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A Risk Assessment of Waste Oil Burning in Boilers & Space Heaters

A RISK ASSESSMENT OF WASTE OIL BURNING IN BOILERS AND SPACE HEATERS

FINAL REPORT

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the Office of Solid Waste
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SECTION 1

SUMMARY

1.1 INTRODUCTION

The regulations promulgated under the Resource Conservation and Recovery Act (RCRA) in 1980 (and the additions/revisions of 1981 and 1982) covered hazardous wastes, but left used oil largely unregulated. In line with sections that allow exemptions for materials that are reused, recycled, or reclaimed, used (waste) oils have been used as fuels and dust suppressants without being manifested or tested. Also, waste oils sometimes serve as carriers for other hazardous wastes, such as chlorinated and nonchlorinated organic solvents. As a result of this lack of regulation, waste oils containing heavy metals, organic solvents, and other contaminants (e.g., polychlorinated biphenyls) are dispersed into the environment with little knowledge of the potential health impact and resulting risks to exposed populations. The purpose of this study is to analyze the risks associated with the use of waste oil as a fuel.

Risk assessment is an estimate of the probability and severity of harm to human health or to the environment as a result of some occurrence. This study is a quantitative assessment of the risks associated with waste oil burning. The sources were characterized in Section 3 and in Appendix A by examining waste oil burning practices and estimating emissions from oil space heaters, small waste oil boilers (defined as those with capacities of less than 15 million Btu/h), and medium-size oil boilers (defined as those with capacities of 15 to 150 million Btu/h). This effort was followed by air dispersion modeling to estimate the ground-level concentrations of waste oil contaminants in the emissions. (See Section 3 and Appendices B, C, and D.) The resulting concentrations in air were then used to estimate doses to exposed populations and to determine the response to the population in the form of threshold toxic effects or excess cancers. (See Section 5 and Appendix E.)

1.2 APPROACH

The numbers used to estimate risk to exposed populations were derived from Threshold Limit Values (TLV's) or from carcinogenic potency factors developed by the U.S. Environmental Protection Agency's (EPA's) Cancer Assessment Group. For those waste oil contaminants that have a threshold response (i.e., a threshold level below which no adverse effects are observed), the TLV's were modified in two ways: 1) a factor was added to account for lifetime vs. workweek exposure, and 2) another factor was added to account for exposure to the most susceptible portion of the population vs. the typical adult male worker. Risk was estimated by comparing the modified TLV's--referred to as Environmental Exposure Limits (EEL's)--with the concentrations calculated by the dispersion models. For those waste oil contaminants classed as carcinogens, the current theory is that no safe threshold exists.

For these contaminants, the carcinogenic potency factors modified for airborne exposure (referred to as reference concentrations) were used to calculate excess cancers. The ambient air concentration estimated from the dispersion modeling is compared with the reference concentrations to calculate the number of cancers that would occur from exposure to the ambient air concentration. Risk is determined by stating the number of cancers per 10,000, 100,000, or 1,000,000 people, referred to as risk levels of 10^{-4}, 10^{-5}, or 10^{-6}, respectively. Risk was also stated as the risk of cancer to an individual (one chance in 300,000, etc.). Appendix B explains the method for assessing health effects in more detail.

Waste oil varies widely in its composition, depending on the type of oil (e.g., industrial oils such as hydraulic oil vs. crankcase oil from automobiles and diesel engines), the extent of its previous use, and the addition of other wastes (such as degreasing solvents) to the oil. Because its composition varies, waste oil cannot be easily characterized. The approach taken in this study was to compile available waste oil composition data and to look at the distribution of concentrations of contaminants. The median, 75th percentile, and 90th percentile concentrations were calculated for each contaminant, as shown in Table 1-1. The waste oil composition used for the modeling represented the 90th percentile concentrations so that risk estimation would err on the side of overestimating rather than underestimating the risk. Table 1-2 identifies the modeled contaminants that exhibit threshold responses (referred to as threshold contaminants) and those that do not exhibit threshold responses (carcinogens, which

TABLE 1-1. SUMMARY OF WASTE OIL CONCENTRATION AT THE 50TH, 75TH, AND 90TH PERCENTILE

	Number of samples	Median concentration at 50th percentile,[a] ppm	Concentration at 75th percentile,[b] ppm	Concentration at 90th percentile,[c] ppm
Metals				
Arsenic	17	11	14	16
Barium	159	50	200	485
Cadmium	189	1.1	1.3	4.0
Chromium	273	10	12	28
Lead[d]	227	220	420	1,000
Zinc	232	469	890	1,150
Chlorinated solvents				
Dichlorodifluoromethane	78	20	210	860
Trichlorotrifluoroethane	26	<1	33	130
1,1,1-trichloroethane	123	270	590	1,300
Trichloroethylene	126	60	490	1,049
Tetrachloroethylene	100	120	370	1,200
Total chlorine	62	1,400	2,600	6,150
Other organics				
Benzene	32	46	77	160
Toluene	30	190	490	1,200
Xylene	22	36	270	570
Benzo(a)anthracene	17	16	26	35
Benzo(a)pyrene	19	9	12	33
Naphthalene	15	290	490	580
PCB's	264	9	41	50

[a] At the median, 50 percent of the analyzed waste oil samples had contaminant concentrations below the given value.

