. The x-axis label indicates the total number of data points in each group. The lower half of the figure displays confidence internals at a 95 percent degree of confidence for each group. The confidence intervals were calculated assuming that the data is log normally distributed rather than normally distributed. The log normal distribution better represents all of the data and is not impacted significantly by the presence of outliers. Overlapping confidence intervals indicate no significant difference. Data sets with three or fewer points have been marked *S* for small data set. These sets are generally not used to support the development of subgroups unless the difference is large or supported by other research.

There are 45 data points in the database for BTX as shown in Figure 3-2. Comparing the BTX results for boilers and process heaters, it is clear that there is no significant difference. The range of BTX emissions appears to be slightly broader for process heaters compared to boilers; however, confidence intervals overlap, indicating no significant differences. Thus, it is reasonable to aggregate the BTX data for boilers and process heaters to produce a more robust emission factor.



* Confidence interval calculated assuming log normal distribution
** Includes liquid and gas fuels
S - Small data set. Differences between these data sets and others are not considered significant

Figure 3-2. External Combustion System Type Comparison.

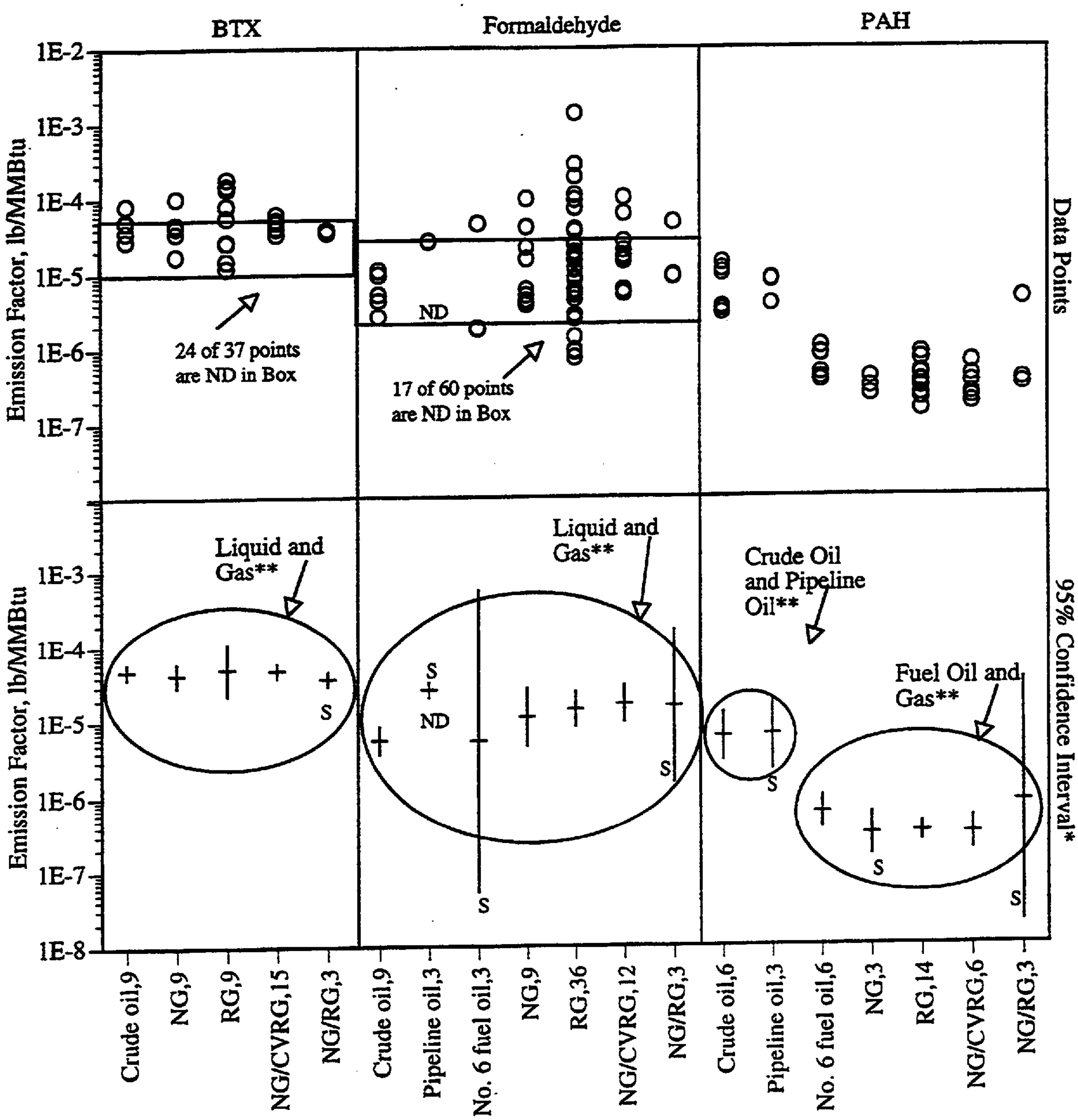
The range of formaldehyde emission factors shown in Figure 3-2 is considerably broader than BTX or PAH emissions. This is due in large part to the difficulty in making reliable formaldehyde measurements due to contamination. Formaldehyde is present at low concentrations in ambient air as a natural product of transpiration and respiration. Many common materials such as carpeting and wood paneling emit small amounts of formaldehyde. Thus, it is ubiquitous in many environments and contamination is sometimes unavoidable, even with the best field and laboratory QA practices. Nevertheless, formaldehyde is an intermediate combustion product that theoretically may escape complete destruction in "real" systems under extreme conditions. As with the BTX results, it is evident that there is no difference between boilers and process heaters with respect to formaldehyde emission factors. This is clearly indicated by the data and confidence intervals.

Figure 3-2 presents 41 total PAH results. For this analysis, sixteen separately-measured substances common to all tests are included in the sum. Results from crude oil and pipeline oil-fired boilers have been listed separately. These units have been separated because it appears that their emissions are higher than sources firing gas and fuel oil No. 6. Inspection of the total PAH results for gas and fuel oil No. 6 indicate there is no significant difference between boilers and process heaters; therefore an aggregate emission factor may be used.

In addition to natural gas, process gases are frequently used as a primary or supplemental fuel. Process gases vary in heating value depending on the gas source and other process operations. Figure 3-1 shows the fuel heating value for several common process gases compared to natural gas. Natural gas exhibits a small variation in heating value of approximately 1050 British thermal units per standard cubic foot (Btu/scf). For the process gas samples shown, heating value ranges from approximately 900 to nearly 2000 Btu/scf. The heating value of refinery gas typically ranges from 800 to 1500 Btu/scf, and may vary from hour to hour in cooposition and hence, heating value, depending on refinery process operations. It can be seen in Figure 3-1 that refinery gas heating values may occasionally exceed this range.

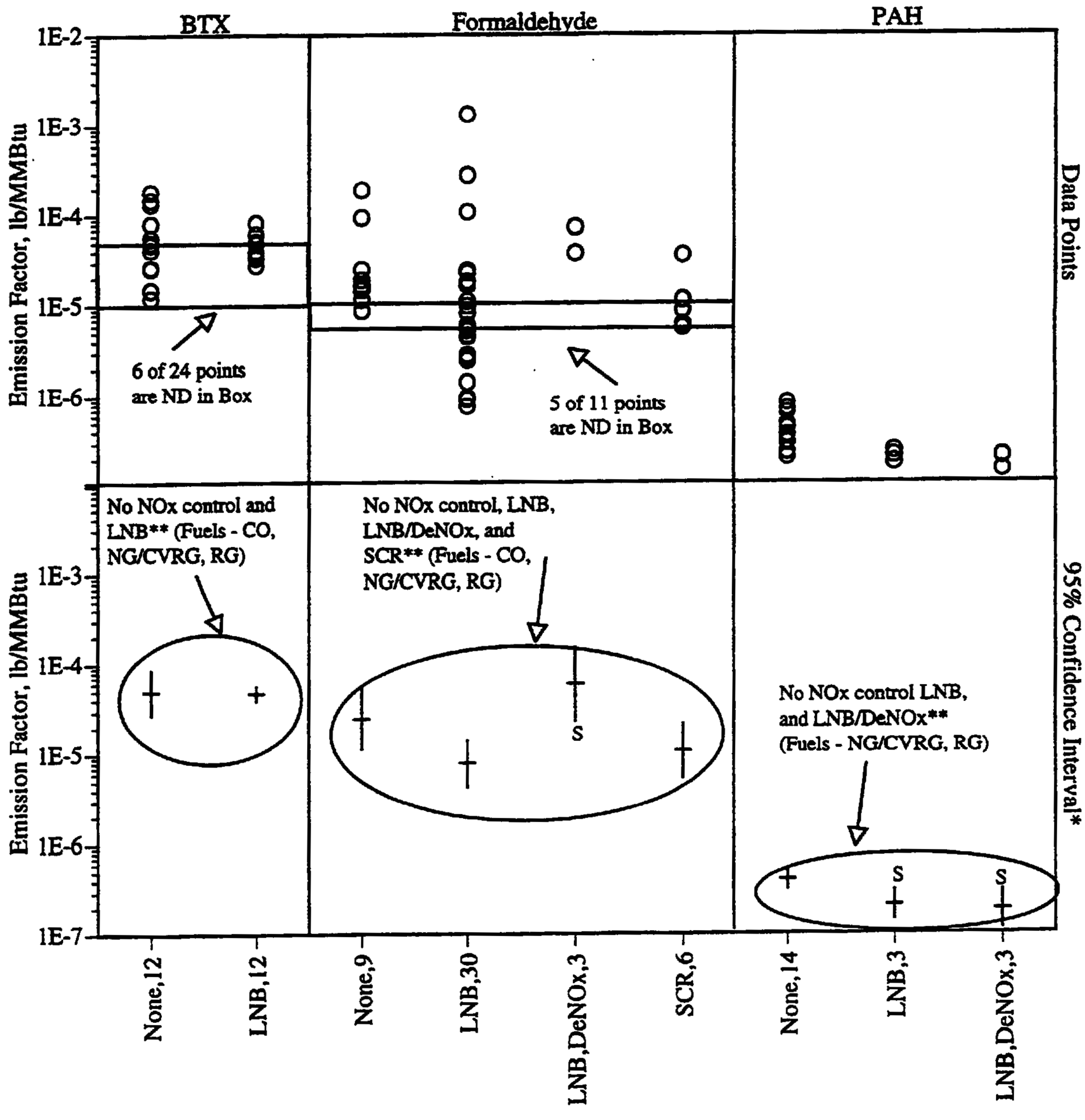
Both natural gas and various process gases may be fired in petroleum industry boilers and process heaters. Figure 3-3 compares BTX, formaldehyde and total PAH emissions for several different fuel gases. Liquid fuels also are included for comparison. The data represent combined tests on process heaters and boilers. BTX emissions are not significantly different for the different fuels, although the variability observed for refinery gas was somewhat greater than for the other fuel gases. Formaldehyde emissions generally showed the most variability both for an individual fuel gas and among different gases. The confidence intervals overlap for most of the fuels shown. Pipeline oil appears to have higher emissions, although all of the data is not detected. Crude oil has slightly lower emissions than sources burning a combination of natural gas and casing vapor recovery gas, as indicated by the confidence intervals. However, the difference is small and the fuels can be considered to produce similar emissions. The total PAH comparison indicates that crude oil and pipeline oil sources have higher emissions than gas-fired sources. NOx emission controls have been installed on many petroleum industry boilers and process heaters, and are especially common in California due to stringent air quality regulations. It has been speculated that NOx emission controls may increase or decrease HAP emissions. For example, those conditions which favor low NOx emissions in combustion controls (i.e., delayed fuel-air mixing) would be expected to favor increased HAP emissions; conversely, certain catalysts used for NOx control also may reduce trace organic emissions. Figure 3-4 compares field data from process heaters and boilers with different NOx control equipment including low-NOx burners (LNB), selective catalytic NOx reduction (SCR) and selective non-catalytic NOx reduction (SNCR or DeNOx) to data from units with no NOx controls. Again, several of the data sets are small, so some of the differences, although statistically significant, cannot be viewed with great confidence.

BTX emissions from units with and without low-NOx burners are not significantly different. Formaldehyde emissions again showed the characteristic variability both within and among categories. There appear to be no statistically significant differences in formaldehyde emissions between units equipped with LNB, SCR and no NOx controls. The unit with LNB and SNCR appears to have higher emissions; again, it is difficult to place great reliance on three tests of a single unit. The unit with no controls has similar emissions to the unit with LNB and SNCR.



* Confidence interval calculated assuming log normal distribution.
** Includes boilers and heaters
S - Small data set. Differences between these data sets and others are not considered significant

Figure 3-3. External Combustion Fuel Comparison.



* Confidence interval calculated assuming log normal distribution
** Boilers and heaters and liquid and gas fuels
S - Small data set. Differences between these data sets and others are not considered significant

Figure 3-4. External Combustion NOx Control Comparison.

Tests of units with low-NOx burners revealed the greatest variability of formaldehyde emissions. PAH emissions were similar for units without controls and units with LNB or LNB+SCR.

Statistical t-test results indicate a significant difference between units with low-NOx burners and conventional burners. Again, the small data set leads to high uncertainty and, therefore, the differences should not be viewed as significant. Additional tests should be performed to confirm whether a significant difference truly exists.

Results from the statistical analysis are summarized in Table 3-4. This table shows the results of the system type, fuel type, and NOx control comparisons for total BTX, formaldehyde, and total PAH. The table indicates whether the average emission factors for the groups being compared are the same, similar, or higher/lower. Comparisons which are significant are underlined. Notes on the comparison of the variability of the data in each group also are provided.

The final external combustion subgroups include crude oil/pipeline oil, fuel oil No. 6, and gas. The gas category includes natural gas and process gas-fired sources. A comparison of the total BTX, formaldehyde, and total PAH data points and confidence intervals is provided in Figure 3-5. A description of the graph is provided in the system comparison subsection of Section 3.7.1. Figure 3-5 shows that the only significant difference in the emission factors is in the total PAH emission factor for crude oil/pipeline oil.

3.7.2 Reciprocating internal combustion engines

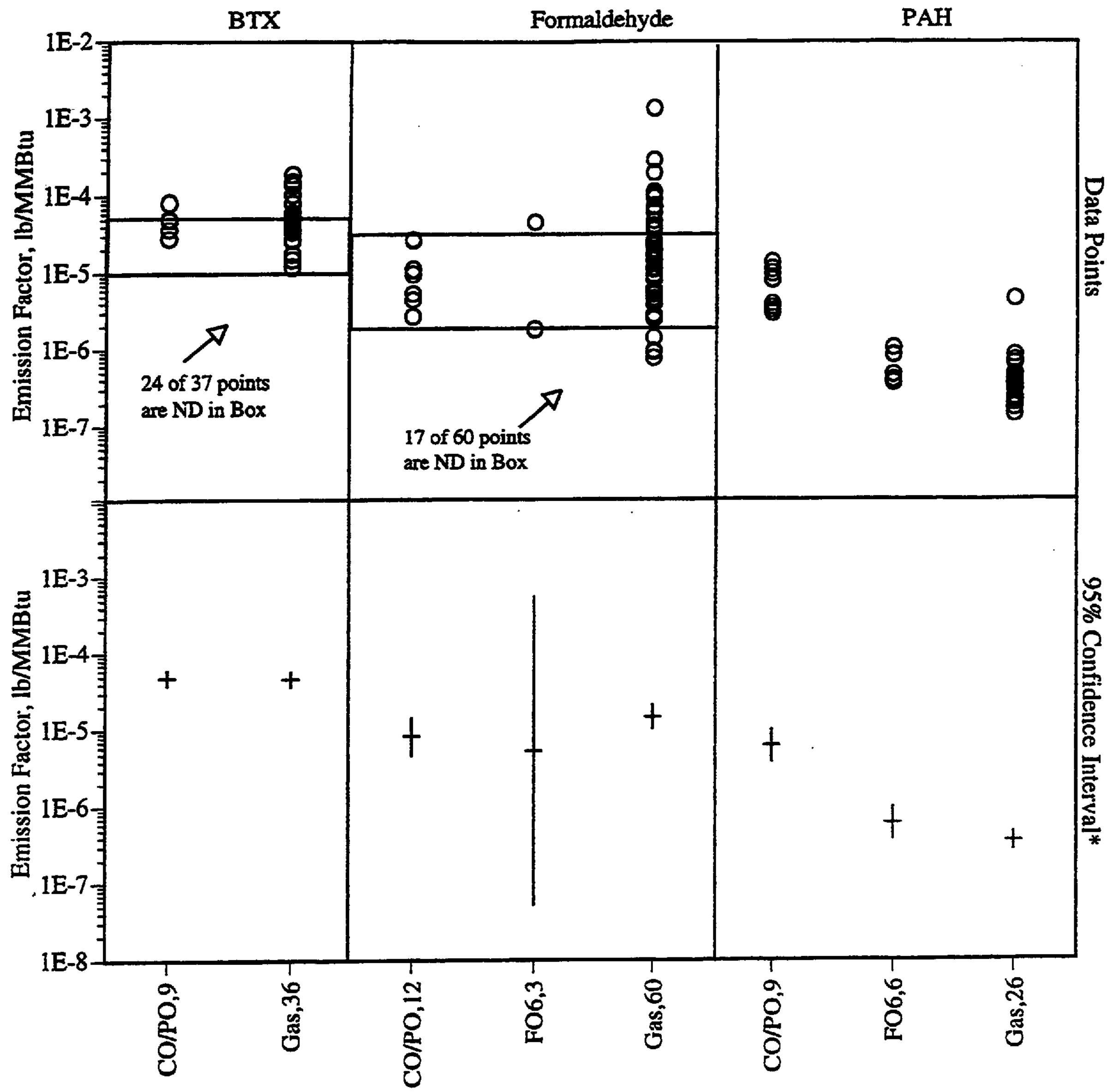
Several possible subgroup parameters were identified in Table 3-1 for reciprocating internal combustion engine sources, including: fuel type, strokes per cycle, size, post-combustion air pollution controls, and emission oxygen content. Based on an examination of the graphs in Section 9 of Volume 3 and the analysis presented in Section 6.8 of Volume 2, capacity was eliminated from the list of possible subgroup parameters. None of the sources had post-combustion air pollution controls. The emissions data were grouped by the remaining parameters, including: fuel type, strokes per cycle, and oxygen. The data points and confidence intervals for

TABLE 3-4. EXTERNAL COMBUSTION EMISSION FACTOR COMPARISON SUMMARY

HAP	Emission Factor Comparison					
	System Type (Boiler vs Heater) See Figure 3-2		Fuel Type (1) See Figure 3-3		NOx Control (2) See Figure 3-4	
	Average	Variability	Average	Variability	Average	Variability
BTX Total	Boilers and heaters same	Heaters more variable	No impact of gas type: gas and liquid same	RG more variable (3)	Low-NOx burner and conventional burner same	Conventional Burner more variable
Formaldehyde	Boilers and heaters same	Heaters more variable	No impact of gas type: gas and liquid same	RG more variable (3)	Low-NOx burner, conventional burner, and SCR same	Low-NOx burner more variable
PAH Total	Boilers and heaters same	Similar	CO and FO higher than gas	Similar	Low-NOx burner and conventional burner similar	Conventional burner more variable

Same: No significant difference in emission factor average
Similar: No difference in emission factor average or variability
Higher/Lower: Significant difference in emission factor average
Underline/Significant:
- t-test at 95% confidence with variances unknown but equal.
- Comparison includes 2 or more tests