[b] Seventy-five percent of the analyzed waste oil samples had contaminant concentrations below the given value.

[c] Ninety percent of the analyzed waste oil samples had contaminant concentrations below the given value.

[d] Values for lead were taken from 1979-1983 data only.

are referred to as nonthreshold contaminants). Hydrogen chloride, listed as a threshold contaminant, is assumed to be formed from chlorinated compounds during the combustion of waste oil.

In addition to the waste oil contaminants listed in Table 1-2 and modeled in Section 4, dioxins are covered in a separate section. These were treated separately for two reasons:

1. They are not contaminants that are usually found in waste oil, but they may be formed during its combustion as a result of precursors present in the oil.
2) Some dioxins are extremely toxic and their health impacts are potentially significant; thus, more attention was given to the health effects description.

TABLE 1-2. THRESHOLD AND NONTHRESHOLD CONTAMINANTS CONSIDERED IN DISPERSION MODELING ANALYSES

Threshold	Nonthreshold
Barium	Arsenic
Cadmium	Chromium
Chromium	1,1,2-Trichloroethane
Lead	Tetrachloroethylene
Zinc	Trichloroethylene
1,1,1-Trichloroethane	Carbon tetrachloride
Toluene	PCB's
Hydrogen chloride	Dioxins

Two air dispersion models were used to estimate ground-level concentrations of contaminants from sources burning waste oil: the Industrial Source Complex (ISC) model and the Hanna-Gifford model. The ISC model, a point-source model used to estimate maximum concentrations around a single point source or several point sources, was used to estimate ground-level concentrations of threshold contaminants. The Hanna-Gifford model, an area-source model used to estimate ground-level concentrations from many sources throughout an entire area (such as a city and its suburbs), was used as the "urban model" to determine concentrations of both threshold and nonthreshold contaminants from the widespread burning of waste oil. Air dispersion modeling results are presented in Section 4.

For proper interpretation of the results, it is important to know several of the assumptions used in the modeling. Emissions of metals from waste oil burning can vary from 20 percent (or less) to 100 percent, depending on boiler operation and condition. This range is very wide, but a review of data in the literature indicated that the emission of about 50 percent of the metals in the waste oil is common. In the dispersion modeling, it was assumed that 75 percent of the metals are emitted. Although this assumption is realistic, it could result in overestimating risk in some cases. A limited amount of modeling was also done based on an assumed emission of 50 percent of the metals in the oil.

Destruction removal efficiencies (DRE's) of organics in waste oil boilers were assumed to be 97 percent. Some additional modeling was done based on a 99 percent DRE. Some recently completed waste oil test burns done as part of a current study for the EPA confirm that the usual DRE exceeds 99 percent (occasionally, slightly less). Again, the DRE assumption used in the modeling is realistic, but may err slightly on the side of overestimating risk.

1.3 RESULTS

The concentrations calculated from the air dispersion modeling were compared with the EEL's and the reference concentrations for threshold and nonthreshold contaminants (see Section 5 for detailed results). The threshold contaminants that appear to present a potentially significant risk are barium, hydrogen chloride, and lead (see Table 1-3). Concentrations of each of these substances from sources burning waste oil could have a significant impact on air quality. The other threshold pollutants (cadmium, chromium, zinc, naphthalene, toluene, and 1,1,1-trichloroethane) do not appear to have a serious impact on air quality or pose a significant health risk.

TABLE 1-3. RESULTS OF RISK ANALYSIS

Threshold substances posing a significant risk:

Barium
Hydrogen chloride
Lead

Nonthreshold substances posing given cancer risk levels:

Risk level	Nonthreshold substances
10^{-4}	Chromium
10^{-5}	Chromium Arsenic Dioxins
10^{-6}	Chromium Arsenic Cadmium Dioxins

Potential cancer risk estimates are also summarized in Table 1-3. At a risk level of approximately one cancer in 10,000 or

10^{-4}, chromium is a contaminant of concern. At a risk level of 10^{-5}, arsenic and, in some cases, dioxins become additional contaminants of concern. At a risk level of 10^{-6}, or one excess cancer in a million people, cadmium also becomes a contaminant of concern.

Other waste oil nonthreshold contaminants pose lesser cancer risk levels of 10^{-7} (carbon tetrachloride, PCB's, tetrachloroethylene, and 1,1,2-trichloroethane) or 10^{-8} (benzene and trichloroethylene).

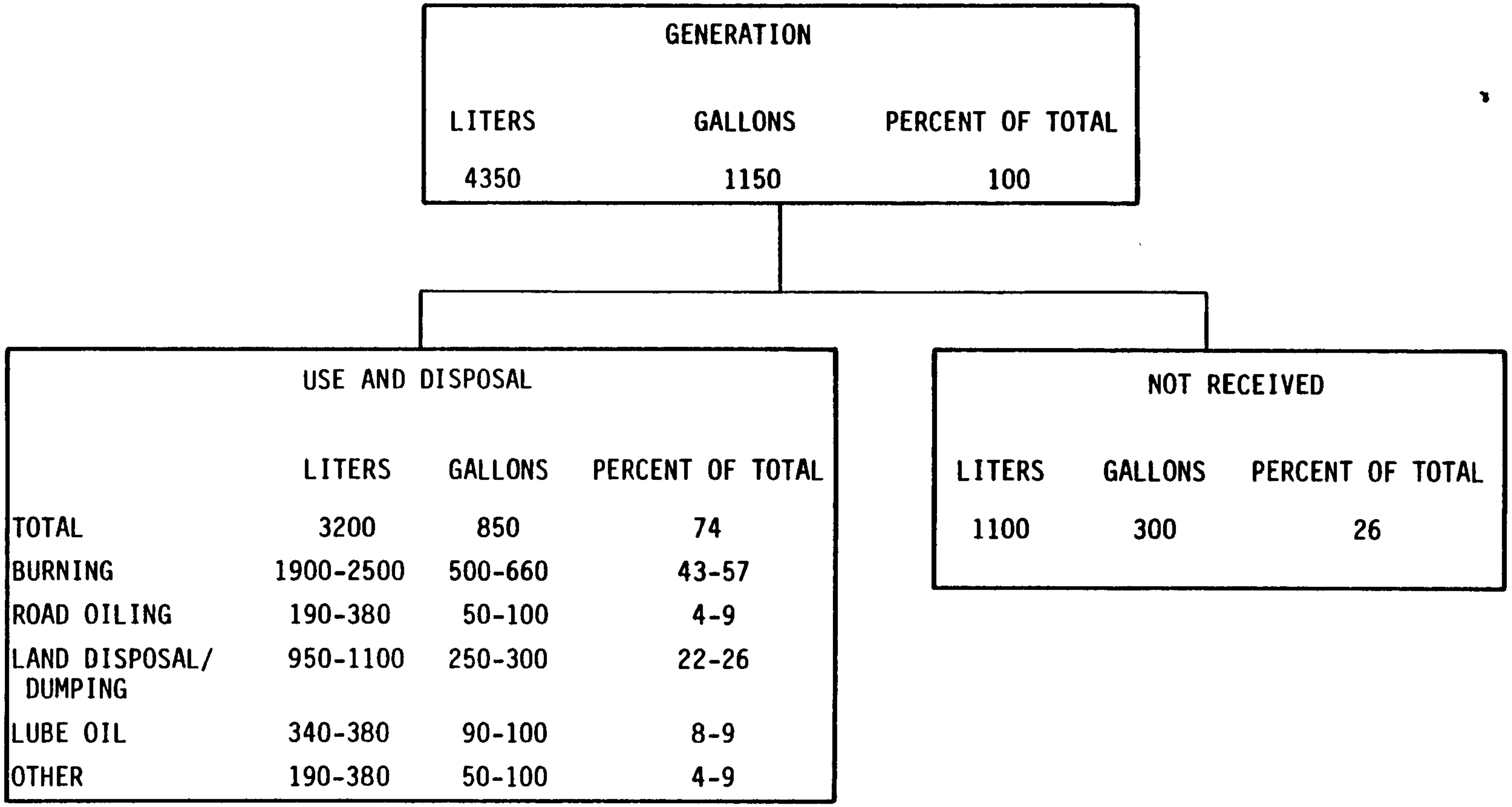
SECTION 2

INTRODUCTION

Of the approximately 4.3 billion liters (1.1 billion gallons) of waste oil generated per year in the United States, a major portion, about 1900 to 2500 million liters (500 to 660 million gallons), is burned in boilers, kilns, diesel engines, and waste oil heaters.[1] This is the largest single use of waste oil; the remainder is re-refined, used as dust suppressants, landfilled, or dumped. (See Figure 2-1.)

Waste oils contain many contaminants, either because of their uses or because they are mixed with other chemical wastes. Some of the contaminants found in waste oil include heavy metals, particularly lead; organic solvents such as benzene, xylene, and toluene; and chlorinated organics such as trichloroethane, trichloroethylene, and polychlorinated biphenyls (PCB's). Many contaminants commonly found in waste oil are either toxins or carcinogens and are therefore potentially hazardous.