CG: Casing Gas, RG: Refinery Gas, NG: Natural Gas, CVRG: Casing Vapor Recovery Gas, CO: Crude Oil, FO: Fuel Oil
(1) - CO, FO, PO, NG, RG, CG/NG, NG/CVRG, NG/RG (Not all comparisons include all fuel types)
(2) - None, LNB, LNB/DeNOx, SCR (Not all comparisons include all NOx controls)
(3) - Variability not a result of any parameter investigated



* Confidence interval calculated assuming log normal distribution
** Includes boilers and heaters

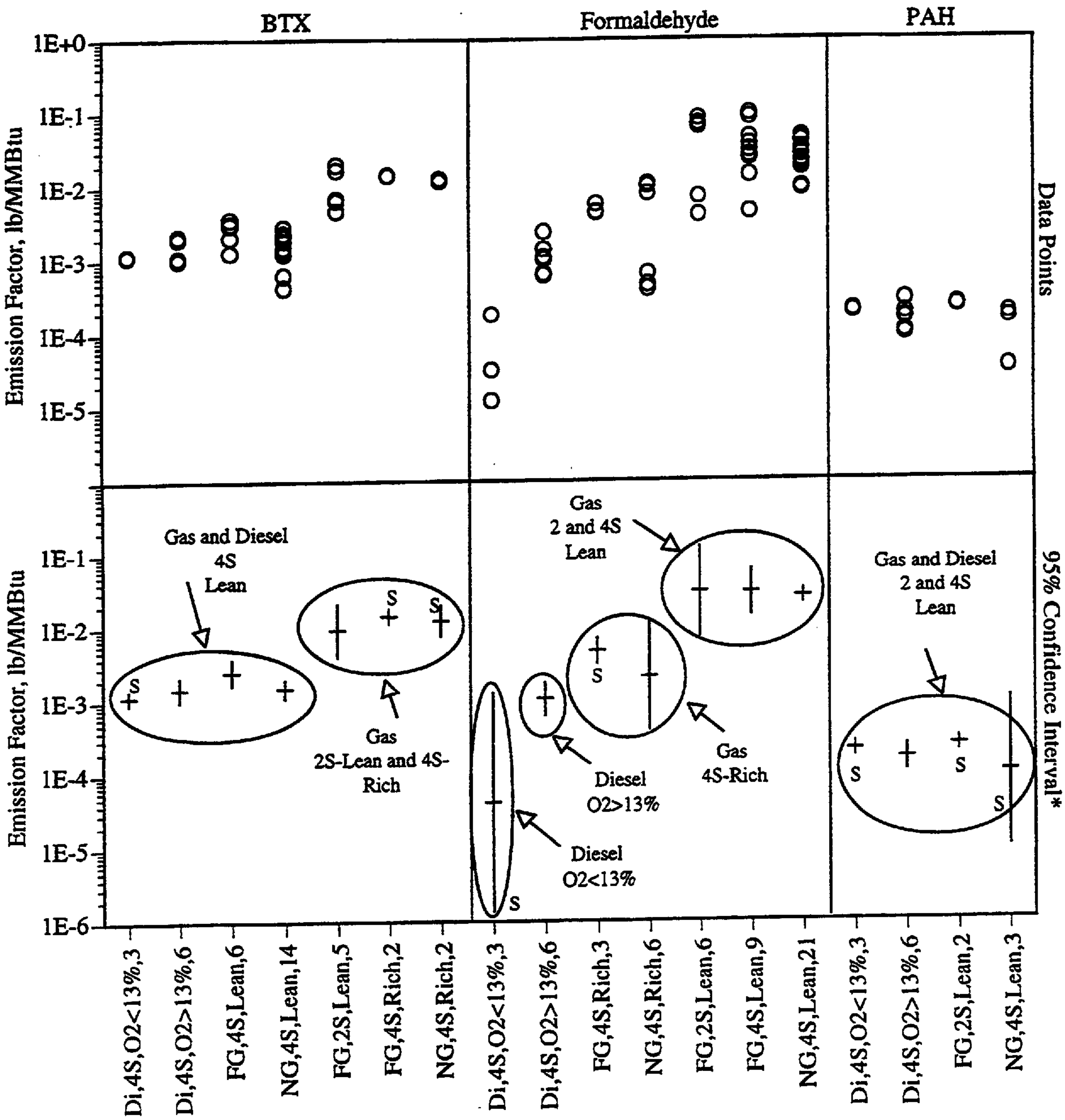
Figure 3-5. External Combustion** Emission Factor Group Comparison.

the resulting groups are provided in Figure 3-6 for total BTX, formaldehyde, and total PAH. Results of the t-test comparison for each of the groups in Figure 3-6 are provided in Table 8-3 of Volume 3. Both Figure 3-6 and Table 8-3 of Volume 3 are described in Section 3.7.1.

In some of the comparisons displayed in Figure 3-6, the data sets compared include results from a single source test. In general, these comparisons are not considered reliable. However, when the differences are large and supported by process knowledge, subgroups can be developed. Potential groupings have been circled in Figure 3-6. As shown in the figure, 2-stroke and rich burn sources have higher total BTX emissions. A comparison of emissions by diesel, natural gas or field gas for lean burn engines indicates that there is no impact of fuel type on emissions. Lean burn gas-fired sources have higher formaldehyde emissions than rich burn gas-fired sources. Lean burn diesel sources have lower formaldehyde emissions than lean burn gas-fired sources. This indicates that fuel type impacts the emission of formaldehyde. Field gas and natural gas sources have similar formaldehyde emissions. Lean burn natural gas, field gas, and diesel sources have similar total PAH emissions. No total PAH results are available for rich burn engines. Additional testing is needed to develop statistically significant conclusions for total PAH emissions.

Results from the statistical analysis are summarized in Table 3-5. This table shows the results of the fuel type, strokes per cycle, and NOx control comparisons for total BTX, formaldehyde, and total PAH. The table indicates whether the average emission factors for the groups being compared are the same, similar, or higher/lower. Comparisons which are significant are underlined. Additionally, notes on the comparison of the variability of the data in each group are provided.

The reciprocating internal combustion engine subgroups include diesel/O_2>13%, diesel/O_2<13%, gas/2S/lean, gas/4S/lean, and gas/4S/rich. The gas category includes natural gas- and field gas-fired sources. A comparison of the total BTX, formaldehyde, and total PAH data points, as well as the confidence interval for each subgroup, is provided in Figure 3-7. A description of the graph is provided in Section 3.7.1.



* Confidence interval calculated assuming log normal distribution

S - Small data set. Differences between these data sets and others are not considered significant

Figure 3-6. Reciprocating Internal Combustion Engine Comparison.

TABLE 3-5. RECIPROCATING INTERNAL COMBUSTION ENGINE
EMISSION FACTOR COMPARISON SUMMARY

HAP	Emission Factor Comparison					
	Fuel Type (1) See Figure 3-6		2 or 4S See Figures 3-6 & 3-7		NOx Control (2) See Figures 3-6 & 3-7	
	Average	Variability	Average	Variability	Average	Variability
BTX Total	FG, NG, and diesel same (See 4S lean RICEs)	Similar	2S Higher than 4S (See Lean RICEs)	Similar	Rich higher than lean (See 4S RICEs)	Rich is less variable than Lean (Small sample for Rich)
Formaldehyde	FG and NG same and diesel lower (See 2S and 4S lean RICEs)	Similar	2S Same as 4S (See Lean Gas Fired RICEs)	Similar	Lean higher than rich (See 2S and 4S gas-fired RICEs)	Similar
PAH Total	FG, NG and diesel similar	Similar	2S similar to 4S	2S is less variable than 4S (Small sample for 2S)	Information available for Lean RICEs only	Insufficient information for comparison

Same: No significant difference in emission factor average
Similar: No difference in emission factor average or variability
Higher/Lower: Significant difference in emission factor average
Underline/Significant:
- t-test at 95% confidence with variances unknown but equal.
- Comparison includes 2 or more tests

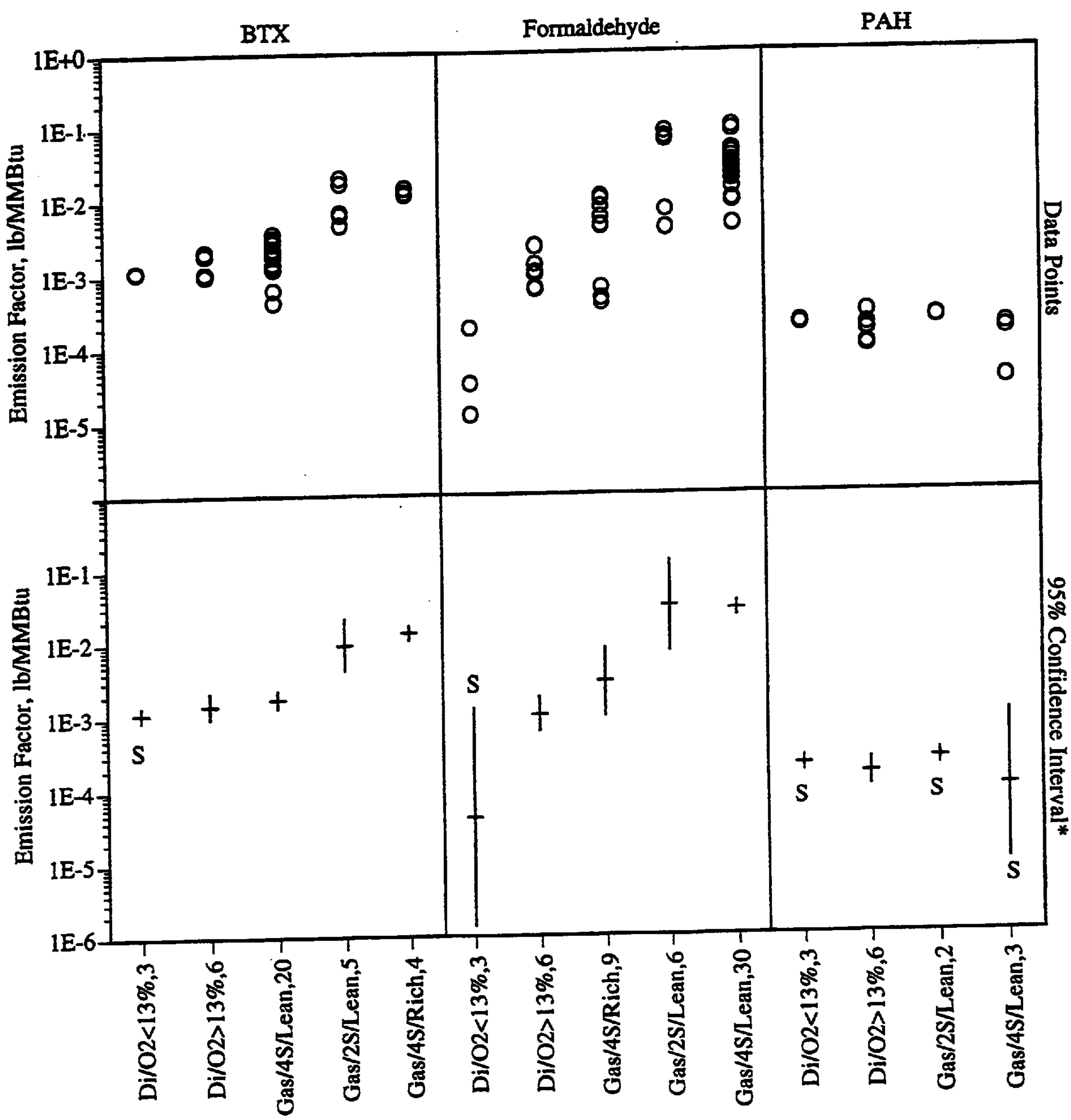
RICE: Reciprocating Internal Combustion Engine
FG: Field Gas, NG: Natural Gas
(1) - Diesel, Natural Gas, and Field Gas (Not all comparisons include all fuel types)
(2) - Rich and Lean (Not all comparisons include all NOx controls)

3.7.3 Gas turbines

Several possible subgroup parameters were identified in Table 3-1 for gas turbine sources including fuel type, duct burners, and post-combustion air pollution controls. The data points and confidence intervals for the resulting groups are provided in Figure 3-8 for total BTX, formaldehyde, and total PAH. Results of the t-test comparison for each of the groups in Figure 3-8 are provided in Table 8-3 of Volume 3. Both Figure 3-8 and Table 8-3 of Volume 3 are described in Section 3.7.1. In each of the comparisons conducted, the data sets compared include results from a single source test. In general, these comparisons are not considered reliable. Each of the data sets for each substance have a different configuration as shown in Figure 3-8. Thus it is difficult to determine which parameter, if any, is responsible for the observed differences. Comparing the formaldehyde and Total PAH results with no post-combustion APCs and SCR/COC for the data sets with natural gas and no duct burners, it appears that neither SCR nor COC impact emissions. If it is assumed that fuel type does not impact emissions as observed for the external and reciprocating internal combustion sources, total PAH emissions are higher for sources with duct burners. The natural gas results for formaldehyde also show that duct burners produce higher emissions, assuming that post-combustion APCs do not impact emissions. Based on these observations, subgroups for gas turbines, with and without duct burners, were developed.

3.8 EMISSION FACTOR TABULATION

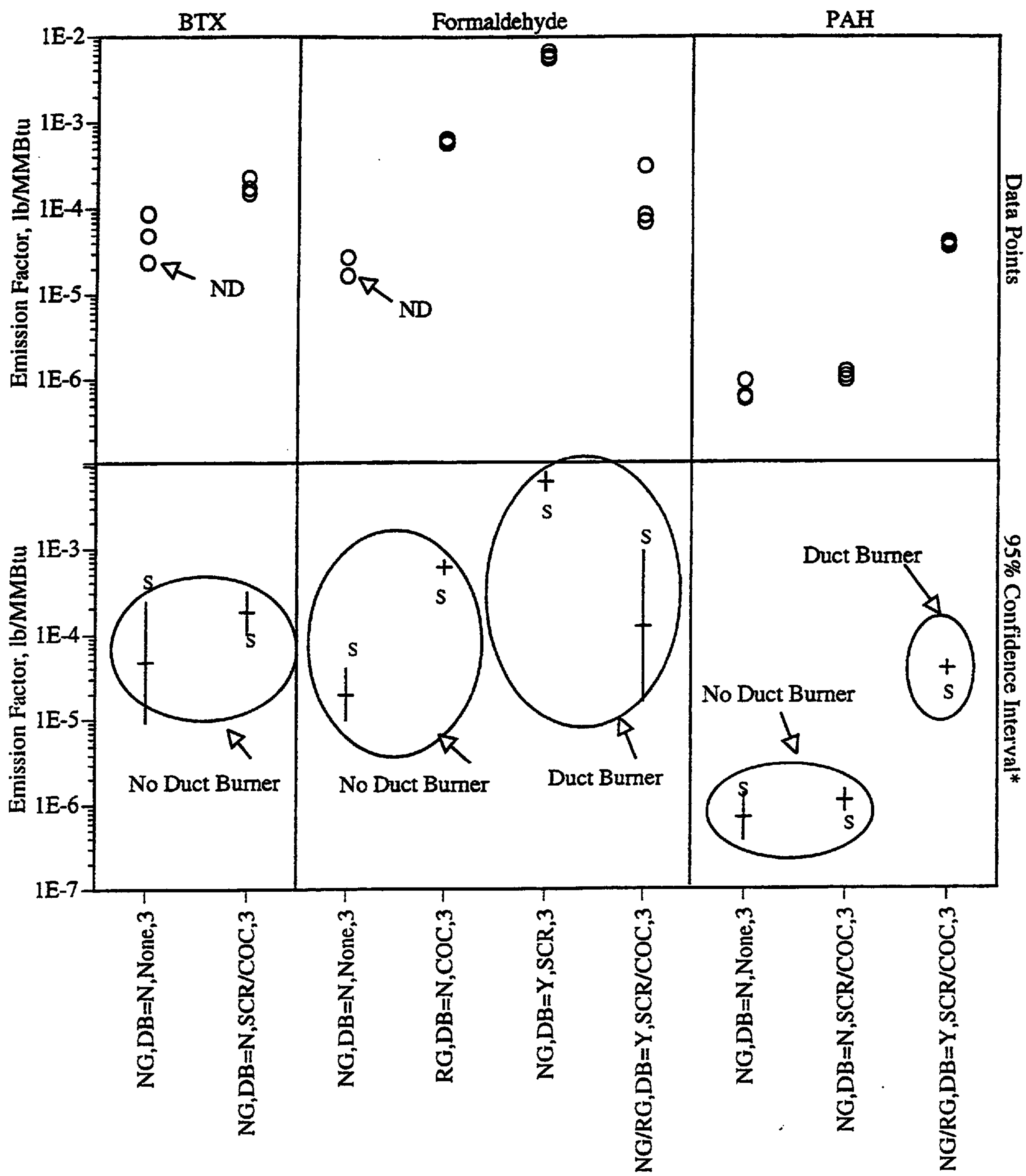
Once subgroups have been established, run-specific emission factors must be averaged for each substance in each subgroup. For this project, the run-specific emission factors were averaged arithmetically. Since the arithmetic average is impacted by outliers, it provides a conservative estimate of emissions. Most tests included three runs. Therefore, if a subgroup included two tests, the corresponding six-run emission factors would be averaged. In addition to the arithmetic average mean, several statistics were calculated, including: number of tests, number of runs, CARB rating, EPA rating, detection ratio, median, maximum and minimum emission factors, upper confidence limit, relative standard deviation, and uncertainty. The detect ratio is defined as the ratio of the sum of detected values to the sum of detected and nondetected values. A detect



* Confidence interval calculated assuming log normal distribution

S - Small data set. Differences between these data sets and other are not Considered significant

Figure 3-7. Reciprocating Internal Combustion Engine Emission Factor Group Comparison.



* Confidence interval calculated assuming log normal distribution
S - Small data set. Differences between these data sets and others are not considered significant

Figure 3-8. Gas Turbine Comparison.

ratio of one indicates that all of the data was detected. A detect ratio of zero indicates that all of the data was not detected. The relative standard deviation and uncertainty are indicators of the precision and accuracy of the emission factors. The relative standard deviation is calculated as 100 times the standard deviation divided by the arithmetic average. The uncertainty is calculated as 100 times the 95 percent confidence interval divided by the arithmetic average. Ideally the relative standard deviation and uncertainty should be zero. The upper confidence limit is the confidence interval at a 95 percent degree of confidence plus the arithmetic average. The CARB rating and EPA rating are described in Section 6.11 and 6.12 of Volume 2.

The EPA ratings listed in Appendices A through C are assigned on an A through E scale. The emission factor ratings from these appendices are summarized below:

EPA Quality Rating	Emission Factors
A - Excellent	28
B - Above Average	2
C - Average	12
D - Below Average	260
E - Poor	107
NR - Not Reported	25

As illustrated above, most of the emission factors developed have EPA ratings of D or E. The main reason for the assignment of low EPA ratings is that a majority of the emission factors were developed from one or two tests. Under the EPA rating system, these emission factors can only receive a D or E rating. With additional testing most of the D-rated emission factors would move to the A through C ratings because these factors were collected using sound source test methodologies developed by CARB and EPA. In addition, data points with significant problems have been identified and eliminated as a result of the validation activities, outlier analysis, and low sensitivity data analysis activities. Emission factors with E ratings also were developed using sound source test methodologies and data points with significant problems have been identified and eliminated. The E rating was assigned because the source test methodologies used mainly CARB 428, CARB 430 and EPA MMT, which have been updated since the E-rated data were collected. Thus the E rating was assigned according to EPA procedures, even though CARB has not required any retesting for data collected using previous versions of test methods and still considers data collected using these methods to be valid.

While CARB considers results collected using the EPA MMT to be valid, some discussion of the differences between the EPA MMT and its replacement method, CARB 436, is warranted. This discussion is necessary because many of the CARB 436 procedures were implemented based on lessons learned using the EPA MMT in 1989 and 1990. Most of the metals results provided in this report, including those for gas-fired turbines and oil-fired external combustion sources, were collected in 1989 and 1990 using the EPA MMT. One of the three gas-fired turbine data sets was collected using CARB methods 12, 424 and 433. All of the gas-fired external combustion metals tests used CARB 436. The main differences between CARB 436 and EPA MMT methods are listed below.

CARB 436 (Items not included in EPA MMT)

- Extra impinger added
- No particulate determination option
- More guidance on calculating test parameters to provide desired in-stack detection limits
- HCl rinse not combined with $KMnO_4$
- Blank train requirement added
- General clarifications on sampling, analysis and QA procedures.

To reduce cross-contamination an empty impinger was added to the CARB 436 sample train between the HNO_3/H_2O_2 and $KMnO_4/H_2SO_4$ impingers. Cross-contamination may have resulted in high Manganese levels for the tests conducted using the EPA MMT. For this reason gas-fired turbine and oil-fired external combustion unit Manganese emission factors are considered suspect.

The detection limits for the gas-fired external combustion metals tests which used CARB 436 are generally lower than the detection limits for the gas-fired turbine and oil-fired external combustion tests conducted using EPA MMT. These lower detection limits are likely a result of additional guidance in the CARB 436 method and other guidance documents such as the WSPA document titled "Pooled Source Testing of Combustion Devices" dated July 15, 1994. It should be noted that while the detection limits for tests conducted using EPA MMT are generally higher, many of these low sensitivity data points were removed as described in Section 3.6. For example Arsenic, Beryllium, and Selenium emission factors were not developed for gas-fired turbines because the sampling and analysis techniques were not sufficiently sensitive.

Another important difference between the EPA MMT and CARB 436 is the level of QA required. CARB 436 requires a field blank train to identify additional sources of contamination that would not be detected with EPA MMT QA procedures. Both methods require that reagent blanks be collected and analyzed. The reagents include the filter, rinses, and impinger solutions. The reagents can contain varying levels of trace metals depending on the reagent quality and type. CARB 436 also includes a field blank train. The field blank consists of a sample train which has been charged, leak-checked and then recovered. The field blank will indicate contamination resulting from the reagents, sample preparation and recovery as well as background levels in the ambient air. The field blank is especially important at facilities like refineries where multiple sources exist in close proximity.

While the EPA MMT did not require the collection of a field blank some of the oil-fired combustion sources collected field blanks. These blanks indicated significant levels of Arsenic, Chromium (Total), Copper, Lead, Manganese and Zinc for oil-fired combustion sources. A significant level is defined as one where the ratio of the blank to sample is greater than 0.10. For the gas-fired turbines, trip blanks were available for each of the three devices tested. These blanks indicated significant levels of Manganese, Mercury, and Zinc for the sources with duct burners. Since a description of the trip blank was not provided in the gas-fired turbine test reports it was not possible to determine how the blank was prepared and if it included leak check, sample preparation and recovery procedures. The trip blank did include all of the sample train reagents (filter, rinses, and impinger solutions) as required by the EPA MMT. Thus for the gas-fired turbines, the reagents did not contain metals at levels of concern for most of the target metals. However, without additional information it is not possible to determine if the gas-fired turbine results were impacted by the sample preparation and recovery procedures, and background levels in the ambient air. Each of the gas-fired external combustion tests included a field blank as required by CARB 436. These blanks indicated significant levels of Lead only.

3.9 COMPARISON OF CARB AND API/WSPA EMISSION FACTORS

The emission factor analysis provided in Volume 1 includes several revisions to the CARB procedures described in Volume 2 including:

- Emission factors from different major groups as identified in Volume 2 Section 6.5 were pooled together to increase the robustness of the emission factors (see Section 3.2);
- Statistical comparisons are conducted assuming the data is log normally distributed as opposed to normally distributed (see Section 3.7); and
- Nondetect data collected using low sensitivity analytical techniques also were excluded from subgroup development analysis and emission factor calculations (see Section 3.6).

Aside from these changes, all other procedures are identical to those developed by CARB. Tables 3-6 through 3-10 present a comparison of the emission factors developed using the WSPA/API procedures and those developed using the CARB procedure as described in Volume two. The WSPA/API emission factors are shaded. WSPA/API emission factors which are impacted by the removal of low sensitivity data (see Section 3.6) are labeled as *LS* for low sensitivity or enclosed in parenthesis. *LS* indicates all of the data was eliminated for the group and parenthesis indicates only some of the data was eliminated. If the CARB and WSPA/API emission factors are the same then CARB and WSPA/API emission factors are replaced by *same*.

The comparison tables illustrate where the CARB and WSPA/API groups differ and the magnitude of the differences in the emission factors. For example, for gas-fired external combustion sources,the WSPA/API grouping is gas-fired external combustion sources while the CARB has groups for each system and fuel type; a total of six subgroups. The WSPA/API analysis indicated that there was no impact of system or fuel type on emissions thus no subgroups were developed. As required by CARB procedures, different fuel and system types could not be combined, so subgroups were developed. Variations between the different CARB groups are not attributable to system or fuel type and are likely a result of the uncertainty of the measurement technique or an unidentified process parameter(s). The WSPA/API external combustion gas emission factors provide a better accounting of the measurement uncertainty and thus will provide a better estimate of emissions.

The WSPA/API and CARB diesel-fired reciprocating internal combustion engine (RICE) emission factor groups listed in Table 3-8 are the same. Thus, most of the emission factors are also the same. Any differences are a result of the removal of low sensitivity data. For gas-fired RICEs, CARB has subgroups for each fuel type. The WSPA/API analysis indicated no significant impact of fuel type on emissions. Thus, the WSPA/API RICE emission factors provide a better accounting of measurement uncertainty and will provide a better estimate of emissions.

TABLE 3-6. LIQUID FUEL-FIRED EXTERNAL COMBUSTION EMISSION FACTORS: COMPARISON OF API/WSPA AND CARB PROCEDURES

Category	Substance	Emission Factor, lb/MMBtu (Arithmetic Mean)				
		External Combustion, Crude Oil/ Pipeline Oil	Steam Generator, Crude Oil	Heater, Pipeline Oil	External Combustion, Fuel Oil No. 6	Boiler, Fuel Oil No. 6
Halogens	HCl	same	same	-	-	-
Metals	Arsenic	(6.7E-06)	6.7E-06	5.8E-06	LS	9.8E-06
	Beryllium	(1.9E-06)	1.9E-06	5.4E-07	same	same
	Cadmium	2.2E-06	1.1E-06	5.7E-06	LS	5.8E-06
	Chromium (Hex)	(1.1E-06)	1.1E-06	2.0E-06	LS	7.8E-06
	Chromium (Total)	8.7E-06	5.7E-06	1.8E-05	same	same
	Copper	9.5E-06	6.6E-06	1.8E-05	same	same
	Lead	1.9E-06	1.9E-06	2.1E-06	LS	1.1E-05
	Manganese	1.8E-05	2.0E-05	1.3E-05	same	same
	Mercury	(1.0E-05)	1.5E-05	1.2E-07	same	same
	Nickel	same	same	same	same	same
	Phosphorus	same	same	-	-	-
	Selenium	(7.9E-06)	7.9E-06	3.2E-05	same	same
	Zinc	4.2E-04	5.4E-04	6.2E-05	same	same
PAH	Acenaphthene	1.7E-07	2.6E-07	1.2E-08	same	same
	Acenaphthylene	(2.3E-08)	5.0E-08	5.6E-10	same	same
	Anthracene	3.7E-08	5.1E-08	4.6E-10	same	same
	Benzo(a)anthracene	(3.2E-08)	5.2E-08	2.7E-08	same	same
	Benzo(a)pyrene	(1.4E-08)	5.4E-08	6.8E-10	same	same
	Benzo(b)fluoranthene	(5.5E-09)	4.7E-08	5.5E-09	same	same
	Benzo(b+k)fluoranthene	same	same	-	-	-
	Benzo(e)pyrene	same	-	same	same	same
	Benzo(g,h,i)perylene	(1.9E-08)	5.2E-08	1.5E-08	same	same
	Benzo(k)fluoranthene	(2.3E-10)	4.0E-09	2.3E-10	(4.6E-10)	1.3E-09
	Chrysene	7.5E-08	7.4E-08	7.8E-08	same	same
	Dibenz(a,h)anthracene	(1.2E-08)	5.3E-08	1.2E-08	LS	4.7E-09
	Fluoranthene	6.9E-08	8.7E-08	1.4E-08	same	same
	Fluorene	2.0E-07	9.4E-08	5.2E-07	same	same
	Indeno(1,2,3-cd)pyrene	(1.9E-08)	5.3E-08	1.3E-08	same	same
	Naphthalene	5.5E-06	5.3E-06	5.9E-06	same	same
	Phenanthrene	1.7E-07	1.6E-07	1.7E-07	same	same
	Pyrene	1.2E-07	1.5E-07	9.2E-09	same	same
SVOC	2-Chloronaphthalene	same	-	same	same	same
	2-Methylnaphthalene	same	-	same	same	same
	Benzaldehyde	same	same	-	-	-
	Perylene	same	-	same	same	same
VOC	1,3-Butadiene	same	-	same	LS	4.2E-05
	Acetaldehyde	(1.1E-05)	1.8E-05	3.8E-06	same	same
	Acrolein	(3.3E-06)	1.2E-05	4.2E-06	LS	1.5E-05
	Benzene	(4.1E-06)	4.1E-06	5.9E-05	LS	3.1E-05
	Chloroform	same	-	same	same	same
	Formaldehyde	1.1E-05	6.3E-06	2.7E-05	(1.7E-05)	4.5E-05
	Propylene	(4.4E-05)	3.9E-04	1.1E-04	LS	1.5E-04
	Toluene	3.5E-05	2.4E-05	7.0E-05	same	same
	Xylene (Total)	(2.9E-06)	2.2E-05	1.3E-04	LS	7.5E-05

LS: Low sensitivity data not included
Shaded: Combined groupings developed using API/WSPA emission factor procedure (see Volume 1)
Not Shaded: Groupings developed using California Air Resources Board emission factor procedure (see Volume 2)
-: No data available
( ): Some low sensitivity data excluded as per API/WSPA procedure
same: Same emission factor developed using either CARB or API/WSPA procedure

TABLE 3-7. GAS FUEL-FIRED EXTERNAL COMBUSTION EMISSION FACTORS: COMPARISON OF API/WSPA AND CARB PROCEDURES

Category	Substance	Emission Factor, lb/MMBtu (Arithmetic Mean)						
		External Combustion, Gas	Boiler, Refinery Gas	Steam Generator, Natural Gas	Steam Generator, Natural/ CVR Gas	Heater, Natural Gas	Heater, Natural/ Refinery Gas	Heater, Refinery Gas
Metals	Antimony	same	-	-	-	-	-	same
	Arsenic	7.2E-07	5.9E-07	-	-	-	-	8.5E-07
	Barium	same	-	-	-	-	-	same
	Beryllium	(1.3E-07)	1.3E-07	-	-	-	-	2.6E-07
	Cadmium	1.5E-06	2.0E-06	-	-	-	-	9.9E-07
	Chromium (Hex)	LS	6.3E-06	-	-	-	-	2.2E-06
	Chromium (Total)	5.7E-06	1.0E-05	-	-	-	-	1.1E-06
	Copper	4.7E-06	5.3E-06	-	-	-	-	4.2E-06
	Lead	3.8E-06	2.0E-06	-	-	-	-	4.9E-06
	Manganese	4.9E-06	2.0E-06	-	-	-	-	6.8E-06
	Mercury	(1.8E-07)	2.7E-07	-	-	-	-	1.8E-07
	Nickel	7.5E-06	4.7E-06	-	-	-	-	9.4E-06
	Phosphorus	same	-	-	-	-	-	same
	Selenium	8.8E-07	1.7E-06	-	-	-	-	2.0E-08
	Silver	same	-	-	-	-	-	same
	Thallium	same	-	-	-	-	-	same
	Zinc	1.4E-03	2.8E-03	-	-	-	-	2.1E-05
PAH	Acenaphthene	2.4E-09	4.9E-09	-	1.1E-09	1.4E-09	4.1E-09	2.4E-09
	Acenaphthylene	6.5E-09	2.1E-09	-	2.7E-09	1.2E-08	3.2E-08	1.5E-09
	Anthracene	4.7E-09	1.9E-08	-	2.2E-09	1.6E-09	5.6E-09	2.9E-09
	Benzo(a)anthracene	2.2E-08	1.5E-08	-	1.3E-09	1.4E-09	5.2E-09	3.2E-08
	Benzo(a)pyrene	5.7E-08	2.9E-09	-	7.1E-10	1.1E-09	3.2E-09	9.0E-08
	Benzo(b)fluoranthene	2.7E-08	5.6E-09	-	2.0E-09	1.1E-09	1.4E-09	4.0E-08
	Benzo(g,h,i)perylene	1.3E-09	3.2E-09	-	1.0E-09	1.2E-09	2.2E-10	1.2E-09
	Benzo(k)fluoranthene	(1.7E-08)	2.1E-09	-	8.4E-10	1.1E-09	7.6E-10	2.4E-08
	Chrysene	1.6E-09	2.9E-09	-	1.6E-09	1.4E-09	4.3E-10	1.6E-09
	Dibenz(a,h)anthracene	(1.5E-09)	2.1E-09	-	5.5E-10	1.1E-09	7.5E-11	1.0E-08
	Fluoranthene	8.7E-09	3.6E-08	-	3.7E-09	1.2E-08	9.7E-09	3.1E-09
	Fluorene	4.8E-08	8.2E-09	-	5.7E-09	4.5E-09	3.5E-07	1.1E-08
	Indeno(1,2,3-cd)pyrene	(7.1E-08)	2.1E-09	-	1.2E-09	1.1E-09	2.4E-10	1.0E-07
	Naphthalene	3.9E-07	1.7E-07	-	2.9E-07	2.3E-07	1.2E-06	3.1E-07
	Phenanthrene	3.2E-08	4.7E-08	-	1.7E-08	3.3E-08	1.1E-07	1.5E-08
	Pyrene	9.8E-09	5.0E-08	-	6.0E-09	5.5E-09	6.7E-09	2.8E-09
SVOC	Ethylbenzene	(1.6E-05)	-	-	9.6E-06	2.2E-06	-	3.0E-05
	Phenol	4.0E-06	1.8E-06	-	-	-	9.2E-07	5.6E-06
VOC	Acetaldehyde	1.2E-05	3.0E-06	1.7E-05	1.8E-05	4.5E-06	7.0E-06	1.5E-05
	Acrolein	(1.7E-05)	-	2.0E-05	1.7E-05	4.4E-06	1.1E-06	-
	Benzene	(6.0E-05)	1.7E-04	3.9E-06	4.5E-06	2.3E-06	1.0E-05	6.5E-05
	Formaldehyde	5.2E-05	1.3E-05	3.1E-05	2.5E-05	4.6E-06	2.2E-05	1.1E-04
	Hydrogen Sulfide	(8.5E-05)	2.2E-04	-	1.6E-04	-	-	2.9E-04
	Propylene	1.5E-04	-	1.2E-04	2.3E-04	4.5E-04	5.7E-06	2.2E-06
	Toluene	1.5E-04	7.2E-04	1.2E-05	1.7E-05	3.2E-05	1.3E-05	1.1E-04
	Xylene (Total)	(2.5E-05)	-	2.8E-05	2.7E-05	1.8E-05	1.4E-05	3.7E-05

LS: Low sensitivity data not included

Shaded: Combined groupings developed using API/WSPA emission factor procedure (see Volume 1)

Not Shaded: Groupings developed using California Air Resources Board emission factor procedure (see Volume 2)

-: No data available

( ): Some low sensitivity data excluded as per API/WSPA procedure

same: Same emission factor developed using either CARB or API/WSPA procedure

TABLE 3-8. DIESEL RECIPROCATING INTERNAL COMBUSTION ENGINE EMISSION FACTORS: COMPARISON OF API/WSPA AND CARB PROCEDURES

Category	Substance	Emission Factor, lb/MMBtu (Arithmetic Mean)			
		Diesel, Oxygen <13%	Diesel, Oxygen <13%	Diesel, Oxygen >13%	Diesel, Oxygen >13%
PAH	Acenaphthene	same	same	same	same
	Acenaphthylene	same	same	same	same
	Anthracene	same	same	same	same
	Benzo(a)anthracene	same	same	same	same
	Benzo(a)pyrene	same	same	(1.0E-08)	1.9E-07
	Benzo(b)fluoranthene	same	same	same	same
	Benzo(b+k)fluoranthene	-	-	same	same
	Benzo(g,h,i)perylene	same	same	(4.9E-07)	4.9E-07
	Benzo(k)fluoranthene	same	same	same	same
	Chrysene	same	same	same	same
	Dibenz(a,h)anthracene	same	same	(4.1E-07)	5.8E-07
	Fluoranthene	same	same	same	same
	Fluorene	same	same	same	same
	Indeno(1,2,3-cd)pyrene	same	same	(2.7E-07)	4.6E-07
	Naphthalene	same	same	same	same
	Phenanthrene	same	same	same	same
	Pyrene	same	same	same	same
SVOC	Benzaldehyde	-	-	same	same
VOC	1,3-Butadiene	-	-	same	same
	Acetaldehyde	same	same	same	same
	Acrolein	same	same	same	same
	Benzene	same	same	same	same
	Formaldehyde	same	same	same	same
	Propylene	same	same	same	same
	Toluene	same	same	same	same
	Xylene (m,p)	-	-	same	same
	Xylene (o)	-	-	same	same
	Xylene (Total)	same	same	same	same

LS: Low sensitivity data not included
Shaded: Combined groupings developed using API/WSPA emission factor procedure (see Volume 1)
Not Shaded: Groupings developed using California Air Resources Board emission factor procedure (see Volume 2)
-: No data available
( ): Some low sensitivity data excluded as per API/WSPA procedure
same: Same emission factor developed using either CARB or API/WSPA procedure