Table 2-1 shows the waste oil contaminants that were modeled for this study. The metals and the organics listed were chosen because they are commonly found in waste oil and because all can be measured in emissions. This latter point is important because stack emissions from waste oil-fired boilers are being measured in concurrent studies (by other firms), and results



GENERATION

LITERS	GALLONS	PERCENT OF TOTAL
4350	1150	100

USE AND DISPOSAL

	LITERS	GALLONS	PERCENT OF TOTAL
TOTAL	3200	850	74
BURNING	1900-2500	500-660	43-57
ROAD OILING	190-380	50-100	4-9
LAND DISPOSAL/ DUMPING	950-1100	250-300	22-26
LUBE OIL	340-380	90-100	8-9
OTHER	190-380	50-100	4-9

NOT RECEIVED

LITERS	GALLONS	PERCENT OF TOTAL
1100	300	26

ALL VALUES IN MILLIONS
OF LITERS AND MILLIONS
OF GALLONS

Figure 2-1. Quantities of waste oil generated annually and their uses and disposal.

from these studies will be used to modify assumptions used in the modeling if the data show that adjustments are necessary.

TABLE 2-1. WASTE OIL CONTAMINANTS CONSIDERED IN DISPERSION MODELING ANALYSES

Response	
Threshold	Nonthreshold
Barium	Arsenic
Cadmium	Cadmium
Chromium	Chromium
Lead	
Zinc	1,1,2-Trichloroethane
	Tetrachloroethylene
1,1,1-Trichloroethane	Trichloroethylene
Toluene	Benzene
Hydrogen chloride[a]	Carbon tetrachloride
	Dioxins[a]
	PCB's

[a] Assumed to be formed during combustion rather than present as a waste oil contaminant.

Contaminants in Table 2-1 are also divided into those that elicit a toxic response above a threshold level, and those that are classed as nonthreshold substances (e.g., those for which no safe threshold is known). This distinction is important in the models chosen to estimate ambient concentrations and in the interpretation of the results.

To date, the environmental impacts of burning waste oil have not been fully assessed. Several studies have measured lead emissions,[2-4] and some have used modeling to predict ambient concentrations of lead from a source burning waste oil.[2,5-8] Lead emissions from a source burning waste oil are significantly greater than those from a source burning fuel oil.

The impact of waste oil burning on ambient air depends on many factors: number of sources, emission control equipment, stack heights, meteorological conditions, background levels, and the waste oil itself. Ground-level concentrations can approach or exceed the National Ambient Air Quality Standard for lead of 1.5 $\mu g/m^3$.[2,5,6,8] Thus, the data indicate that the burning of waste oil containing lead may pose a human health hazard, at least under some conditions.

Data on the environmental impact from other metals and organic contaminants as a result of burning waste oil are far more limited. Recent media coverage[9] has focused attention on the potential for adverse effects from chemical wastes in waste oil, and a limited number of studies have concluded that there is a potential for adverse effects from both organic contaminants and from trace metals other than lead.[3,4]

The U.S. Environmental Protection Agency's Office of Solid Waste is funding a study to assess the environmental impact of various waste oil practices, including its use as a fuel, its use as a dust suppressant, and its storage. Three separate reports (this and two others) characterize each of the practices and analyze the associated risks.

This report describes the practices of waste oil burning, estimates its impact on air quality, and assesses the resulting risks to human health. Figure 2-2 is a flow diagram of the approach to this study, which consists of three main parts: a source characterization, air dispersion modeling, and risk assessment. The source characterization in Section 3 describes