TABLE 3-9. GAS RECIPROCATING INTERNAL COMBUSTION ENGINE EMISSION FACTORS: COMPARISON OF API/WSPA AND CARB PROCEDURES

Category	Substance	Emission Factor, lb/MMBtu (Arithmetic Mean)							
		Gas, 2S, Lean	Field Gas, 2S, Lean	Gas, 4S, Lean	Field Gas, 4S, Lean	Natural Gas, 4S, Lean	Gas, 4S, Rich*	Field Gas, 4S, Rich	Natural Gas, 4S, Rich
PAH	Acenaphthene	same	same	same	-	same	-	-	-
	Acenaphthylene	same	same	same	-	same	-	-	-
	Anthracene	same	same	same	-	same	-	-	-
	Benzo(a)anthracene	same	same	same	-	same	-	-	-
	Benzo(a)pyrene	LS	8.3E-07	same	-	same	-	-	-
	Benzo(b)fluoranthene	same	same	same	-	same	-	-	-
	Benzo(g,h,i)perylene	same	same	same	-	same	-	-	-
	Benzo(k)fluoranthene	same	same	same	-	same	-	-	-
	Chrysene	same	same	same	-	same	-	-	-
	Dibenz(a,h)anthracene	LS	7.3E-08	same	-	same	-	-	-
	Fluoranthene	same	same	same	-	same	-	-	-
	Fluorene	same	same	same	-	same	-	-	-
	Indeno(1,2,3-cd)pyrene	LS	1.3E-07	same	-	same	-	-	-
	Naphthalene	same	same	same	-	same	-	-	-
	Phenanthrene	same	same	same	-	same	-	-	-
	Pyrene	same	same	same	-	same	-	-	-
VOC	Acetaldehyde	same	same	same	-	same	same	-	same
	Acrolein	same	same	same	-	same	same	-	same
	Benzene	same	same	1.3E-03	1.6E-03	1.1E-03	9.9E-03	1.0E-02	9.4E-03
	Formaldehyde	same	same	3.1E-02	4.0E-02	2.7E-02	5.0E-03	4.8E-03	5.1E-03
	Propylene	same	same	1.7E-02	1.5E-02	1.8E-02	2.0E-02	2.9E-03	3.8E-02
	Toluene	same	same	4.9E-04	7.3E-04	3.9E-04	2.8E-03	3.3E-03	2.4E-03
	Xylene (m,p)	same	same	1.4E-04	2.9E-04	8.2E-05	4.7E-04	5.1E-04	4.2E-04
	Xylene (o)	same	same	5.9E-05	8.5E-05	4.7E-05	2.3E-04	2.6E-04	2.1E-04

LS: Low sensitivity data not included
Shaded: Combined groupings developed using API/WSPA emission factor procedure (see Volume 1)
Not Shaded: Groupings developed using California Air Resources Board emission factor procedure (see Volume 2)
-: No data available
*: Formaldehyde measured by CARB 430 Method, which is under review for NO_2 interference (emissions may be under-reported)
same: Same emission factor developed using either CARB or API/WSPA procedure

TABLE 3-10. GAS TURBINE EMISSION FACTORS: COMPARISON OF API/WSPA AND CARB PROCEDURES

Category	Substance	Emission Factor, lb/MMBtu (Arithmetic Mean)						
		Gas, No Duct Burners	Natural Gas, No Duct Burners	Refinery Gas, No Duct Burners	Gas, Duct Burners	Natural Gas, Duct Burners	Natural/ Refinery Gas, Duct Burners	Natural/ Refinery/ LP Gas, Duct
Metals	Arsenic	LS	-	2.9E-06	LS	-	-	9.0E-06
	Beryllium	LS	-	1.5E-06	LS	-	-	1.8E-06
	Cadmium	same	-	same	2.9E-06	-	1.9E-06	3.9E-06
	Chromium (Hex)	same	-	same	(1.7E-06)	-	7.0E-06	-
	Chromium (Total)	same	-	same	same	-	same	-
	Copper	same	-	same	1.2E-05	-	1.8E-06	2.1E-05
	Lead	same	-	same	same	-	-	same
	Manganese	same	-	same	4.8E-05	-	3.2E-06	9.2E-05
	Mercury	same	-	same	same	-	same	-
	Nickel	same	-	same	7.7E-05	-	7.6E-06	1.5E-04
	Selenium	LS	-	3.9E-06	LS	-	-	9.0E-06
	Zinc	same	-	same	1.2E-04	-	1.5E-05	2.2E-04
PAH	Acenaphthene	same	same	-	same	-	same	-
	Acenaphthylene	same	same	-	same	-	same	-
	Anthracene	same	same	-	same	-	same	-
	Benzo(a)anthracene	same	same	-	same	-	same	-
	Benzo(a)pyrene	LS	2.1E-09	-	LS	-	9.5E-09	-
	Benzo(b)fluoranthene	same	same	-	same	-	same	-
	Benzo(g,h,i)perylene	(1.9E-09)	2.4E-09	-	LS	-	1.9E-08	-
	Benzo(k)fluoranthene	(2.3E-09)	2.6E-09	-	LS	-	1.2E-08	-
	Chrysene	same	same	-	same	-	same	-
	Dibenz(a,h)anthracene	LS	2.1E-09	-	LS	-	6.6E-09	-
	Fluoranthene	same	same	-	same	-	same	-
	Fluorene	same	same	-	same	-	same	-
	Indeno(1,2,3-cd)pyrene	(1.8E-09)	2.3E-09	-	LS	-	9.1E-09	-
	Naphthalene	same	same	-	same	-	same	-
	Phenanthrene	same	same	-	same	-	same	-
	Pyrene	same	same	-	same	-	same	-
SVOC	Ethylbenzene	LS	1.5E-05	-	-	-	-	-
	Phenol	same	-	same	2.2E-05	-	1.4E-05	3.0E-05
VOC	Acetaldehyde	2.7E-05	3.8E-05	1.6E-05	same	-	same	-
	Acrolein	same	same	-	-	-	-	-
	Benzene	LS	1.2E-05	1.1E-04	LS	-	1.5E-04	-
	Formaldehyde	3.1E-04	2.0E-05	6.0E-04	3.1E-03	6.0E-03	1.5E-04	-
	Hydrogen Sulfide	LS	-	1.2E-04	LS	-	1.5E-04	-
	Propylene	same	same	-	-	-	-	-
	Toluene	3.1E-04	7.0E-05	7.8E-04	same	-	same	-
	Xylene (Total)	7.7E-04	3.5E-05	2.2E-03	same	-	same	-

LS: Low sensitivity data not included
Shaded: Combined groupings developed using API/WSPA emission factor procedure (see Volume 1)
Not Shaded: Groupings developed using California Air Resources Board emission factor procedure (see Volume 2)
-: No data available

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Appendix A

EXTERNAL COMBUSTION EMISSION FACTORS

APPENDIX A. EXTERNAL COMBUSTION EMISSION FACTORS

Group	Category	Substance	Tests	Runs	ARB Rating	EPA Rating	Detect Ratio	Mean, lb/MMBtu	Median, lb/MMBtu	Maximum, lb/MMBtu	Minimum, lb/MMBtu	UCL, lb/MMBtu	RSD, %	Uncertainty, %
Crude/Pipeline Oil - Fired	Dioxin/Furan	Dioxin:4D 2378	1	3	C3-v0	E	0.00	3.5E-12	4.1E-12	4.2E-12	2.1E-12	6.4E-12	35	86
Crude/Pipeline Oil - Fired	Dioxin/Furan	Dioxin:5D 12378	1	3	C3-v1	E	0.00	1.7E-11	4.1E-12	4.6E-11	2.1E-12	7.9E-11	142	353
Crude/Pipeline Oil - Fired	Dioxin/Furan	Dioxin:6D 123478	1	3	C3-v1	E	0.00	1.5E-11	4.1E-12	4.0E-11	2.1E-12	6.8E-11	138	343
Crude/Pipeline Oil - Fired	Dioxin/Furan	Dioxin:6D 123678	1	3	C3-v1	E	0.07	2.1E-11	4.1E-12	5.6E-11	2.1E-12	9.7E-11	147	366
Crude/Pipeline Oil - Fired	Dioxin/Furan	Dioxin:6D 123789	1	3	C3-v1	E	0.04	3.3E-11	4.1E-12	9.4E-11	2.1E-12	1.6E-10	157	390
Crude/Pipeline Oil - Fired	Dioxin/Furan	Dioxin:7D 1234678	1	3	C3-v1	E	1.00	9.3E-11	3.1E-11	2.3E-10	1.9E-11	3.9E-10	127	316
Crude/Pipeline Oil - Fired	Dioxin/Furan	Dioxin:8D	1	3	C3-v0	E	1.00	3.3E-10	3.9E-10	4.2E-10	1.7E-10	6.7E-10	42	105
Crude/Pipeline Oil - Fired	Dioxin/Furan	Furan:4F 2378	1	3	C3-v2	E	1.00	6.2E-10	1.0E-11	1.9E-09	4.2E-12	3.3E-09	171	425
Crude/Pipeline Oil - Fired	Dioxin/Furan	Furan:5F 12378	1	3	C3-v1	E	0.00	6.0E-11	4.1E-12	1.7E-10	2.1E-12	3.0E-10	164	408
Crude/Pipeline Oil - Fired	Dioxin/Furan	Furan:5F 23478	1	3	C3-v2	E	0.00	1.1E-10	4.1E-12	3.1E-10	2.1E-12	5.5E-10	168	418
Crude/Pipeline Oil - Fired	Dioxin/Furan	Furan:6F 123478	1	3	C3-v2	E	0.01	1.3E-10	4.1E-12	4.0E-10	1.0E-12	7.0E-10	170	422
Crude/Pipeline Oil - Fired	Dioxin/Furan	Furan:6F 123678	1	3	C3-v2	E	0.02	4.3E-11	2.1E-12	1.3E-10	1.0E-12	2.2E-10	167	415
Crude/Pipeline Oil - Fired	Dioxin/Furan	Furan:6F 123789	1	3	C3-v0	E	0.00	3.5E-12	4.1E-12	4.2E-12	2.1E-12	6.4E-12	35	86
Crude/Pipeline Oil - Fired	Dioxin/Furan	Furan:6F 234678	1	3	C3-v1	E	0.03	6.1E-11	6.2E-12	1.7E-10	4.2E-12	3.0E-10	159	394
Crude/Pipeline Oil - Fired	Dioxin/Furan	Furan:7F 1234678	1	3	C3-v1	E	1.00	1.4E-10	8.3E-12	4.0E-10	4.2E-12	7.0E-10	165	411
Crude/Pipeline Oil - Fired	Dioxin/Furan	Furan:7F 1234789	1	3	C3-v0	E	0.00	8.3E-12	4.1E-12	1.9E-11	2.1E-12	3.1E-11	109	271
Crude/Pipeline Oil - Fired	Dioxin/Furan	Furan:8F	1	3	C3-v1	E	1.00	7.3E-11	3.3E-11	1.8E-10	8.3E-12	3.0E-10	125	311
Crude/Pipeline Oil - Fired	Halogens	HCl	1	3	C3-v0	D	1.00	1.3E-06	1.2E-06	1.4E-06	1.2E-06	1.5E-06	9	22
Crude/Pipeline Oil - Fired	Metals	Arsenic	3	9	D2-v0	NR	1.00	6.7E-06	4.2E-06	1.9E-05	2.4E-06	1.1E-05	84	65
Crude/Pipeline Oil - Fired	Metals	Beryllium	2	6	D3-v0	E	0.51	1.9E-06	2.0E-06	2.1E-06	1.6E-06	2.2E-06	14	14
Crude/Pipeline Oil - Fired	Metals	Cadmium	4	12	D2-v1	NR	1.00	2.2E-06	1.1E-06	8.6E-06	1.6E-07	4.2E-06	136	86
Crude/Pipeline Oil - Fired	Metals	Chromium (Hex)	3	9	B2-v0	NR	0.47	1.1E-06	1.0E-06	2.2E-06	3.9E-07	1.6E-06	55	43
Crude/Pipeline Oil - Fired	Metals	Chromium (Total)	4	12	B2-v1	NR	1.00	8.7E-06	7.1E-06	1.9E-05	1.0E-06	1.3E-05	79	50
Crude/Pipeline Oil - Fired	Metals	Copper	4	12	D2-v1	NR	1.00	9.5E-06	7.8E-06	3.2E-05	3.2E-06	1.4E-05	82	52
Crude/Pipeline Oil - Fired	Metals	Lead	4	12	D2-v0	NR	0.55	1.9E-06	1.7E-06	3.8E-06	1.1E-06	2.5E-06	44	28
Crude/Pipeline Oil - Fired	Metals	Manganese	4	10	D2-v1	NR	0.87	1.8E-05	1.6E-05	3.8E-05	1.6E-06	2.6E-05	61	44
Crude/Pipeline Oil - Fired	Metals	Mercury	4	10	D2-v2	NR	1.00	1.0E-05	2.5E-07	3.5E-05	5.7E-08	2.2E-05	158	113
Crude/Pipeline Oil - Fired	Metals	Nickel	4	12	D2-v0	NR	1.00	2.4E-03	2.4E-03	2.9E-03	2.0E-03	2.5E-03	9	6
Crude/Pipeline Oil - Fired	Metals	Phosphorus	2	6	D3-v1	E	1.00	1.8E-04	9.6E-05	4.6E-04	1.8E-05	3.7E-04	102	107
Crude/Pipeline Oil - Fired	Metals	Selenium	3	9	D2-v1	NR	0.96	7.9E-06	2.9E-06	2.1E-05	1.2E-06	1.5E-05	108	83
Crude/Pipeline Oil - Fired	Metals	Zinc	4	12	D2-v2	NR	0.94	4.2E-04	1.0E-04	1.8E-03	1.6E-05	8.3E-04	149	95
Crude/Pipeline Oil - Fired	PAH	Acenaphthene	3	9	C2-v3	C	1.00	1.7E-07	2.1E-08	6.2E-07	4.8E-10	3.7E-07	147	113
Crude/Pipeline Oil - Fired	PAH	Acenaphthylene	3	9	C2-v2	C	1.00	2.3E-08	7.1E-09	1.2E-07	3.5E-10	5.3E-08	166	128
Crude/Pipeline Oil - Fired	PAH	Anthracene	4	11	C2-v2	C	1.00	3.7E-08	1.4E-08	1.7E-07	3.9E-10	7.9E-08	166	111
Crude/Pipeline Oil - Fired	PAH	Benzo(a)anthracene	3	8	C2-v2	C	1.00	3.2E-08	1.9E-08	9.9E-08	9.3E-10	6.3E-08	119	99
Crude/Pipeline Oil - Fired	PAH	Benzo(a)pyrene	2	6	C3-v2	D	0.96	1.4E-08	2.4E-09	4.9E-08	1.7E-10	3.5E-08	148	155
Crude/Pipeline Oil - Fired	PAH	Benzo(b)fluoranthene	1	3	C3-v0	D	1.00	5.5E-09	4.4E-09	8.0E-09	4.2E-09	1.1E-08	39	96
Crude/Pipeline Oil - Fired	PAH	Benzo(b+k)fluoranthene	1	3	C3-v0	D	0.00	8.1E-08	8.0E-08	8.4E-08	7.8E-08	8.9E-08	4	10
Crude/Pipeline Oil - Fired	PAH	Benzo(e)pyrene	1	3	C3-v0	D	1.00	3.9E-09	3.7E-09	5.4E-09	2.5E-09	7.5E-09	37	93
Crude/Pipeline Oil - Fired	PAH	Benzo(g,h,i)perylene	2	6	C3-v1	D	0.94	1.9E-08	1.4E-08	4.2E-08	1.8E-09	3.8E-08	94	98
Crude/Pipeline Oil - Fired	PAH	Benzo(k)fluoranthene	1	3	C3-v0	D	1.00	2.3E-10	1.5E-10	4.8E-10	8.3E-11	7.6E-10	90	224
Crude/Pipeline Oil - Fired	PAH	Chrysene	4	12	C2-v1	C	0.73	7.5E-08	5.4E-08	2.3E-07	7.1E-09	1.2E-07	100	63
Crude/Pipeline Oil - Fired	PAH	Dibenz(a,h)anthracene	1	3	C3-v1	D	1.00	1.2E-08	8.2E-10	3.6E-08	4.6E-10	6.2E-08	164	408
Crude/Pipeline Oil - Fired	PAH	Fluoranthene	4	12	C2-v1	C	0.71	6.9E-08	3.9E-08	3.5E-07	7.1E-09	1.3E-07	134	85
Crude/Pipeline Oil - Fired	PAH	Fluorene	4	12	C2-v2	C	1.00	2.0E-07	6.0E-08	1.2E-06	7.1E-09	4.0E-07	159	101
Crude/Pipeline Oil - Fired	PAH	Indeno(1,2,3-cd)pyrene	2	6	C3-v1	D	0.94	1.9E-08	1.1E-08	5.6E-08	1.0E-09	4.3E-08	116	122

APPENDIX A. EXTERNAL COMBUSTION EMISSION FACTORS

Group	Category	Substance	Tests	Runs	ARB Rating	EPA Rating	Detect Ratio	Mean, lb/MMBtu	Median, lb/MMBtu	Maximum, lb/MMBtu	Minimum, lb/MMBtu	UCL, lb/MMBtu	RSD, %	Uncertainty, %
Crude/Pipeline Oil - Fired	PAH	Naphthalene	4	11	C2-v0	C	1.00	5.5E-06	3.5E-06	1.1E-05	1.4E-06	8.0E-06	70	47
Crude/Pipeline Oil - Fired	PAH	PAH Total	3	9	C2-v0	C	0.96	7.2E-06	8.1E-06	1.3E-05	3.0E-06	1.0E-05	54	42
Crude/Pipeline Oil - Fired	PAH	Phenanthrene	4	12	C2-v1	C	1.00	1.7E-07	4.8E-08	1.1E-06	1.5E-08	3.6E-07	183	117
Crude/Pipeline Oil - Fired	PAH	Pyrene	4	12	C2-v2	C	0.82	1.2E-07	7.9E-08	4.8E-07	4.4E-09	2.0E-07	120	76
Crude/Pipeline Oil - Fired	SVOC	2-Chloronaphthalene	1	3	C3-v2	D	1.00	8.2E-08	3.7E-10	2.4E-07	2.5E-10	4.3E-07	173	429
Crude/Pipeline Oil - Fired	SVOC	2-Methylnaphthalene	1	3	C3-v1	D	1.00	2.5E-07	7.4E-08	6.5E-07	3.2E-08	1.1E-06	137	340
Crude/Pipeline Oil - Fired	SVOC	Benzaldehyde	1	3	A3-v0	E	0.00	4.7E-05	4.9E-05	4.9E-05	4.4E-05	5.5E-05	7	17
Crude/Pipeline Oil - Fired	SVOC	Perylene	1	3	C3-v0	D	1.00	5.2E-10	2.5E-10	1.2E-09	1.4E-10	1.9E-09	108	268
Crude/Pipeline Oil - Fired	VOC	1,3-Butadiene	1	3	A3-v0	D	0.00	1.4E-04	1.4E-04	1.4E-04	1.3E-04	1.5E-04	3	8
Crude/Pipeline Oil - Fired	VOC	Acetaldehyde	2	9	B3-v0	E	0.88	1.1E-05	9.1E-06	3.4E-05	3.8E-06	1.8E-05	87	67
Crude/Pipeline Oil - Fired	VOC	Acrolein	1	6	A3-v0	E	0.00	3.3E-06	3.3E-06	3.3E-06	3.3E-06	3.3E-06	0	0
Crude/Pipeline Oil - Fired	VOC	Aldehyde Total	3	12	B2-v0	NR	0.36	2.6E-05	3.0E-05	3.9E-05	1.2E-05	3.2E-05	41	26
Crude/Pipeline Oil - Fired	VOC	Benzene	2	9	B3-v0	D	0.36	4.1E-06	4.4E-06	6.6E-06	2.0E-06	5.4E-06	44	34
Crude/Pipeline Oil - Fired	VOC	BTX Total	2	9	B3-v0	D	0.39	5.0E-05	4.9E-05	8.3E-05	2.8E-05	6.1E-05	30	23
Crude/Pipeline Oil - Fired	VOC	Chloroform	1	3	A3-v0	D	0.00	6.0E-05	6.0E-05	6.2E-05	5.8E-05	6.5E-05	3	8
Crude/Pipeline Oil - Fired	VOC	Formaldehyde	3	12	B2-v1	NR	0.18	1.1E-05	7.6E-06	2.7E-05	2.7E-06	1.7E-05	84	54
Crude/Pipeline Oil - Fired	VOC	Propylene	2	9	A3-v0	D	0.00	4.4E-05	1.2E-05	1.1E-04	1.2E-05	8.0E-05	107	83
Crude/Pipeline Oil - Fired	VOC	Toluene	3	12	B2-v0	B	0.38	3.5E-05	1.8E-05	7.8E-05	1.4E-05	5.3E-05	78	50
Crude/Pipeline Oil - Fired	VOC	Xylene (Total)	1	3	C3-v0	D	0.00	2.9E-06	2.9E-06	2.9E-06	2.9E-06	2.9E-06	0	0
Fuel Oil No. 6 - Fired	Dioxin/Furan	Dioxin:4D 2378	1	3	C3-v0	E	0.00	4.3E-12	3.9E-12	5.3E-12	3.7E-12	6.5E-12	21	51
Fuel Oil No. 6 - Fired	Dioxin/Furan	Dioxin:5D 12378	1	3	C3-v0	E	0.00	2.5E-12	1.9E-12	3.9E-12	1.8E-12	5.5E-12	48	118
Fuel Oil No. 6 - Fired	Dioxin/Furan	Dioxin:6D 123478	1	3	C3-v0	E	0.00	2.5E-12	1.9E-12	3.9E-12	1.8E-12	5.5E-12	48	118
Fuel Oil No. 6 - Fired	Dioxin/Furan	Dioxin:6D 123678	1	3	C3-v0	E	0.25	2.5E-12	1.9E-12	3.9E-12	1.8E-12	5.5E-12	48	118
Fuel Oil No. 6 - Fired	Dioxin/Furan	Dioxin:6D 123789	1	3	C3-v0	E	0.25	2.5E-12	1.9E-12	3.9E-12	1.8E-12	5.5E-12	48	118
Fuel Oil No. 6 - Fired	Dioxin/Furan	Dioxin:7D 1234678	1	3	C3-v0	E	1.00	2.1E-11	1.9E-11	3.5E-11	8.9E-12	5.4E-11	63	156
Fuel Oil No. 6 - Fired	Dioxin/Furan	Dioxin:8D	1	3	C3-v0	E	1.00	5.1E-10	5.6E-10	8.4E-10	1.3E-10	1.4E-09	70	173
Fuel Oil No. 6 - Fired	Dioxin/Furan	Furan:4F 2378	1	3	C3-v0	E	1.00	5.5E-12	5.3E-12	7.4E-12	3.9E-12	1.0E-11	32	80
Fuel Oil No. 6 - Fired	Dioxin/Furan	Furan:5F 12378	1	3	C3-v0	E	0.00	3.1E-12	3.7E-12	3.9E-12	1.8E-12	6.0E-12	38	93
Fuel Oil No. 6 - Fired	Dioxin/Furan	Furan:5F 23478	1	3	C3-v0	E	0.00	3.1E-12	3.7E-12	3.9E-12	1.8E-12	6.0E-12	38	93
Fuel Oil No. 6 - Fired	Dioxin/Furan	Furan:6F 123478	1	3	C3-v0	E	0.50	2.5E-12	1.9E-12	3.7E-12	1.8E-12	5.1E-12	43	108
Fuel Oil No. 6 - Fired	Dioxin/Furan	Furan:6F 123678	1	3	C3-v0	E	0.33	1.9E-12	1.9E-12	1.9E-12	1.8E-12	2.1E-12	5	11
Fuel Oil No. 6 - Fired	Dioxin/Furan	Furan:6F 123789	1	3	C3-v0	E	0.00	2.5E-12	1.9E-12	3.9E-12	1.8E-12	5.5E-12	48	118
Fuel Oil No. 6 - Fired	Dioxin/Furan	Furan:6F 234678	1	3	C3-v0	E	0.50	3.7E-12	3.9E-12	5.6E-12	1.8E-12	8.5E-12	51	126
Fuel Oil No. 6 - Fired	Dioxin/Furan	Furan:7F 1234678	1	3	C3-v0	E	1.00	9.8E-12	7.8E-12	1.4E-11	7.4E-12	1.9E-11	39	97
Fuel Oil No. 6 - Fired	Dioxin/Furan	Furan:7F 1234789	1	3	C3-v0	E	0.00	3.2E-12	1.9E-12	5.8E-12	1.8E-12	8.9E-12	73	182
Fuel Oil No. 6 - Fired	Dioxin/Furan	Furan:8F	1	3	C3-v0	E	1.00	4.9E-11	4.9E-11	7.1E-11	2.7E-11	1.0E-10	45	112
Fuel Oil No. 6 - Fired	Metals	Beryllium	1	3	B3-v0	E	0.00	4.3E-07	4.3E-07	4.8E-07	3.7E-07	5.6E-07	12	30
Fuel Oil No. 6 - Fired	Metals	Chromium (Total)	1	3	A3-v0	E	1.00	3.3E-05	3.5E-05	4.0E-05	2.3E-05	5.4E-05	26	64
Fuel Oil No. 6 - Fired	Metals	Copper	1	3	B3-v0	E	1.00	2.6E-05	1.4E-05	5.9E-05	6.1E-06	9.7E-05	109	270
Fuel Oil No. 6 - Fired	Metals	Manganese	1	3	B3-v0	E	1.00	3.9E-05	1.9E-05	8.3E-05	1.6E-05	1.3E-04	95	237
Fuel Oil No. 6 - Fired	Metals	Mercury	1	3	B3-v0	E	0.00	7.0E-08	6.1E-08	1.0E-07	4.9E-08	1.4E-07	38	95
Fuel Oil No. 6 - Fired	Metals	Nickel	1	3	B3-v0	E	1.00	2.3E-03	2.1E-03	2.8E-03	2.0E-03	3.3E-03	19	47
Fuel Oil No. 6 - Fired	Metals	Selenium	1	3	B3-v0	E	0.17	2.0E-05	2.4E-05	2.5E-05	9.8E-06	4.1E-05	43	107
Fuel Oil No. 6 - Fired	Metals	Zinc	1	3	B3-v0	E	1.00	1.1E-04	5.9E-05	2.1E-04	5.8E-05	3.3E-04	80	200
Fuel Oil No. 6 - Fired	PAH	Acenaphthene	2	6	B3-v0	D	0.88	6.0E-09	5.7E-09	1.1E-08	2.1E-09	1.0E-08	69	73
Fuel Oil No. 6 - Fired	PAH	Acenaphthylene	2	6	B3-v0	D	0.00	2.1E-09	2.2E-09	2.3E-09	1.6E-09	2.4E-09	12	13

APPENDIX A. EXTERNAL COMBUSTION EMISSION FACTORS

Group	Category	Substance	Tests	Runs	ARB Rating	EPA Rating	Detect Ratio	Mean, lb/MMBtu	Median, lb/MMBtu	Maximum, lb/MMBtu	Minimum, lb/MMBtu	UCL, lb/MMBtu	RSD, %	Uncertainty, %
Fuel Oil No. 6 - Fired	PAH	Anthracene	2	6	B3-v1	D	0.93	2.1E-09	1.8E-09	4.8E-09	1.3E-10	4.2E-09	98	103
Fuel Oil No. 6 - Fired	PAH	Benzo(a)anthracene	2	6	B3-v1	D	0.00	1.3E-09	1.4E-09	2.3E-09	2.0E-10	2.4E-09	77	81
Fuel Oil No. 6 - Fired	PAH	Benzo(a)pyrene	2	6	B3-v0	D	0.00	1.4E-09	1.5E-09	2.3E-09	3.1E-10	2.4E-09	72	75
Fuel Oil No. 6 - Fired	PAH	Benzo(b)fluoranthene	2	6	B3-v0	D	0.40	8.1E-09	6.8E-09	1.6E-08	2.1E-09	1.5E-08	76	80
Fuel Oil No. 6 - Fired	PAH	Benzo(e)pyrene	1	3	C3-v0	D	0.00	5.8E-09	7.0E-09	7.6E-09	2.8E-09	1.2E-08	45	112
Fuel Oil No. 6 - Fired	PAH	Benzo(g,h,i)perylene	2	6	B3-v0	D	0.00	6.7E-09	5.7E-09	1.5E-08	2.1E-09	1.2E-08	79	83
Fuel Oil No. 6 - Fired	PAH	Benzo(k)fluoranthene	1	3	C3-v0	D	0.00	4.6E-10	2.1E-10	9.5E-10	2.0E-10	1.5E-09	94	235
Fuel Oil No. 6 - Fired	PAH	Chrysene	2	6	B3-v0	D	1.00	2.6E-08	2.2E-08	5.8E-08	7.5E-09	4.8E-08	81	85
Fuel Oil No. 6 - Fired	PAH	Fluoranthene	2	6	B3-v1	D	1.00	5.3E-08	4.1E-08	1.1E-07	6.0E-09	1.0E-07	89	94
Fuel Oil No. 6 - Fired	PAH	Fluorene	2	6	B3-v1	D	1.00	3.1E-08	3.1E-08	5.8E-08	5.7E-09	5.9E-08	85	89
Fuel Oil No. 6 - Fired	PAH	Indeno(1,2,3-cd)pyrene	2	6	B3-v0	D	0.00	3.1E-09	2.3E-09	5.3E-09	2.0E-09	4.5E-09	46	48
Fuel Oil No. 6 - Fired	PAH	Naphthalene	2	6	B3-v0	D	1.00	4.0E-07	4.1E-07	5.5E-07	2.7E-07	5.2E-07	28	30
Fuel Oil No. 6 - Fired	PAH	PAH Total	2	6	B3-v0	D	0.95	6.5E-07	6.4E-07	1.0E-06	3.6E-07	9.5E-07	43	46
Fuel Oil No. 6 - Fired	PAH	Phenanthrene	2	6	B3-v0	D	1.00	7.4E-08	7.4E-08	1.3E-07	2.1E-08	1.2E-07	60	63
Fuel Oil No. 6 - Fired	PAH	Pyrene	2	6	B3-v1	D	0.97	2.7E-08	1.6E-08	7.4E-08	2.3E-09	5.9E-08	111	116
Fuel Oil No. 6 - Fired	SVOC	2-Chloronaphthalene	1	3	C3-v0	D	0.00	1.5E-10	1.6E-10	1.9E-10	1.1E-10	2.6E-10	27	67
Fuel Oil No. 6 - Fired	SVOC	2-Methylnaphthalene	1	3	C3-v0	D	1.00	7.4E-08	7.2E-08	8.3E-08	6.6E-08	9.5E-08	12	29
Fuel Oil No. 6 - Fired	SVOC	Perylene	1	3	C3-v0	D	0.00	7.4E-10	4.0E-10	1.5E-09	3.3E-10	2.4E-09	88	218
Fuel Oil No. 6 - Fired	VOC	Acetaldehyde	2	6	A3-v1	D	0.76	7.0E-06	3.3E-06	2.3E-05	1.8E-06	1.6E-05	117	123
Fuel Oil No. 6 - Fired	VOC	Aldehyde Total	2	6	A3-v1	D	0.25	5.2E-05	5.0E-05	1.4E-04	3.6E-06	1.0E-04	94	99
Fuel Oil No. 6 - Fired	VOC	Chloroform	1	3	A3-v0	D	0.00	3.4E-05	3.4E-05	3.5E-05	3.3E-05	3.6E-05	3	8
Fuel Oil No. 6 - Fired	VOC	Formaldehyde	1	3	A3-v1	D	0.93	1.7E-05	1.8E-06	4.6E-05	1.8E-06	8.0E-05	154	383
Fuel Oil No. 6 - Fired	VOC	Toluene	1	3	A3-v0	D	0.00	3.9E-05	3.9E-05	4.0E-05	3.8E-05	4.2E-05	3	8
Gas - Fired	Metals	Antimony	1	3	C3-v0	D	1.00	5.2E-07	5.8E-07	7.6E-07	2.1E-07	1.2E-06	54	134
Gas - Fired	Metals	Arsenic	2	6	D3-v0	E	1.00	7.2E-07	7.9E-07	1.3E-06	1.8E-07	1.2E-06	60	63
Gas - Fired	Metals	Barium	1	3	C3-v0	D	0.00	5.8E-06	5.8E-06	5.9E-06	5.6E-06	6.1E-06	2	6
Gas - Fired	Metals	Beryllium	1	2	D3-v0	E	1.00	1.3E-07	1.3E-07	1.3E-07	1.3E-07	1.5E-07	1	12
Gas - Fired	Metals	Cadmium	2	6	D3-v0	E	1.00	1.5E-06	1.4E-06	2.6E-06	8.1E-07	2.2E-06	45	47
Gas - Fired	Metals	Chromium (Total)	2	6	C3-v1	D	0.96	5.7E-06	1.9E-06	2.5E-05	6.3E-07	1.6E-05	166	174
Gas - Fired	Metals	Copper	2	5	C3-v0	D	1.00	4.7E-06	4.1E-06	9.4E-06	1.3E-06	8.8E-06	72	89
Gas - Fired	Metals	Lead	2	5	C3-v0	D	1.00	3.8E-06	3.2E-06	7.5E-06	2.0E-06	6.5E-06	60	74
Gas - Fired	Metals	Manganese	2	5	C3-v0	D	1.00	4.9E-06	2.7E-06	1.2E-05	1.4E-06	1.0E-05	92	114
Gas - Fired	Metals	Mercury	1	3	C3-v0	D	0.36	1.8E-07	1.8E-07	1.9E-07	1.7E-07	2.1E-07	6	16
Gas - Fired	Metals	Nickel	2	5	C3-v1	D	0.97	7.5E-06	3.5E-06	2.6E-05	1.3E-06	2.0E-05	137	170
Gas - Fired	Metals	Phosphorus	1	3	C3-v0	D	0.00	6.4E-07	6.4E-07	6.6E-07	6.3E-07	6.8E-07	2	6
Gas - Fired	Metals	Selenium	2	6	D3-v2	E	0.16	8.8E-07	4.2E-07	2.4E-06	1.3E-08	2.0E-06	122	128
Gas - Fired	Metals	Silver	1	3	C3-v1	D	0.94	1.6E-06	1.3E-06	3.2E-06	3.1E-07	5.3E-06	91	227
Gas - Fired	Metals	Thallium	1	3	C3-v0	D	0.00	5.8E-06	5.8E-06	5.9E-06	5.6E-06	6.1E-06	2	6
Gas - Fired	Metals	Zinc	2	6	D3-v2	E	1.00	1.4E-03	5.3E-05	8.1E-03	8.5E-06	4.9E-03	229	241
Gas - Fired	PAH	Acenaphthene	9	26	A1-v1	A	0.79	2.4E-09	1.5E-09	9.7E-09	4.1E-10	3.3E-09	90	36
Gas - Fired	PAH	Acenaphthylene	9	26	A1-v2	A	0.89	6.5E-09	1.3E-09	9.2E-08	4.1E-10	1.4E-08	284	115
Gas - Fired	PAH	Anthracene	9	26	A1-v1	A	0.97	4.7E-09	2.6E-09	3.3E-08	4.1E-10	7.5E-09	146	59
Gas - Fired	PAH	Benzo(a)anthracene	14	41	A1-v2	A	0.99	2.2E-08	2.4E-09	3.4E-07	7.1E-10	4.3E-08	310	95
Gas - Fired	PAH	Benzo(a)pyrene	14	41	A1-v3	A	0.98	5.7E-08	1.4E-09	1.4E-06	2.8E-10	1.3E-07	441	135
Gas - Fired	PAH	Benzo(b)fluoranthene	14	41	A1-v2	A	0.98	2.7E-08	2.4E-09	4.9E-07	7.1E-10	5.8E-08	385	118
Gas - Fired	PAH	Benzo(g,h,i)perylene	9	26	A1-v1	A	0.39	1.3E-09	1.1E-09	4.4E-09	7.1E-11	1.6E-09	71	29

APPENDIX A. EXTERNAL COMBUSTION EMISSION FACTORS

Group	Category	Substance	Tests	Runs	ARB Rating	EPA Rating	Detect Ratio	Mean, lb/MMBtu	Median, lb/MMBtu	Maximum, lb/MMBtu	Minimum, lb/MMBtu	UCL, lb/MMBtu	RSD, %	Uncertainty, %
Gas - Fired	PAH	Benzo(k)fluoranthene	13	38	A1-v3	A	0.95	1.7E-08	1.3E-09	3.0E-07	2.1E-10	3.7E-08	372	118
Gas - Fired	PAH	Chrysene	9	26	A1-v1	A	0.51	1.6E-09	1.3E-09	4.8E-09	2.5E-10	2.0E-09	65	26
Gas - Fired	PAH	Dibenz(a,h)anthracene	9	26	A1-v1	A	0.00	1.5E-09	1.2E-09	3.6E-09	5.5E-11	1.9E-09	59	24
Gas - Fired	PAH	Fluoranthene	9	26	A1-v1	A	1.00	8.7E-09	3.5E-09	6.1E-08	1.1E-09	1.4E-08	145	59
Gas - Fired	PAH	Fluorene	9	26	A1-v2	A	1.00	4.8E-08	6.9E-09	9.1E-07	1.9E-09	1.2E-07	371	150
Gas - Fired	PAH	Indeno(1,2,3-cd)pyrene	13	38	A1-v3	A	0.99	7.1E-08	1.3E-09	1.4E-06	1.7E-10	1.6E-07	416	132
Gas - Fired	PAH	Naphthalene	9	26	A1-v1	A	1.00	3.9E-07	2.1E-07	3.3E-06	1.2E-07	6.4E-07	159	64
Gas - Fired	PAH	PAH Total	9	26	A1-v1	A	0.99	5.1E-07	3.3E-07	4.6E-06	1.5E-07	8.6E-07	166	67
Gas - Fired	PAH	Phenanthrene	9	26	A1-v1	A	1.00	3.2E-08	1.9E-08	2.3E-07	6.5E-09	5.0E-08	137	55
Gas - Fired	PAH	Pyrene	9	26	A1-v1	A	1.00	9.8E-09	3.2E-09	7.0E-08	8.5E-10	1.6E-08	165	67
Gas - Fired	SVOC	Ethylbenzene	6	18	A1-v1	A	0.80	1.6E-05	5.8E-06	1.0E-04	2.2E-06	2.9E-05	163	81
Gas - Fired	SVOC	Phenol	12	36	C1-v1	NR	0.95	4.0E-06	1.3E-06	2.5E-05	2.8E-07	5.7E-06	135	44
Gas - Fired	VOC	Acetaldehyde	20	60	B1-v4	NR	0.88	1.2E-05	6.4E-06	8.6E-05	4.1E-09	1.6E-05	122	31
Gas - Fired	VOC	Acrolein	5	15	A1-v0	A	0.93	1.7E-05	1.9E-05	2.6E-05	5.5E-06	2.1E-05	37	21
Gas - Fired	VOC	Aldehyde Total	19	57	B1-v3	NR	0.95	6.6E-05	2.5E-05	1.4E-03	1.3E-06	1.1E-04	276	72
Gas - Fired	VOC	Benzene	16	49	B1-v2	NR	0.79	6.0E-05	4.5E-06	1.2E-03	1.6E-06	1.2E-04	329	92
Gas - Fired	VOC	BTX Total	12	36	B1-v1	A	0.51	5.4E-05	4.7E-05	1.8E-04	1.2E-05	6.6E-05	66	22
Gas - Fired	VOC	Formaldehyde	20	60	B1-v3	NR	0.97	5.2E-05	1.5E-05	1.3E-03	7.7E-07	9.6E-05	342	86
Gas - Fired	VOC	Hydrogen Sulfide	3	10	B2-v0	B	0.56	8.5E-05	5.7E-05	2.4E-04	5.0E-05	1.3E-04	74	53
Gas - Fired	VOC	Propylene	10	30	B1-v2	A	0.69	1.5E-04	1.2E-04	6.8E-04	1.1E-06	2.2E-04	134	50
Gas - Fired	VOC	Toluene	23	69	C1-v3	NR	0.81	1.5E-04	3.4E-05	4.4E-03	4.0E-06	2.8E-04	355	84
Gas - Fired	VOC	Xylene (Total)	7	21	A1-v1	A	0.78	2.5E-05	1.5E-05	1.1E-04	4.7E-06	3.8E-05	118	54