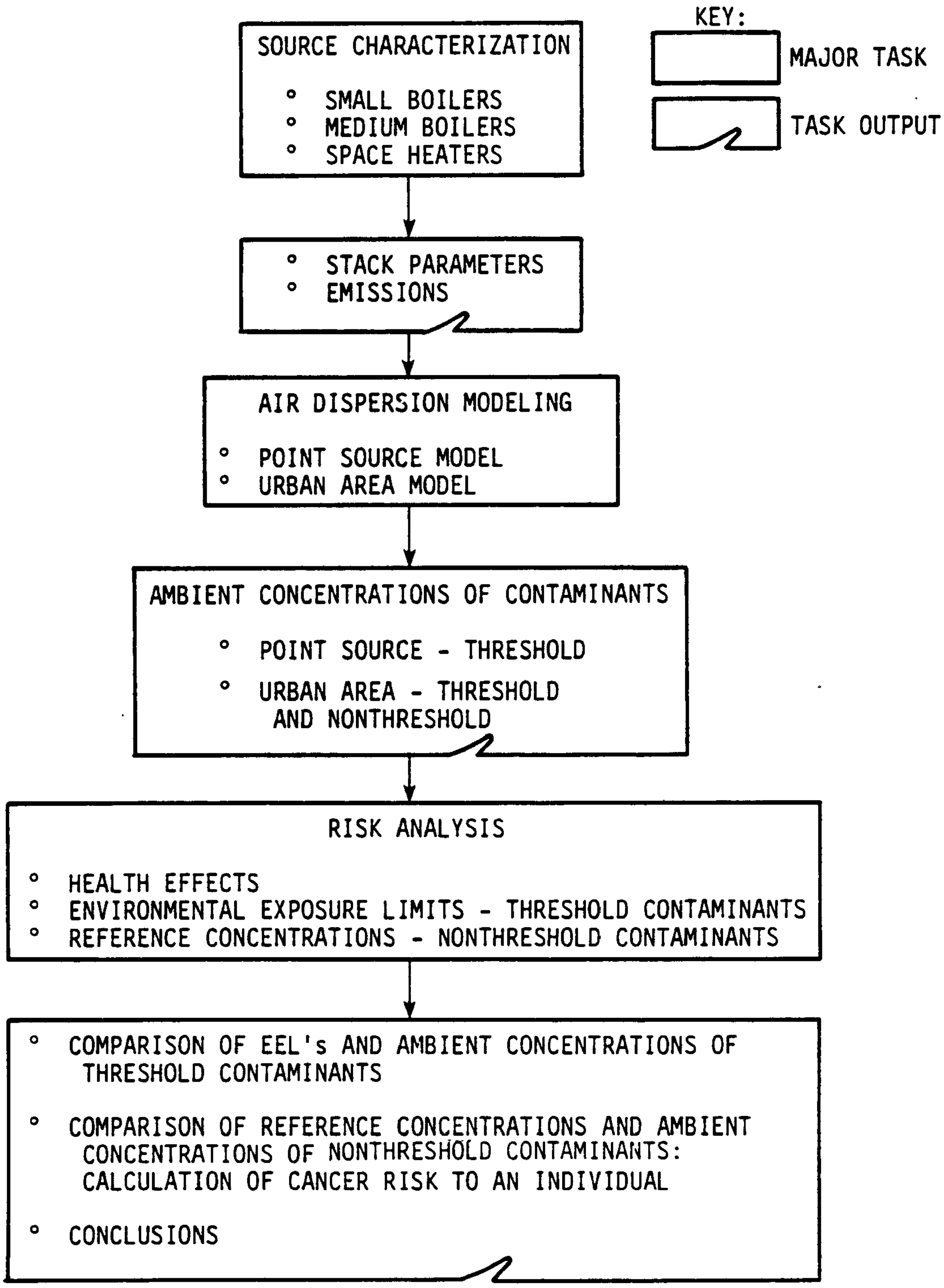


Figure 2-2. Flow diagram of project approach.

the boilers and space heaters modeled. This analysis focuses on burning of waste oil in small boilers (defined as those with a capacity of less than 15 million Btu/h) and in waste oil space heaters (commonly used in service stations). Some modeling and discussion of medium-sized boilers (defined as those between 15 and 150 million Btu/h) is also included. The stack parameters chosen for each modeled source and the emissions calculated for each source are used in the air dispersion modeling.

Section 4 presents a description of the air dispersion models used to estimate ground-level concentrations of contaminants emitted by waste oil boilers and space heaters. The two types of air dispersion modeling used were 1) a point source model to estimate emission dispersion from an individual source, and 2) an urban area model to estimate emission dispersion from many sources spread over a densely populated area. Section 4 presents the results of the two air dispersion models. The output of point source modeling is ambient concentrations of waste oil contaminants eliciting a threshold response. The urban area modeling results include concentrations of both threshold and nonthreshold contaminants.

The preliminary work described in Sections 2 through 4 provides the background data for the risk analysis in Section 5. The risk analysis is a quantitative assessment of the hazard that waste oil burning poses to human health. It is divided into an evaluation of the risks associated with exposure to the threshold and nonthreshold contaminants in the oil. For threshold substances, "Environmental Exposure Limits" (EEL's) were derived, based on modifications of Threshold Limit Values for occupational exposure. For nonthreshold contaminants (carcinogens), reference concentrations were derived as a means of calculating the cancer risk to an individual from exposure to contaminants released into the air from waste oil burning. Appendix C presents the derivation of the EEL's and reference concentrations; Section 5 focuses on the air dispersion modeling results and includes a discussion of the associated risks. Section 6 addresses dioxins, their potential for formation during combustion of waste oil, potential health effects, dispersion modeling, and risk assessment.

REFERENCES FOR SECTION 2

1. Franklin Associates Limited and PEDCo Environmental, Inc. Survey of the Waste Oil Industry and Waste Oil Composition. (Draft Report.) April 1983.

2. Waite, D. A., et al. Waste Oil Combustion: An Environmental Case Study. APCA Paper No. 82-5.1. Presented at Annual Meeting of Air Pollution Control Association, New Orleans, June 20-25, 1982. p. 1-15.

3. Brinkman, D. W., P. Fennelly, and N. Suprenant. The Fate of Hazardous Wastes in Used Oil Recycling. GCA Corporation. July 1983.

4. Walker, W. B. Pollution of the Environment by Burning of Waste Oils. Environmental Pollution Management, 11(3): 80-82, May/June 1981.

5. Recon Systems, Inc., and ETA Engineering, Inc. Used Oil Burned as a Fuel. Vols. 1 and 2. October 1980.

6. Devitt, T., et al. Population and Characteristics of Industrial/Commercial Boilers in the U.S. EPA-600/7-79-178a, August 1979.