Det Ratio: Ratio of detected values to the sum of detected and nondetected values.
RSD: 100 times the standard deviation divided by the arithmetic average.
Uncertainty: 100 times the confidence interval at a 95% degree of confidence divided by the arithmetic average.
UCL: Upper confidence limit is the confidence interval at a 95% degree of confidence plus arithmetic average
ARB Rating: xy-vz where x is the ARB method rating, y is the population rating, and z is order of magnitude between min and max emission factors

Appendix B

INTERNAL COMBUSTION ENGINE EMISSION FACTORS

APPENDIX B. INTERNAL COMBUSTION ENGINE EMISSION FACTORS

Group	Category	Substance	Tests	Runs	ARB Rating	EPA Rating	Detect Ratio	Mean, lb/MMBtu	Median, lb/MMBtu	Maximum, lb/MMBtu	Minimum, lb/MMBtu	UCL, lb/MMBtu	RSD, %	Uncertainty, %
RICE, Diesel/O2<13%	PAH	Acenaphthene	1	3	C3-v0	D	1.00	4.5E-06	4.8E-06	6.1E-06	2.7E-06	8.9E-06	38	95
RICE, Diesel/O2<13%	PAH	Acenaphthylene	1	3	C3-v0	D	1.00	9.0E-06	9.2E-06	9.3E-06	8.3E-06	1.0E-05	6	15
RICE, Diesel/O2<13%	PAH	Anthracene	1	3	C3-v0	D	1.00	1.2E-06	9.4E-07	2.0E-06	6.1E-07	3.1E-06	63	155
RICE, Diesel/O2<13%	PAH	Benzo(a)anthracene	1	3	C3-v0	D	1.00	6.1E-07	5.9E-07	6.8E-07	5.7E-07	7.6E-07	10	24
RICE, Diesel/O2<13%	PAH	Benzo(a)pyrene	1	3	C3-v0	D	0.45	2.5E-07	2.7E-07	3.4E-07	1.4E-07	5.0E-07	40	99
RICE, Diesel/O2<13%	PAH	Benzo(b)fluoranthene	1	3	C3-v0	D	0.27	1.1E-06	1.0E-06	1.4E-06	8.9E-07	1.7E-06	23	56
RICE, Diesel/O2<13%	PAH	Benzo(g,h,i)perylene	1	3	C3-v0	D	1.00	5.4E-07	5.5E-07	5.9E-07	4.9E-07	6.7E-07	9	23
RICE, Diesel/O2<13%	PAH	Benzo(k)fluoranthene	1	3	C3-v0	D	0.76	2.1E-07	8.7E-08	4.9E-07	6.5E-08	8.0E-07	112	277
RICE, Diesel/O2<13%	PAH	Chrysene	1	3	C3-v0	D	1.00	1.5E-06	1.6E-06	1.6E-06	1.3E-06	1.9E-06	11	27
RICE, Diesel/O2<13%	PAH	Dibenz(a,h)anthracene	1	3	C3-v0	D	0.00	3.4E-07	3.3E-07	3.6E-07	3.3E-07	3.8E-07	6	14
RICE, Diesel/O2<13%	PAH	Fluoranthene	1	3	C3-v0	D	1.00	3.9E-06	3.9E-06	4.1E-06	3.8E-06	4.4E-06	4	11
RICE, Diesel/O2<13%	PAH	Fluorene	1	3	C3-v0	D	1.00	1.2E-05	1.2E-05	1.3E-05	1.2E-05	1.3E-05	3	6
RICE, Diesel/O2<13%	PAH	Indeno(1,2,3-cd)pyrene	1	3	C3-v0	D	0.34	4.0E-07	4.1E-07	4.7E-07	3.3E-07	5.8E-07	18	44
RICE, Diesel/O2<13%	PAH	Naphthalene	1	3	C3-v0	D	1.00	1.3E-04	1.3E-04	1.3E-04	1.2E-04	1.4E-04	4	9
RICE, Diesel/O2<13%	PAH	PAH Total	1	3	C3-v0	D	0.99	2.1E-04	2.1E-04	2.1E-04	2.0E-04	2.2E-04	3	6
RICE, Diesel/O2<13%	PAH	Phenanthrene	1	3	C3-v0	D	1.00	4.0E-05	4.0E-05	4.1E-05	3.9E-05	4.2E-05	3	6
RICE, Diesel/O2<13%	PAH	Pyrene	1	3	C3-v0	D	1.00	3.6E-06	3.4E-06	3.9E-06	3.4E-06	4.3E-06	8	20
RICE, Diesel/O2<13%	VOC	Acetaldehyde	1	3	A3-v0	E	1.00	2.4E-05	1.6E-05	4.6E-05	1.2E-05	7.0E-05	75	187
RICE, Diesel/O2<13%	VOC	Acrolein	1	3	A3-v0	E	0.56	7.6E-06	5.0E-06	1.3E-05	5.0E-06	1.8E-05	58	143
RICE, Diesel/O2<13%	VOC	Aldehyde Total	1	3	A3-v0	E	1.00	1.0E-04	5.8E-05	2.0E-04	4.9E-05	3.1E-04	82	204
RICE, Diesel/O2<13%	VOC	Benzene	1	3	A3-v0	D	1.00	7.1E-04	7.0E-04	7.3E-04	7.0E-04	7.6E-04	3	7
RICE, Diesel/O2<13%	VOC	BTX Total	1	3	A3-v0	D	1.00	1.2E-03	1.2E-03	1.2E-03	1.1E-03	1.2E-03	2	4
RICE, Diesel/O2<13%	VOC	Formaldehyde	1	3	A3-v1	E	1.00	7.7E-05	3.3E-05	1.9E-04	1.2E-05	3.1E-04	123	306
RICE, Diesel/O2<13%	VOC	Propylene	1	3	A3-v0	D	1.00	2.7E-03	2.8E-03	2.8E-03	2.5E-03	3.3E-03	8	20
RICE, Diesel/O2<13%	VOC	Toluene	1	3	A3-v0	D	1.00	2.6E-04	2.6E-04	2.7E-04	2.6E-04	2.8E-04	3	8
RICE, Diesel/O2<13%	VOC	Xylene (Total)	1	3	A3-v0	D	1.00	1.9E-04	1.9E-04	2.0E-04	1.8E-04	2.1E-04	4	10
RICE, Diesel/O2>13%	PAH	Acenaphthene	2	6	C3-v2	D	1.00	1.4E-06	8.3E-07	5.0E-06	1.0E-08	3.5E-06	136	143
RICE, Diesel/O2>13%	PAH	Acenaphthylene	2	6	C3-v3	D	1.00	5.1E-06	2.3E-06	1.3E-05	1.0E-08	1.2E-05	125	131
RICE, Diesel/O2>13%	PAH	Anthracene	2	6	C3-v1	D	1.00	1.9E-06	2.1E-06	2.6E-06	2.2E-07	2.7E-06	45	47
RICE, Diesel/O2>13%	PAH	Benzo(a)anthracene	2	6	C3-v1	D	1.00	1.7E-06	1.5E-06	4.8E-06	1.1E-07	3.5E-06	104	109
RICE, Diesel/O2>13%	PAH	Benzo(a)pyrene	1	3	C3-v0	D	0.00	1.0E-08	1.0E-08	1.0E-08	1.0E-08	1.1E-08	2	5
RICE, Diesel/O2>13%	PAH	Benzo(b)fluoranthene	1	3	C3-v0	D	0.50	1.9E-07	2.0E-07	2.8E-07	8.4E-08	4.3E-07	53	131
RICE, Diesel/O2>13%	PAH	Benzo(b+k)fluoranthene	1	3	C3-v0	D	0.00	1.0E-08	1.0E-08	1.0E-08	1.0E-08	1.1E-08	2	5
RICE, Diesel/O2>13%	PAH	Benzo(g,h,i)perylene	1	3	C3-v0	D	1.00	4.1E-07	3.7E-07	5.6E-07	3.1E-07	7.4E-07	32	80
RICE, Diesel/O2>13%	PAH	Benzo(k)fluoranthene	1	3	C3-v0	D	0.50	3.0E-07	3.1E-07	4.5E-07	1.4E-07	6.8E-07	52	128
RICE, Diesel/O2>13%	PAH	Chrysene	2	6	C3-v0	D	1.00	3.5E-07	3.8E-07	4.8E-07	2.0E-07	4.7E-07	33	35
RICE, Diesel/O2>13%	PAH	Dibenz(a,h)anthracene	1	3	C3-v0	D	1.00	4.1E-07	3.9E-07	5.2E-07	3.2E-07	6.7E-07	25	63
RICE, Diesel/O2>13%	PAH	Fluoranthene	2	6	C3-v1	D	1.00	7.6E-06	5.9E-06	1.9E-05	5.1E-07	1.5E-05	90	94
RICE, Diesel/O2>13%	PAH	Fluorene	2	6	C3-v1	D	0.99	2.9E-05	2.8E-05	5.4E-05	1.5E-06	5.6E-05	87	92
RICE, Diesel/O2>13%	PAH	Indeno(1,2,3-cd)pyrene	1	3	C3-v0	D	1.00	2.7E-07	2.6E-07	3.2E-07	2.3E-07	3.9E-07	18	44
RICE, Diesel/O2>13%	PAH	Naphthalene	2	6	C3-v0	D	1.00	8.5E-05	5.6E-05	2.2E-04	4.3E-05	1.6E-04	81	85
RICE, Diesel/O2>13%	PAH	PAH Total	2	6	C3-v0	D	0.99	1.7E-04	1.6E-04	2.8E-04	9.7E-05	2.4E-04	41	43
RICE, Diesel/O2>13%	PAH	Phenanthrene	2	6	C3-v1	D	1.00	2.9E-05	3.0E-05	5.4E-05	2.2E-06	4.9E-05	65	68
RICE, Diesel/O2>13%	PAH	Pyrene	2	6	C3-v0	D	1.00	4.8E-06	4.4E-06	7.6E-06	8.4E-07	7.4E-06	52	55
RICE, Diesel/O2>13%	SVOC	Benzaldehyde	1	3	A3-v0	E	0.68	9.0E-05	8.8E-05	9.6E-05	8.5E-05	1.0E-04	6	16
RICE, Diesel/O2>13%	VOC	1,3-Butadiene	1	3	C3-v0	D	0.00	3.9E-05	3.9E-05	3.9E-05	3.9E-05	3.9E-05	0	0
RICE, Diesel/O2>13%	VOC	Acetaldehyde	2	6	A3-v0	E	1.00	7.6E-04	7.7E-04	1.1E-03	4.2E-04	1.1E-03	42	45
RICE, Diesel/O2>13%	VOC	Acrolein	2	6	A3-v0	E	0.82	9.4E-05	6.1E-05	2.3E-04	4.7E-05	1.7E-04	75	78
RICE, Diesel/O2>13%	VOC	Aldehyde Total	2	6	A3-v0	E	1.00	2.0E-03	1.8E-03	3.5E-03	1.1E-03	2.8E-03	42	45
RICE, Diesel/O2>13%	VOC	Benzene	2	6	B3-v0	D	1.00	8.8E-04	8.2E-04	1.4E-03	4.7E-04	1.3E-03	49	51
RICE, Diesel/O2>13%	VOC	BTX Total	2	6	B3-v0	D	0.95	1.6E-03	1.5E-03	2.2E-03	1.0E-03	2.1E-03	36	37
RICE, Diesel/O2>13%	VOC	Formaldehyde	2	6	A3-v0	E	1.00	1.2E-03	1.0E-03	2.4E-03	6.2E-04	1.9E-03	55	58

APPENDIX B. INTERNAL COMBUSTION ENGINE EMISSION FACTORS

Group	Category	Substance	Tests	Runs	ARB Rating	EPA Rating	Detect Ratio	Mean, lb/MMBtu	Median, lb/MMBtu	Maximum, lb/MMBtu	Minimum, lb/MMBtu	UCL, lb/MMBtu	RSD, %	Uncertainty, %
RICE, Diesel/O2>13%	VOC	Propylene	2	6	B3-v0	D	1.00	2.6E-03	2.4E-03	4.2E-03	1.0E-03	4.1E-03	57	60
RICE, Diesel/O2>13%	VOC	Toluene	2	6	B3-v0	D	1.00	4.0E-04	4.0E-04	5.5E-04	2.5E-04	5.6E-04	39	41
RICE, Diesel/O2>13%	VOC	Xylene (m,p)	1	3	C3-v0	D	1.00	1.5E-04	1.5E-04	1.7E-04	1.4E-04	1.9E-04	10	25
RICE, Diesel/O2>13%	VOC	Xylene (o)	1	3	C3-v0	D	0.00	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	0	0
RICE, Diesel/O2>13%	VOC	Xylene (Total)	1	3	A3-v0	D	1.00	2.6E-04	3.2E-04	3.2E-04	1.4E-04	5.3E-04	41	102
RICE, Gas/2S/Lean	PAH	Acenaphthene	1	2	A3-v0	D	0.00	7.1E-07	7.1E-07	1.0E-06	3.8E-07	4.8E-06	65	585
RICE, Gas/2S/Lean	PAH	Acenaphthylene	1	2	A3-v0	D	1.00	1.1E-05	1.1E-05	1.5E-05	6.1E-06	6.6E-05	59	531
RICE, Gas/2S/Lean	PAH	Anthracene	1	2	A3-v0	D	1.00	4.3E-06	4.3E-06	6.3E-06	2.2E-06	3.0E-05	68	610
RICE, Gas/2S/Lean	PAH	Benzo(a)anthracene	1	2	A3-v0	D	1.00	8.5E-07	8.5E-07	8.7E-07	8.4E-07	1.0E-06	2	20
RICE, Gas/2S/Lean	PAH	Benzo(b)fluoranthene	1	2	A3-v0	D	0.00	1.4E-07	1.4E-07	1.6E-07	1.2E-07	4.2E-07	22	201
RICE, Gas/2S/Lean	PAH	Benzo(g,h,i)perylene	1	2	A3-v0	D	0.00	9.0E-08	9.0E-08	9.4E-08	8.5E-08	1.5E-07	8	69
RICE, Gas/2S/Lean	PAH	Benzo(k)fluoranthene	1	2	A3-v0	D	1.00	4.3E-06	4.3E-06	4.5E-06	4.2E-06	5.8E-06	4	34
RICE, Gas/2S/Lean	PAH	Chrysene	1	2	A3-v0	D	1.00	1.6E-06	1.6E-06	1.7E-06	1.5E-06	3.0E-06	9	85
RICE, Gas/2S/Lean	PAH	Fluoranthene	1	2	A3-v0	D	0.00	1.6E-07	1.6E-07	2.1E-07	1.1E-07	7.7E-07	43	386
RICE, Gas/2S/Lean	PAH	Fluorene	1	2	A3-v0	D	0.00	2.3E-06	2.3E-06	3.4E-06	1.2E-06	1.6E-05	68	610
RICE, Gas/2S/Lean	PAH	Naphthalene	1	2	A3-v0	D	1.00	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.4E-04	2	17
RICE, Gas/2S/Lean	PAH	PAH Total	1	2	A3-v0	D	0.98	2.4E-04	2.4E-04	2.4E-04	2.4E-04	2.7E-04	1	12
RICE, Gas/2S/Lean	PAH	Phenanthrene	1	2	A3-v0	D	1.00	4.7E-06	4.7E-06	6.2E-06	3.2E-06	2.4E-05	45	408
RICE, Gas/2S/Lean	PAH	Pyrene	1	2	A3-v0	D	0.64	2.3E-07	2.3E-07	2.9E-07	1.6E-07	1.0E-06	40	360
RICE, Gas/2S/Lean	VOC	Acetaldehyde	1	3	A3-v0	E	1.00	8.4E-03	9.0E-03	1.1E-02	5.3E-03	1.5E-02	34	84
RICE, Gas/2S/Lean	VOC	Acrolein	1	3	A3-v1	E	1.00	1.9E-03	1.4E-03	4.2E-03	1.9E-04	7.0E-03	107	265
RICE, Gas/2S/Lean	VOC	Aldehyde Total	1	3	A3-v0	E	1.00	3.3E-02	1.3E-02	7.3E-02	1.2E-02	1.2E-01	106	264
RICE, Gas/2S/Lean	VOC	Benzene	2	5	A3-v0	D	1.00	7.5E-03	4.4E-03	1.3E-02	4.0E-03	1.3E-02	61	75
RICE, Gas/2S/Lean	VOC	BTX Total	2	5	A3-v0	D	1.00	1.1E-02	6.9E-03	2.0E-02	4.7E-03	2.0E-02	64	79
RICE, Gas/2S/Lean	VOC	Formaldehyde	2	6	A3-v1	E	1.00	4.8E-02	6.5E-02	8.1E-02	4.0E-03	8.4E-02	70	73
RICE, Gas/2S/Lean	VOC	Propylene	2	5	A3-v0	D	1.00	2.4E-02	1.7E-02	3.8E-02	1.1E-02	4.0E-02	57	70
RICE, Gas/2S/Lean	VOC	Toluene	2	5	A3-v1	D	1.00	2.7E-03	2.2E-03	5.5E-03	2.1E-04	5.2E-03	73	90
RICE, Gas/2S/Lean	VOC	Xylene (m,p)	2	5	A3-v0	D	1.00	5.8E-04	3.0E-04	1.2E-03	1.8E-04	1.2E-03	81	100
RICE, Gas/2S/Lean	VOC	Xylene (o)	2	5	A3-v0	D	1.00	2.7E-04	1.3E-04	5.6E-04	6.5E-05	5.7E-04	88	110
RICE, Gas/4S/Lean	PAH	Acenaphthene	1	3	A3-v0	D	1.00	6.8E-07	6.1E-07	9.1E-07	5.3E-07	1.2E-06	30	74
RICE, Gas/4S/Lean	PAH	Acenaphthylene	1	3	A3-v0	D	1.00	7.2E-06	7.3E-06	1.0E-05	4.2E-06	1.5E-05	42	103
RICE, Gas/4S/Lean	PAH	Anthracene	1	3	A3-v0	D	1.00	2.4E-07	2.3E-07	3.5E-07	1.5E-07	4.9E-07	41	102
RICE, Gas/4S/Lean	PAH	Benzo(a)anthracene	1	3	A3-v0	D	1.00	7.4E-08	7.5E-08	9.1E-08	5.6E-08	1.2E-07	24	59
RICE, Gas/4S/Lean	PAH	Benzo(a)pyrene	1	3	A3-v0	D	0.76	3.4E-08	2.8E-08	4.9E-08	2.4E-08	6.7E-08	40	99
RICE, Gas/4S/Lean	PAH	Benzo(b)fluoranthene	1	3	A3-v2	D	0.95	3.1E-07	4.2E-08	8.8E-07	6.0E-09	1.5E-06	160	397
RICE, Gas/4S/Lean	PAH	Benzo(g,h,i)perylene	1	3	A3-v1	D	1.00	9.8E-08	2.8E-08	2.5E-07	2.0E-08	4.2E-07	131	325
RICE, Gas/4S/Lean	PAH	Benzo(k)fluoranthene	1	3	A3-v1	D	0.98	5.0E-07	4.6E-07	1.0E-06	2.9E-08	1.7E-06	98	245
RICE, Gas/4S/Lean	PAH	Chrysene	1	3	A3-v0	D	1.00	9.2E-08	1.1E-07	1.1E-07	6.3E-08	1.5E-07	27	68
RICE, Gas/4S/Lean	PAH	Dibenz(a,h)anthracene	1	3	A3-v0	D	1.00	1.0E-08	1.1E-08	1.4E-08	6.6E-09	2.0E-08	35	88
RICE, Gas/4S/Lean	PAH	Fluoranthene	1	3	A3-v0	D	1.00	2.4E-07	2.5E-07	3.2E-07	1.5E-07	4.5E-07	36	90
RICE, Gas/4S/Lean	PAH	Fluorene	1	3	A3-v0	D	0.00	4.4E-07	4.0E-07	6.0E-07	3.2E-07	7.9E-07	33	81
RICE, Gas/4S/Lean	PAH	Indeno(1,2,3-cd)pyrene	1	3	A3-v1	D	1.00	1.1E-07	3.7E-08	2.8E-07	2.3E-08	4.7E-07	127	316
RICE, Gas/4S/Lean	PAH	Naphthalene	1	3	A3-v0	D	1.00	1.2E-04	1.5E-04	1.8E-04	1.9E-05	3.3E-04	73	182
RICE, Gas/4S/Lean	PAH	PAH Total	1	3	A3-v0	D	1.00	1.3E-04	1.6E-04	1.8E-04	3.5E-05	3.3E-04	64	158
RICE, Gas/4S/Lean	PAH	Phenanthrene	1	3	A3-v0	D	1.00	8.5E-07	7.9E-07	1.2E-06	5.6E-07	1.6E-06	38	94
RICE, Gas/4S/Lean	PAH	Pyrene	1	3	A3-v0	D	1.00	1.2E-07	1.4E-07	1.5E-07	6.3E-08	2.4E-07	41	102
RICE, Gas/4S/Lean	VOC	Acetaldehyde	5	15	A1-v0	NR	1.00	3.8E-03	2.8E-03	9.5E-03	1.5E-03	5.2E-03	65	36
RICE, Gas/4S/Lean	VOC	Acrolein	5	14	A1-v1	NR	1.00	1.6E-03	1.0E-03	5.2E-03	1.9E-04	2.4E-03	92	53
RICE, Gas/4S/Lean	VOC	Aldehyde Total	5	15	A1-v0	NR	1.00	3.1E-02	2.9E-02	5.1E-02	1.2E-02	3.9E-02	45	25
RICE, Gas/4S/Lean	VOC	Benzene	10	20	A1-v1	A	1.00	1.3E-03	1.2E-03	2.3E-03	2.3E-04	1.6E-03	45	21
RICE, Gas/4S/Lean	VOC	BTX Total	10	20	A1-v0	A	1.00	2.0E-03	2.0E-03	3.6E-03	4.4E-04	2.4E-03	44	21
RICE, Gas/4S/Lean	VOC	Formaldehyde	10	30	A1-v1	NR	1.00	3.1E-02	2.7E-02	9.3E-02	4.4E-03	3.8E-02	62	23

APPENDIX B. INTERNAL COMBUSTION ENGINE EMISSION FACTORS

Group	Category	Substance	Tests	Runs	ARB Rating	EPA Rating	Detect Ratio	Mean, lb/MMBtu	Median, lb/MMBtu	Maximum, lb/MMBtu	Minimum, lb/MMBtu	UCL, lb/MMBtu	RSD, %	Uncertainty, %
RICE, Gas/4S/Lean	VOC	Propylene	10	20	A1-v1	A	0.98	1.7E-02	9.8E-03	5.6E-02	3.9E-03	2.5E-02	96	45
RICE, Gas/4S/Lean	VOC	Toluene	10	20	A1-v0	A	1.00	4.9E-04	4.4E-04	1.1E-03	1.6E-04	6.2E-04	55	26
RICE, Gas/4S/Lean	VOC	Xylene (m,p)	10	20	A1-v1	A	1.00	1.4E-04	1.0E-04	8.6E-04	3.4E-05	2.3E-04	124	58
RICE, Gas/4S/Lean	VOC	Xylene (o)	10	20	A1-v1	A	0.97	5.9E-05	5.4E-05	1.2E-04	1.0E-05	7.1E-05	45	21
RICE, Gas/4S/Rich	VOC	Acetaldehyde	1	3	A3-v0	E	1.00	1.6E-03	1.6E-03	1.7E-03	1.5E-03	1.9E-03	6	16
RICE, Gas/4S/Rich	VOC	Acrolein	2	6	A3-v2	D	1.00	5.1E-04	4.0E-04	1.3E-03	2.5E-06	1.1E-03	106	111
RICE, Gas/4S/Rich	VOC	Aldehyde Total	1	3	A3-v0	E	1.00	1.1E-02	1.2E-02	1.3E-02	9.5E-03	1.5E-02	14	35
RICE, Gas/4S/Rich	VOC	Benzene	2	4	A3-v0	D	1.00	9.9E-03	1.0E-02	1.1E-02	9.1E-03	1.1E-02	7	11
RICE, Gas/4S/Rich	VOC	BTX Total	2	4	A3-v0	D	1.00	1.3E-02	1.4E-02	1.5E-02	1.2E-02	1.5E-02	9	15
RICE, Gas/4S/Rich	VOC	Formaldehyde	3	9	A2-v1	C	1.00	5.0E-03	4.4E-03	1.1E-02	4.1E-04	8.1E-03	81	62
RICE, Gas/4S/Rich	VOC	Propylene	2	4	A3-v1	D	0.93	2.0E-02	1.9E-02	4.0E-02	2.9E-03	5.2E-02	99	158
RICE, Gas/4S/Rich	VOC	Toluene	2	4	A3-v0	D	1.00	2.8E-03	2.8E-03	3.4E-03	2.3E-03	3.7E-03	18	29
RICE, Gas/4S/Rich	VOC	Xylene (m,p)	2	4	A3-v0	D	1.00	4.7E-04	4.6E-04	5.4E-04	4.1E-04	5.6E-04	12	20
RICE, Gas/4S/Rich	VOC	Xylene (o)	2	4	A3-v0	D	1.00	2.3E-04	2.3E-04	2.7E-04	2.0E-04	2.8E-04	13	21
Turbine, Gas/DB=N	Metals	Cadmium	1	3	B3-v0	E	1.00	5.3E-06	3.7E-06	9.2E-06	3.0E-06	1.4E-05	64	160
Turbine, Gas/DB=N	Metals	Chromium (Hex)	1	3	C3-v0	E	0.00	1.5E-06	1.5E-06	1.5E-06	1.4E-06	1.5E-06	1	2
Turbine, Gas/DB=N	Metals	Chromium (Total)	1	3	C3-v0	E	0.82	1.3E-05	7.2E-06	2.8E-05	4.2E-06	4.5E-05	99	245
Turbine, Gas/DB=N	Metals	Copper	1	3	B3-v0	E	1.00	4.1E-05	3.9E-05	6.9E-05	1.5E-05	1.1E-04	66	164
Turbine, Gas/DB=N	Metals	Lead	1	3	B3-v0	E	0.30	2.8E-05	3.0E-05	3.0E-05	2.6E-05	3.4E-05	8	19
Turbine, Gas/DB=N	Metals	Manganese	1	3	B3-v0	E	1.00	1.3E-04	1.0E-04	2.4E-04	4.0E-05	3.9E-04	81	201
Turbine, Gas/DB=N	Metals	Mercury	1	3	A3-v0	D	1.00	1.5E-05	1.1E-05	2.6E-05	9.1E-06	3.8E-05	60	149
Turbine, Gas/DB=N	Metals	Nickel	1	3	B3-v0	E	1.00	1.7E-04	1.9E-04	2.0E-04	1.1E-04	3.0E-04	32	79
Turbine, Gas/DB=N	Metals	Zinc	1	3	B3-v0	E	1.00	5.0E-03	5.9E-03	6.5E-03	2.5E-03	1.0E-02	43	107
Turbine, Gas/DB=N	PAH	Acenaphthene	2	6	A3-v0	D	0.66	3.3E-09	2.0E-09	8.5E-09	1.2E-09	6.2E-09	88	92
Turbine, Gas/DB=N	PAH	Acenaphthylene	2	6	A3-v0	D	0.54	2.9E-09	2.7E-09	5.7E-09	1.2E-09	4.6E-09	57	60
Turbine, Gas/DB=N	PAH	Anthracene	2	6	A3-v1	D	1.00	3.4E-08	7.2E-09	1.5E-07	3.7E-09	9.5E-08	169	177
Turbine, Gas/DB=N	PAH	Benzo(a)anthracene	2	6	A3-v0	D	0.34	2.8E-09	2.3E-09	5.6E-09	1.8E-09	4.3E-09	52	55
Turbine, Gas/DB=N	PAH	Benzo(b)fluoranthene	2	6	A3-v0	D	0.44	3.3E-09	2.7E-09	8.8E-09	1.2E-09	6.2E-09	85	89
Turbine, Gas/DB=N	PAH	Benzo(g,h,i)perylene	1	3	A3-v0	D	0.56	1.9E-09	1.3E-09	3.2E-09	1.2E-09	4.8E-09	59	148
Turbine, Gas/DB=N	PAH	Benzo(k)fluoranthene	1	3	A3-v0	D	0.64	2.3E-09	1.3E-09	4.5E-09	1.2E-09	6.9E-09	79	197
Turbine, Gas/DB=N	PAH	Chrysene	2	6	A3-v0	D	0.31	4.9E-09	5.9E-09	6.0E-09	2.8E-09	6.6E-09	32	34
Turbine, Gas/DB=N	PAH	Fluoranthene	2	6	A3-v0	D	1.00	1.2E-08	1.2E-08	1.7E-08	5.5E-09	1.6E-08	37	39
Turbine, Gas/DB=N	PAH	Fluorene	2	6	A3-v0	D	1.00	1.5E-08	1.4E-08	3.0E-08	7.9E-09	2.3E-08	54	57
Turbine, Gas/DB=N	PAH	Indeno(1,2,3-cd)pyrene	1	3	A3-v0	D	0.52	1.8E-09	1.3E-09	2.7E-09	1.2E-09	3.9E-09	48	120
Turbine, Gas/DB=N	PAH	Naphthalene	2	6	A3-v0	D	1.00	7.3E-07	7.8E-07	9.3E-07	4.4E-07	9.6E-07	30	31
Turbine, Gas/DB=N	PAH	PAH Total	2	6	A3-v0	D	0.98	9.1E-07	9.6E-07	1.2E-06	5.9E-07	1.2E-06	28	29
Turbine, Gas/DB=N	PAH	Phenanthrene	2	6	A3-v0	D	1.00	6.5E-08	4.9E-08	1.4E-07	2.6E-08	1.1E-07	63	66
Turbine, Gas/DB=N	PAH	Pyrene	2	6	A3-v0	D	1.00	2.3E-08	2.0E-08	4.1E-08	5.5E-09	3.8E-08	64	67
Turbine, Gas/DB=N	SVOC	Phenol	1	3	C3-v0	D	1.00	6.7E-06	4.3E-06	1.2E-05	3.6E-06	1.9E-05	72	178
Turbine, Gas/DB=N	VOC	Acetaldehyde	2	6	B3-v0	D	0.90	2.7E-05	1.8E-05	5.1E-05	1.2E-05	4.5E-05	64	67
Turbine, Gas/DB=N	VOC	Acrolein	1	3	A3-v0	D	0.00	1.7E-05	1.7E-05	1.7E-05	1.7E-05	1.8E-05	1	2
Turbine, Gas/DB=N	VOC	Aldehyde Total	2	6	B3-v1	D	0.98	3.4E-04	3.3E-04	6.5E-04	3.3E-05	6.6E-04	91	96
Turbine, Gas/DB=N	VOC	BTX Total	2	6	A3-v0	D	0.70	1.2E-04	1.2E-04	2.3E-04	2.4E-05	2.0E-04	66	69
Turbine, Gas/DB=N	VOC	Formaldehyde	2	6	B3-v1	D	0.98	3.1E-04	3.0E-04	6.3E-04	1.6E-05	6.4E-04	103	108
Turbine, Gas/DB=N	VOC	Propylene	1	3	A3-v0	D	1.00	1.6E-03	1.6E-03	1.9E-03	1.4E-03	2.3E-03	16	39
Turbine, Gas/DB=N	VOC	Toluene	3	9	B2-v2	NR	1.00	3.1E-04	1.1E-04	1.8E-03	7.8E-06	7.5E-04	191	147
Turbine, Gas/DB=N	VOC	Xylene (Total)	3	9	B2-v2	NR	0.98	7.7E-04	4.3E-05	6.3E-03	9.3E-06	2.4E-03	270	208
Turbine, Gas/DB=Y	Metals	Cadmium	2	6	C3-v0	E	0.49	2.9E-06	3.5E-06	4.7E-06	9.6E-07	4.6E-06	54	57
Turbine, Gas/DB=Y	Metals	Chromium (Hex)	1	3	C3-v0	E	0.00	1.7E-06	1.6E-06	2.1E-06	1.5E-06	2.6E-06	21	52
Turbine, Gas/DB=Y	Metals	Chromium (Total)	2	6	C3-v1	E	1.00	5.0E-05	3.2E-05	1.7E-04	1.4E-05	1.1E-04	121	127
Turbine, Gas/DB=Y	Metals	Copper	2	6	B3-v1	D	0.88	1.2E-05	5.5E-06	4.6E-05	9.6E-07	3.0E-05	149	156
Turbine, Gas/DB=Y	Metals	Lead	1	3	B3-v0	E	0.00	3.6E-05	3.6E-05	3.8E-05	3.4E-05	4.0E-05	5	13

APPENDIX B. INTERNAL COMBUSTION ENGINE EMISSION FACTORS

Group	Category	Substance	Tests	Runs	ARB Rating	EPA Rating	Detect Ratio	Mean, lb/MMBtu	Median, lb/MMBtu	Maximum, lb/MMBtu	Minimum, lb/MMBtu	UCL, lb/MMBtu	RSD, %	Uncertainty, %
Turbine, Gas/DB=Y	Metals	Manganese	2	6	B3-v2	D	1.00	4.8E-05	1.8E-05	2.0E-04	1.2E-06	1.3E-04	157	165
Turbine, Gas/DB=Y	Metals	Mercury	2	6	A3-v0	D	1.00	4.4E-06	3.7E-06	7.8E-06	2.4E-06	6.7E-06	52	54
Turbine, Gas/DB=Y	Metals	Nickel	2	6	C3-v2	E	1.00	7.7E-05	2.7E-05	3.5E-04	3.2E-06	2.2E-04	174	182
Turbine, Gas/DB=Y	Metals	Zinc	2	6	B3-v1	D	1.00	1.2E-04	4.8E-05	3.6E-04	1.4E-05	2.6E-04	122	128
Turbine, Gas/DB=Y	PAH	Acenaphthene	1	3	C3-v0	D	1.00	2.2E-08	2.0E-08	3.6E-08	1.1E-08	5.3E-08	57	141
Turbine, Gas/DB=Y	PAH	Acenaphthylene	1	3	C3-v0	D	1.00	1.1E-08	1.2E-08	1.2E-08	7.9E-09	1.7E-08	23	56
Turbine, Gas/DB=Y	PAH	Anthracene	1	3	C3-v0	D	1.00	2.5E-08	2.3E-08	3.4E-08	1.8E-08	4.6E-08	34	85
Turbine, Gas/DB=Y	PAH	Benzo(a)anthracene	1	3	C3-v1	D	0.86	1.5E-08	3.2E-09	3.9E-08	2.8E-09	6.6E-08	138	343
Turbine, Gas/DB=Y	PAH	Benzo(b)fluoranthene	1	3	C3-v0	D	0.82	2.5E-08	3.0E-08	3.2E-08	1.4E-08	5.0E-08	40	100
Turbine, Gas/DB=Y	PAH	Chrysene	1	3	C3-v0	D	1.00	1.1E-07	6.4E-08	2.3E-07	3.2E-08	3.7E-07	97	241
Turbine, Gas/DB=Y	PAH	Fluoranthene	1	3	C3-v0	D	1.00	9.9E-08	9.9E-08	1.5E-07	5.1E-08	2.2E-07	48	119
Turbine, Gas/DB=Y	PAH	Fluorene	1	3	C3-v1	D	1.00	1.8E-07	7.5E-08	4.1E-07	4.0E-08	6.9E-07	118	292
Turbine, Gas/DB=Y	PAH	Naphthalene	1	3	C3-v0	D	1.00	3.7E-05	3.7E-05	4.0E-05	3.5E-05	4.3E-05	6	16
Turbine, Gas/DB=Y	PAH	PAH Total	1	3	C3-v0	D	1.00	3.9E-05	3.9E-05	4.1E-05	3.6E-05	4.5E-05	7	17
Turbine, Gas/DB=Y	PAH	Phenanthrene	1	3	C3-v0	D	1.00	6.4E-07	5.1E-07	9.0E-07	4.9E-07	1.2E-06	36	90
Turbine, Gas/DB=Y	PAH	Pyrene	1	3	C3-v0	D	1.00	1.2E-07	9.6E-08	2.1E-07	4.8E-08	3.3E-07	71	176
Turbine, Gas/DB=Y	SVOC	Phenol	2	6	C3-v1	D	0.68	2.2E-05	1.4E-05	7.6E-05	2.9E-06	5.1E-05	120	126
Turbine, Gas/DB=Y	VOC	Acetaldehyde	1	3	A3-v0	E	1.00	4.1E-06	3.1E-06	6.2E-06	3.1E-06	8.6E-06	44	109
Turbine, Gas/DB=Y	VOC	Aldehyde Total	1	3	A3-v0	E	1.00	1.6E-04	8.7E-05	3.2E-04	7.3E-05	5.0E-04	86	213
Turbine, Gas/DB=Y	VOC	Formaldehyde	2	6	B3-v1	E	1.00	3.1E-03	2.9E-03	6.7E-03	7.0E-05	6.5E-03	105	110
Turbine, Gas/DB=Y	VOC	Toluene	1	3	E3-v0	E	0.00	1.6E-04	1.6E-04	1.7E-04	1.6E-04	1.8E-04	4	11
Turbine, Gas/DB=Y	VOC	Xylene (Total)	1	3	E3-v0	E	0.00	3.7E-04	3.8E-04	3.8E-04	3.7E-04	3.8E-04	1	1