7. New Jersey State Department of Environmental Protection. Memo from J. Held to G. Pierce on calculations of metal contaminants from waste oil burning. October 6, 1982.

8. New York State Department of Environmental Conservation Division of Air. Proposed regulations Subpart 225-2 (Fuel Oil and Waste Fuel) of 6NYCRR 225 (Fuel Composition and Use). September 1982.

9. American Broadcasting System. ABC News "20/20" Transcript on Use of Waste Oil as Fuel. December 17, 1981.

SECTION 3

SOURCE CHARACTERIZATION: FACILITIES THAT BURN WASTE OIL

Waste oil can be burned in virtually any facility designed to burn No. 6 fuel oil, and in most facilities designed to burn No. 4 and No. 5 fuel oils, although modifications may be necessary in systems designed for the lighter fuels.[1] The available literature indicates that waste oil is currently burned in the following facilities or devices: boilers, oil heaters, incinerators, asphalt plants, cement kilns, and diesel engines.[1,2] Although no currently available survey data show the exact amount of waste oil burned in each of these units/devices, a study by Development Planning and Research Associates, Inc., reported the proportional distribution to various combustion units or devices as follows[2]:

Combustion unit/device	Relative distribution of waste oil by source, %
Cement kilns	2
Diesel engines	2
Oil space heaters	3
Oil-fired boilers	92

These figures indicate that oil-fired boilers consume the largest portion of waste oil; therefore, these are the sources of concern in this study.

3.1 BOILER CHARACTERIZATION

3.1.1 Types of Boilers

The three major types of boilers are water-tube, fire-tube, and cast iron. Water-tube boilers are generally the largest, and they also have the greatest range of capacity. Cast iron boilers are usually very small.

A water-tube boiler is one in which the hot combustion gases resulting from combustion of fuel contact the outside of the heat transfer tubes, whereas the boiler water and steam contact the inside of the tubes. These boilers, which generate high-pressure, high-temperature steam, are available in many sizes, generally in the range of 15×10^6 to 1500×10^6 Btu/h.

In fire-tube boilers, the hot combustion gases flow from the combustion chamber, which is usually enclosed in a boiler shell, through a tube that is surrounded by a water basin that absorbs heat through the shell and tubes. These units, which are usually small ($<20 \times 10^6$ Btu/h), are used where loads are relatively constant.

Cast iron boilers are similar to fire-tube boilers and are sometimes classified as such. In these very small boilers (0.003×10^6 Btu/h to 14×10^6 Btu/h), the combustion chamber is surrounded by a water basin that is lanced with flues, or in commercial units, a maze of tubes. The flues and tubes allow the combustion gases to transfer heat to the water and escape from the chamber. These boilers require little maintenance and can handle overloading or demand surges.

3.1.2 Boiler Sizes

Figure 3-1 classifies boiler sizes by type and by use. Both residual and distillate fuel oil can be burned in boilers of all sizes. Commercial/institutional use includes space heating, water heating, and cooking at nonmanufacturing establishments, such as apartment buildings, motels, restaurants, wholesale and retail businesses, health and educational institutions, and government office buildings. Domestic or residential use is defined as space heating, water heating, cooking, and other household operations at private households, including farmhouses. The small boilers of most interest in this study are fire-tube and cast iron boilers used for commercial/institutional and residential purposes. The medium-sized boilers modeled in the study are usually water-tube boilers used for space heating.

The following listing of typical applications provides some perspective to the boiler sizes discussed in this report:

Boiler size	Typical application
60,000 Btu/h	1,000 ft^2 apartment
100,000 Btu/h	2,000 ft^2 house
300,000 Btu/h	6,000 ft^2 - 5 small apartments
2,000,000 Btu/h	40,000 ft^2 - large church and school
7,000,000 Btu/h	140,000 ft^2 - large 7-story office building
15,000,000 Btu/h	280,000 ft^2 - large 10-story hospital

3.1.3 Boilers Most Likely to be Fueled by Waste Oil

Despite the lack of data on waste oil users, some assumptions can be made as to the kinds of boilers most amenable to waste oil burning and those for which waste oil is not a likely fuel.