Det Ratio: Ratio of detected values to the sum of detected and nondetected values.
RSD: 100 times the standard deviation divided by the arithmetic average.
Uncertainty: 100 times the confidence interval at a 95% degree of confidence divided by the arithmetic average.
UCL: Upper confidence limit is the confidence interval at a 95% degree of confidence plus arithmetic average
RICE: Reciprocating Internal Combustion Engine, DB: Duct Burner, O2: Oxygen, S: Strokes
ARB Rating: xy-vz where x is the ARB method rating, y is the population rating, and z is order of magnitude between min and max emission factors

Appendix C

DIRECT-FIRED COMBUSTION EMISSION FACTORS

APPENDIX C. DIRECT-FIRED COMBUSTION EMISSION FACTORS

Group	Category	Substance	Tests	Runs	ARB Rating	EPA Rating	Detect Ratio	Mean, lb/MMBtu	Median, lb/MMBtu	Maximum, lb/MMBtu	Minimum, lb/MMBtu	UCL, lb/MMBtu	RSD, %	Uncertainty, %
Asphalt, Blow Cycle	Halogens	HCl	1	1	C3-v-	E	1.00	2.1E-06	2.1E-06	2.1E-06	2.1E-06			
Asphalt, Blow Cycle	Metals	Beryllium	1	1	D3-v-	E	0.00	2.5E-06	2.5E-06	2.5E-06	2.5E-06			
Asphalt, Blow Cycle	Metals	Chromium (Total)	1	1	C3-v-	E	1.00	3.9E-05	3.9E-05	3.9E-05	3.9E-05			
Asphalt, Blow Cycle	Metals	Copper	1	1	D3-v-	E	1.00	4.5E-05	4.5E-05	4.5E-05	4.5E-05			
Asphalt, Blow Cycle	Metals	Manganese	1	1	D3-v-	E	1.00	1.2E-04	1.2E-04	1.2E-04	1.2E-04			
Asphalt, Blow Cycle	Metals	Mercury	1	1	A3-v-	D	1.00	8.5E-06	8.5E-06	8.5E-06	8.5E-06			
Asphalt, Blow Cycle	Metals	Zinc	1	1	D3-v-	E	1.00	7.9E-04	7.9E-04	7.9E-04	7.9E-04			
Asphalt, Blow Cycle	SVOC	Ethylbenzene	1	1	E3-v-	E	0.00	8.1E-04	8.1E-04	8.1E-04	8.1E-04			
Asphalt, Blow Cycle	SVOC	Phenol	1	1	C3-v-	D	1.00	7.1E-05	7.1E-05	7.1E-05	7.1E-05			
Asphalt, Blow Cycle	VOC	Acetaldehyde	1	1	C3-v-	E	1.00	1.7E-06	1.7E-06	1.7E-06	1.7E-06			
Asphalt, Blow Cycle	VOC	Aldehyde Total	1	1	C3-v-	E	1.00	5.0E-06	5.0E-06	5.0E-06	5.0E-06			
Asphalt, Blow Cycle	VOC	Formaldehyde	1	1	C3-v-	E	1.00	3.3E-06	3.3E-06	3.3E-06	3.3E-06			
Asphalt, Blow Cycle	VOC	Hydrogen Sulfide	1	1	A3-v-	D	0.00	1.9E-03	1.9E-03	1.9E-03	1.9E-03			
Asphalt, Blow Cycle	VOC	Xylene (Total)	1	1	E3-v-	E	0.00	8.1E-04	8.1E-04	8.1E-04	8.1E-04			
Asphalt, No Blow Cycle	Halogens	HCl	1	1	C3-v-	E	1.00	7.7E-07	7.7E-07	7.7E-07	7.7E-07			
Asphalt, No Blow Cycle	Metals	Beryllium	1	1	D3-v-	E	0.00	2.2E-06	2.2E-06	2.2E-06	2.2E-06			
Asphalt, No Blow Cycle	Metals	Chromium (Total)	1	1	C3-v-	E	0.00	1.3E-05	1.3E-05	1.3E-05	1.3E-05			
Asphalt, No Blow Cycle	Metals	Copper	1	1	D3-v-	E	1.00	3.6E-05	3.6E-05	3.6E-05	3.6E-05			
Asphalt, No Blow Cycle	Metals	Manganese	1	1	D3-v-	E	1.00	1.9E-04	1.9E-04	1.9E-04	1.9E-04			
Asphalt, No Blow Cycle	Metals	Mercury	1	1	A3-v-	D	1.00	8.0E-06	8.0E-06	8.0E-06	8.0E-06			
Asphalt, No Blow Cycle	Metals	Zinc	1	1	D3-v-	E	1.00	5.0E-04	5.0E-04	5.0E-04	5.0E-04			
Asphalt, No Blow Cycle	SVOC	Ethylbenzene	1	1	E3-v-	E	0.00	7.2E-04	7.2E-04	7.2E-04	7.2E-04			
Asphalt, No Blow Cycle	SVOC	Phenol	1	1	C3-v-	D	1.00	4.4E-05	4.4E-05	4.4E-05	4.4E-05			
Asphalt, No Blow Cycle	VOC	Acetaldehyde	1	1	C3-v-	E	1.00	4.1E-06	4.1E-06	4.1E-06	4.1E-06			
Asphalt, No Blow Cycle	VOC	Aldehyde Total	1	1	C3-v-	E	1.00	1.6E-05	1.6E-05	1.6E-05	1.6E-05			
Asphalt, No Blow Cycle	VOC	Formaldehyde	1	1	C3-v-	E	1.00	1.2E-05	1.2E-05	1.2E-05	1.2E-05			
Asphalt, No Blow Cycle	VOC	Hydrogen Sulfide	1	1	A3-v-	D	0.00	1.7E-03	1.7E-03	1.7E-03	1.7E-03			
Asphalt, No Blow Cycle	VOC	Xylene (Total)	1	1	E3-v-	E	0.00	7.2E-04	7.2E-04	7.2E-04	7.2E-04			
Coke Calcining	Dioxin/Furan	Dioxin:4D 2378	1	3	A3-v0	D	0.00	3.7E-11	3.7E-11	4.9E-11	2.5E-11	6.6E-11	32	79
Coke Calcining	Dioxin/Furan	Dioxin:4D Other	1	3	A3-v0	D	1.00	4.4E-10	4.1E-10	8.3E-10	8.8E-11	1.4E-09	84	208
Coke Calcining	Dioxin/Furan	Dioxin:5D 12378	1	3	A3-v0	D	0.00	2.9E-11	2.6E-11	3.7E-11	2.5E-11	4.7E-11	24	60
Coke Calcining	Dioxin/Furan	Dioxin:5D Other	1	3	A3-v0	D	0.34	2.7E-10	2.8E-10	3.6E-10	1.8E-10	5.1E-10	34	85
Coke Calcining	Dioxin/Furan	Dioxin:6D 123478	1	3	A3-v0	D	0.25	3.5E-11	2.6E-11	6.4E-11	1.3E-11	1.0E-10	77	192
Coke Calcining	Dioxin/Furan	Dioxin:6D 123678	1	3	A3-v0	D	0.60	4.4E-11	5.2E-11	5.7E-11	2.3E-11	9.0E-11	42	103
Coke Calcining	Dioxin/Furan	Dioxin:6D 123789	1	3	A3-v0	D	0.33	4.2E-11	4.2E-11	5.9E-11	2.6E-11	8.4E-11	40	100
Coke Calcining	Dioxin/Furan	Dioxin:6D Other	1	3	A3-v0	D	0.55	2.1E-10	2.5E-10	2.8E-10	9.4E-11	4.5E-10	47	118
Coke Calcining	Dioxin/Furan	Dioxin:7D 1234678	1	3	A3-v0	D	1.00	4.2E-10	3.3E-10	6.0E-10	3.3E-10	8.2E-10	38	95
Coke Calcining	Dioxin/Furan	Dioxin:7D Other	1	3	A3-v0	D	1.00	4.1E-10	4.0E-10	5.3E-10	3.0E-10	6.9E-10	28	69
Coke Calcining	Dioxin/Furan	Dioxin:8D	1	3	A3-v0	D	1.00	5.3E-09	5.0E-09	7.7E-09	3.1E-09	1.1E-08	43	108
Coke Calcining	Dioxin/Furan	Furan:4F 2378	1	3	A3-v0	D	0.62	4.2E-11	4.5E-11	4.9E-11	3.3E-11	6.2E-11	19	48
Coke Calcining	Dioxin/Furan	Furan:4F Other	1	3	A3-v0	D	1.00	4.3E-10	4.5E-10	6.0E-10	2.6E-10	8.6E-10	39	98
Coke Calcining	Dioxin/Furan	Furan:5F 12378	1	3	A3-v0	D	0.56	4.4E-11	4.2E-11	5.9E-11	3.2E-11	7.7E-11	30	75
Coke Calcining	Dioxin/Furan	Furan:5F 23478	1	3	A3-v0	D	0.54	4.1E-11	4.1E-11	5.7E-11	2.5E-11	8.0E-11	38	95
Coke Calcining	Dioxin/Furan	Furan:5F Other	1	3	A3-v0	D	0.66	3.8E-10	3.9E-10	5.0E-10	2.4E-10	7.0E-10	34	85
Coke Calcining	Dioxin/Furan	Furan:6F 123478	1	3	A3-v0	D	1.00	7.9E-11	7.5E-11	1.0E-10	5.9E-11	1.3E-10	28	69
Coke Calcining	Dioxin/Furan	Furan:6F 123678	1	3	A3-v0	D	1.00	7.1E-11	8.7E-11	9.0E-11	3.6E-11	1.5E-10	42	105
Coke Calcining	Dioxin/Furan	Furan:6F 123789	1	3	A3-v0	D	0.58	2.9E-11	3.3E-11	3.7E-11	1.8E-11	5.4E-11	33	82
Coke Calcining	Dioxin/Furan	Furan:6F 234678	1	3	A3-v0	D	1.00	6.5E-11	5.7E-11	8.4E-11	5.4E-11	1.1E-10	25	63
Coke Calcining	Dioxin/Furan	Furan:6F Other	1	3	A3-v0	D	1.00	4.8E-10	5.4E-10	6.5E-10	2.5E-10	1.0E-09	43	107
Coke Calcining	Dioxin/Furan	Furan:7F 1234678	1	3	A3-v0	D	1.00	4.8E-10	4.9E-10	5.4E-10	3.9E-10	6.6E-10	16	39
Coke Calcining	Dioxin/Furan	Furan:7F 1234789	1	3	A3-v0	D	0.64	8.0E-11	8.3E-11	8.7E-11	7.1E-11	1.0E-10	10	25
Coke Calcining	Dioxin/Furan	Furan:7F Other	1	2	A3-v0	D	0.40	1.8E-10	1.8E-10	2.1E-10	1.4E-10	6.1E-10	27	245

APPENDIX C. DIRECT-FIRED COMBUSTION EMISSION FACTORS

Group	Category	Substance	Tests	Runs	ARB Rating	EPA Rating	Detect Ratio	Mean, lb/MMBtu	Median, lb/MMBtu	Maximum, lb/MMBtu	Minimum, lb/MMBtu	UCL, lb/MMBtu	RSD, %	Uncertainty, %
Coke Calcining	Dioxin/Furan	Furan:8F	1	3	A3-v1	D	1.00	4.1E-10	3.8E-10	7.9E-10	6.6E-11	1.3E-09	89	220
Coke Calcining	Metals	Antimony	1	3	C3-v0	D	0.32	1.4E-04	1.4E-04	1.5E-04	1.4E-04	1.6E-04	5	13
Coke Calcining	Metals	Arsenic	1	3	C3-v0	D	0.00	1.5E-05	1.4E-05	1.6E-05	1.4E-05	1.7E-05	7	17
Coke Calcining	Metals	Barium	1	3	C3-v0	D	1.00	6.1E-05	6.4E-05	7.8E-05	4.1E-05	1.1E-04	31	76
Coke Calcining	Metals	Beryllium	1	3	C3-v0	D	0.43	6.0E-06	5.4E-06	7.8E-06	4.8E-06	1.0E-05	26	66
Coke Calcining	Metals	Cadmium	1	3	C3-v0	D	0.00	2.9E-05	2.9E-05	3.1E-05	2.7E-05	3.4E-05	7	17
Coke Calcining	Metals	Chromium (Hex)	1	3	C3-v0	D	1.00	2.1E-06	1.9E-06	2.9E-06	1.5E-06	3.8E-06	32	80
Coke Calcining	Metals	Chromium (Total)	1	3	C3-v0	D	1.00	6.9E-05	5.9E-05	9.3E-05	5.4E-05	1.2E-04	31	77
Coke Calcining	Metals	Copper	1	3	C3-v0	D	0.00	2.9E-05	2.9E-05	3.1E-05	2.7E-05	3.4E-05	7	17
Coke Calcining	Metals	Lead	1	3	C3-v0	D	0.48	1.9E-04	1.6E-04	2.7E-04	1.4E-04	3.7E-04	38	94
Coke Calcining	Metals	Manganese	1	3	C3-v0	D	0.89	1.4E-04	1.4E-04	2.4E-04	4.8E-05	3.8E-04	67	167
Coke Calcining	Metals	Mercury	1	3	C3-v1	D	1.00	1.5E-04	4.8E-05	3.6E-04	3.4E-05	6.1E-04	125	310
Coke Calcining	Metals	Nickel	1	3	C3-v0	D	0.66	2.9E-04	1.6E-04	5.7E-04	1.4E-04	8.9E-04	85	211
Coke Calcining	Metals	Phosphorus	1	3	C3-v0	D	0.00	1.5E-03	1.4E-03	1.6E-03	1.4E-03	1.7E-03	7	17
Coke Calcining	Metals	Selenium	1	3	C3-v0	D	0.00	1.5E-05	1.4E-05	1.6E-05	1.4E-05	1.7E-05	7	17
Coke Calcining	Metals	Silver	1	3	C3-v0	D	0.00	5.1E-05	5.0E-05	5.4E-05	4.8E-05	5.9E-05	7	16
Coke Calcining	Metals	Thallium	1	3	C3-v0	D	0.00	2.2E-04	2.1E-04	2.3E-04	2.1E-04	2.5E-04	7	17
Coke Calcining	Metals	Zinc	1	3	C3-v0	D	1.00	3.7E-04	3.1E-04	5.3E-04	2.7E-04	7.1E-04	38	95
Coke Calcining	PAH	Acenaphthene	1	3	A3-v0	D	1.00	4.4E-08	4.1E-08	5.4E-08	3.7E-08	6.7E-08	21	51
Coke Calcining	PAH	Acenaphthylene	1	3	A3-v0	D	1.00	5.6E-08	4.6E-08	9.3E-08	2.9E-08	1.4E-07	59	147
Coke Calcining	PAH	Anthracene	1	3	A3-v0	D	1.00	5.4E-08	5.4E-08	5.8E-08	5.0E-08	6.4E-08	7	19
Coke Calcining	PAH	Benzo(a)anthracene	1	3	A3-v0	D	0.38	2.6E-08	2.7E-08	3.0E-08	2.1E-08	3.8E-08	18	45
Coke Calcining	PAH	Benzo(a)pyrene	1	3	A3-v0	D	0.00	2.4E-08	2.4E-08	2.7E-08	2.1E-08	3.2E-08	13	33
Coke Calcining	PAH	Benzo(b)fluoranthene	1	3	A3-v0	D	0.00	2.4E-08	2.4E-08	2.7E-08	2.1E-08	3.2E-08	13	33
Coke Calcining	PAH	Benzo(g,h,i)perylene	1	3	A3-v0	D	0.00	2.4E-08	2.4E-08	2.7E-08	2.1E-08	3.2E-08	13	33
Coke Calcining	PAH	Benzo(k)fluoranthene	1	3	A3-v0	D	0.00	2.4E-08	2.4E-08	2.7E-08	2.1E-08	3.2E-08	13	33
Coke Calcining	PAH	Chrysene	1	3	A3-v0	D	0.76	3.7E-08	3.5E-08	5.0E-08	2.7E-08	6.6E-08	31	77
Coke Calcining	PAH	Dibenz(a,h)anthracene	1	3	A3-v0	D	0.00	2.4E-08	2.4E-08	2.7E-08	2.1E-08	3.2E-08	13	33
Coke Calcining	PAH	Fluoranthene	1	3	A3-v0	D	1.00	1.1E-07	1.1E-07	1.2E-07	9.2E-08	1.4E-07	12	30
Coke Calcining	PAH	Fluorene	1	3	A3-v0	D	1.00	1.7E-07	1.5E-07	2.2E-07	1.4E-07	2.7E-07	25	62
Coke Calcining	PAH	Indeno(1,2,3-cd)pyrene	1	3	A3-v0	D	0.00	2.4E-08	2.4E-08	2.7E-08	2.1E-08	3.2E-08	13	33
Coke Calcining	PAH	Naphthalene	1	3	A3-v0	D	1.00	7.3E-06	6.7E-06	1.0E-05	4.8E-06	1.4E-05	39	96
Coke Calcining	PAH	PAH Total	1	3	A3-v0	D	0.98	8.6E-06	7.8E-06	1.2E-05	6.0E-06	1.6E-05	35	87
Coke Calcining	PAH	Phenanthrene	1	3	A3-v0	D	1.00	5.7E-07	5.3E-07	7.1E-07	4.6E-07	8.9E-07	23	57
Coke Calcining	PAH	Pyrene	1	3	A3-v0	D	1.00	7.9E-08	7.7E-08	8.8E-08	7.1E-08	9.9E-08	11	27
Coke Calcining	VOC	Acetaldehyde	1	3	A3-v0	D	1.00	3.1E-03	3.1E-03	3.9E-03	2.3E-03	5.1E-03	25	62
Coke Calcining	VOC	Acrolein	1	3	A3-v0	D	0.00	1.0E-03	1.1E-03	1.1E-03	9.2E-04	1.3E-03	11	26
Coke Calcining	VOC	Aldehyde Total	1	3	A3-v0	D	0.75	4.2E-03	4.1E-03	5.0E-03	3.4E-03	6.2E-03	20	49
Coke Calcining	VOC	Benzene	1	3	C3-v0	D	1.00	1.0E-03	1.4E-03	1.5E-03	2.6E-04	2.7E-03	65	161
Coke Calcining	VOC	BTX Total	1	3	C3-v0	D	0.86	1.4E-03	1.8E-03	1.9E-03	5.6E-04	3.3E-03	53	131
Coke Calcining	VOC	Formaldehyde	1	3	A3-v0	D	0.00	1.0E-03	1.1E-03	1.1E-03	9.2E-04	1.3E-03	11	26
Coke Calcining	VOC	Toluene	1	3	C3-v0	D	1.00	1.6E-04	1.4E-04	2.5E-04	1.0E-04	3.5E-04	46	114
Coke Calcining	VOC	Xylene (m,p)	1	3	C3-v0	D	0.26	8.9E-05	8.6E-05	1.1E-04	7.0E-05	1.4E-04	23	57
Coke Calcining	VOC	Xylene (o)	1	3	C3-v0	D	0.00	1.3E-04	1.4E-04	1.5E-04	1.1E-04	1.8E-04	16	39

Det Ratio: Ratio of detected values to the sum of detected and nondetected values.
RSD: 100 times the standard deviation divided by the arithmetic average.
Uncertainty: 100 times the confidence interval at a 95% degree of confidence divided by the arithmetic average.
UCL: Upper confidence limit is the confidence interval at a 95% degree of confidence plus arithmetic average
ARB Rating: xy-vz where x is the ARB method rating, y is the population rating, and z is order of magnitude between min and max emission factors

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