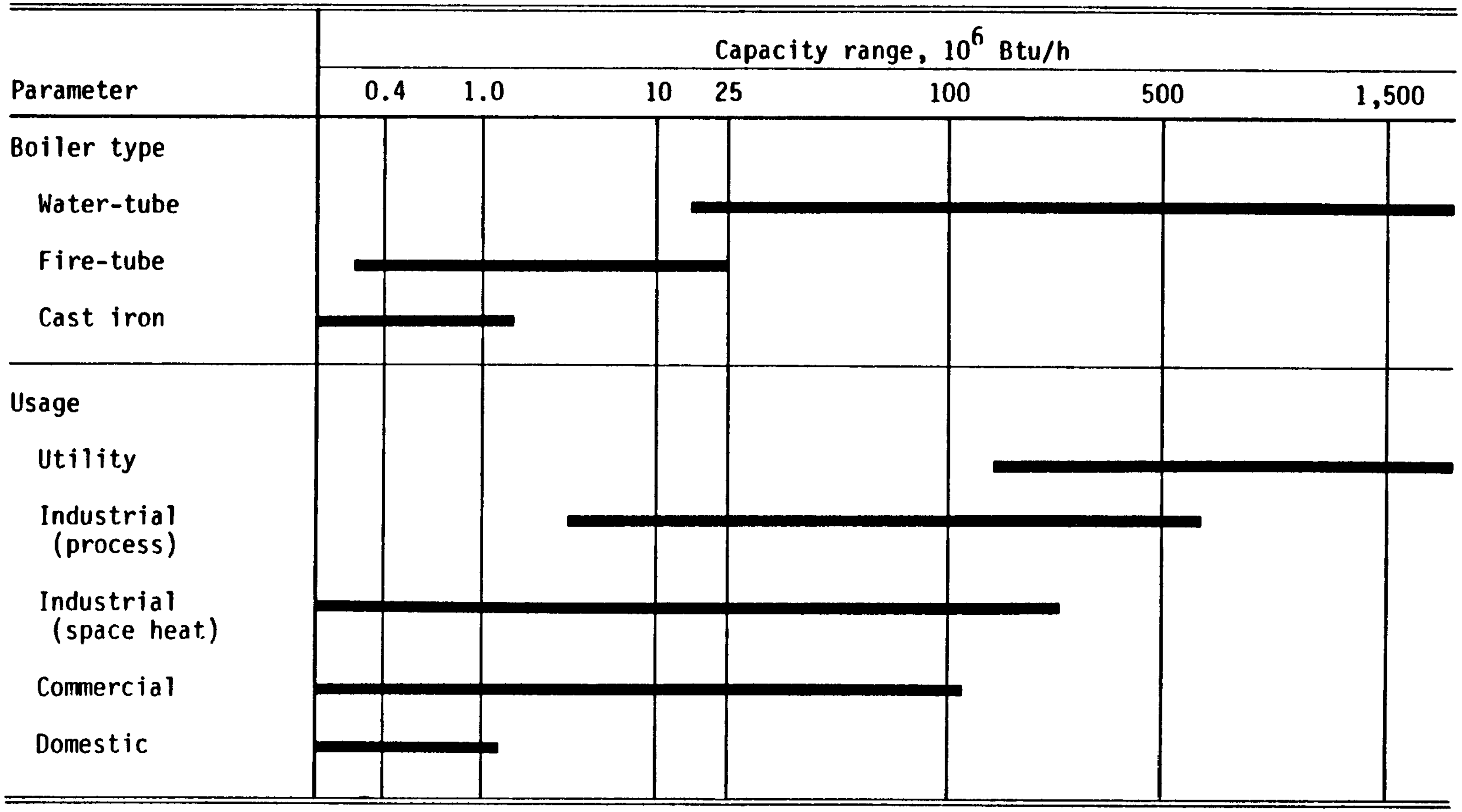


Figure 3-1. Occurrence of various size boilers by type and use.[3]

Waste oil can be burned in any facility designed for No. 6 fuel oil, and in most facilities designed for No. 4 and No. 5 fuel oils (with some possible modifications); therefore, it is assumed that waste oil is more likely to be burned at facilities that currently burn residual fuel oil rather than at those that burn distillate fuel oil.

Because of the potential tube and furnace fouling associated with water-tube boilers, waste oil burning in these boilers may require some design modifications, e.g., the installation of fuel filters, air- and steam-assisted burners, "dirty" tanks, soot blowers (on larger units), and air pollution control equipment. Fire-tube and cast iron boilers lend themselves more readily to "dirty" oil firing than do water-tube boilers. For this reason, waste oil is believed to be fired in many boilers of this type.[1]

Table 3-1 presents the potential population of waste-oil-burning boilers. As shown in Table 3-2, an estimated 50,000 to 60,000 of these boilers now burn waste oil.[1] The assumptions necessary for arriving at this estimate are as follows:

- Waste oil that is burned in boilers is blended with virgin oil: 25 percent waste oil and 75 percent virgin oil.
- Waste oil market penetration is higher in larger boilers and residual oil boilers and lower in the smaller units and distillate oil boilers.

3.1.4 Boiler Stack Parameters

PEDCo compiled a list of stack parameters for small boilers (defined as those less than 15 x 10^6 Btu/h), based on a 1982

TABLE 3-1. BOILERS WITH POTENTIAL FOR BURNING WASTE OIL

Boiler type	Fuel	Size, 10^6 Btu/h	Total number	Total capacity, 10^6 Btu/h	Load factor[a]	Annual fuel consumption, 10^{15} Btu
Water-tube	Residual oil	<25	7,119	62,300	0.106	0.058
		25-250	8,464	527,000	0.106	0.489
		>250	370	166,400	0.106	0.155
Fire-tube	Residual oil	0.4-25	72,850	253,400	0.295	0.655
		25-50	833	31,200	0.295	0.081
Fire-tube	Distillate oil	0.4-25	47,598	165,800	0.469	0.681
		25-50	543	20,400	0.469	0.084
Cast iron	Residual oil	<0.4	203,569	51,300	0.295	0.133
		0.4-10	95,899	132,200	0.295	0.342
Cast iron	Distillate oil	<0.4	127,833	32,200	0.469	0.132
		0.4-10	60,224	82,900	0.469	0.341
Total			625,302	1,525,100		3.151

[a] Based on Table 3-1 of Reference 1. Load factor refers to the fraction of total boiler capacity actually utilized.

TABLE 3-2. AN ORDER-OF-MAGNITUDE ESTIMATE OF BOILERS BURNING WASTE OIL[a]

Boiler type	Boiler size (10^6 Btu/h)	Estimated number of boilers using waste oil
Water-tube, residual oil	Medium (100-500)	615
	Large (500-1500)	15
	Power plant (1500)	1
Fire-tube/cast iron, residual oil	Small (10-50)	2,362
	Very small (0.4-10)	45,175
Fire-tube/cast iron, distillate oil	Small (10-50)	927
	Very small (0.4-10)	3,144
Total		52,239

[a] Source: Reference 1.

retrieval from the Ohio EPA boiler inventory. Tables 3-3 and 3-4 show the numbers obtained from the inventory for boilers with capacities of less than 3 million Btu/h and those with capacities between 3 and 15 million Btu/h.

3.2 OIL SPACE HEATERS

For purposes of this discussion, oil heaters are defined as combustion units with capacities of 0.4 million Btu/h or less and that used to heat either air or water. The principal users of space heaters are automobile service stations. Other users include automobile and truck dealerships; truck, automobile, and taxicab fleet operators; automotive repair shops; and farm operators.

3.2.1 Types and Number of Oil Space Heaters

The firing methods of the two principal types of oil heaters (vaporizers and atomizers) are different. Figure 3-2 illustrates these two different combustion principles. The vaporizing unit burns heated oil vapor, whereas atomizing burners use mechanical force to atomize the fuel before it is ignited. The major differences between these two heating systems are 1) the vaporizing unit leaves a significant amount of residue compared with that left by the atomizing unit, and 2) the atomizing unit yields higher gas-phase concentrations of most inorganic species than the vaporizing unit does.[4,5] Because the vaporizing-pot combustion systems trap metal contaminants in the residue, they emit fewer metal pollutants to the air. Atomizers, on the other hand,

TABLE 3-3. STACK PARAMETERS FOR BOILERS WITH CAPACITIES OF LESS THAN 3 MILLION Btu/h[a]

Boiler size, 10^6 Btu/h	Stack height, m	Stack diameter, m	Maximum temperature, °C	Feed rate, liters/h	Gas flow[b], m^3/min	Exit velocity, m/s
1	5.5	0.46	10	26	9.91	1.0
3	18.9	0.67	77	83	31.18	1.5
3	12.5	0.40	107	83	31.18	4.21
1	18.3	0.46	232	30	11.4	1.16
3	7.3	0.52	204	114	42.54	3.35
2	9.1	0.88	93	53	19.9	0.55
1	10.7	0.43	177	38	14.2	1.6
2	12.2	0.85	177	53	19.9	0.58
2	19.8	1.04	177	53	19.9	0.40
1	7.3	0.40	204	26	9.91	1.3
Average 1.9	12.2	0.61	146	56	21.0	1.56

[a] Source: Ohio EPA Boiler Inventory (1982 retrieval).

[b] Assuming ~22.48 m^3/liter of oil burned. Calculated by use of North American Combustion Handbook, 1st edition, 1957 (average value for fuel oil).

$$\text{Exit velocity (m/s)} = \frac{4G}{60\ \pi\ d^2}$$

where G = gas flow, m^3/min

d = stack diameter, m

TABLE 3-4. STACK PARAMETERS FOR BOILERS WITH CAPACITIES OF BETWEEN 3 AND 15 MILLION Btu/h[a]

Boiler size, 10^6 Btu/h	Stack height, m	Stack diameter, m	Maximum temperature, °C	Feed rate, liters/h	Gas flow[b], m^3/min	Exit velocity, m/s
9	12.2	0.40	149	261	97.85	13.23
4	13.7	0.55	107	114	42.54	2.99
12	20.4	0.76	316	348	130.5	4.79
13	9.14	0.73	288	329	123.4	4.91
4	7.62	0.76	399	95	35.46	1.31
9	7.62	0.46	288	227	85.10	8.66
4	7.32	0.52	204	110	41.12	3.26
Average 7.86	11.14	0.61	250	212	79.41	5.59

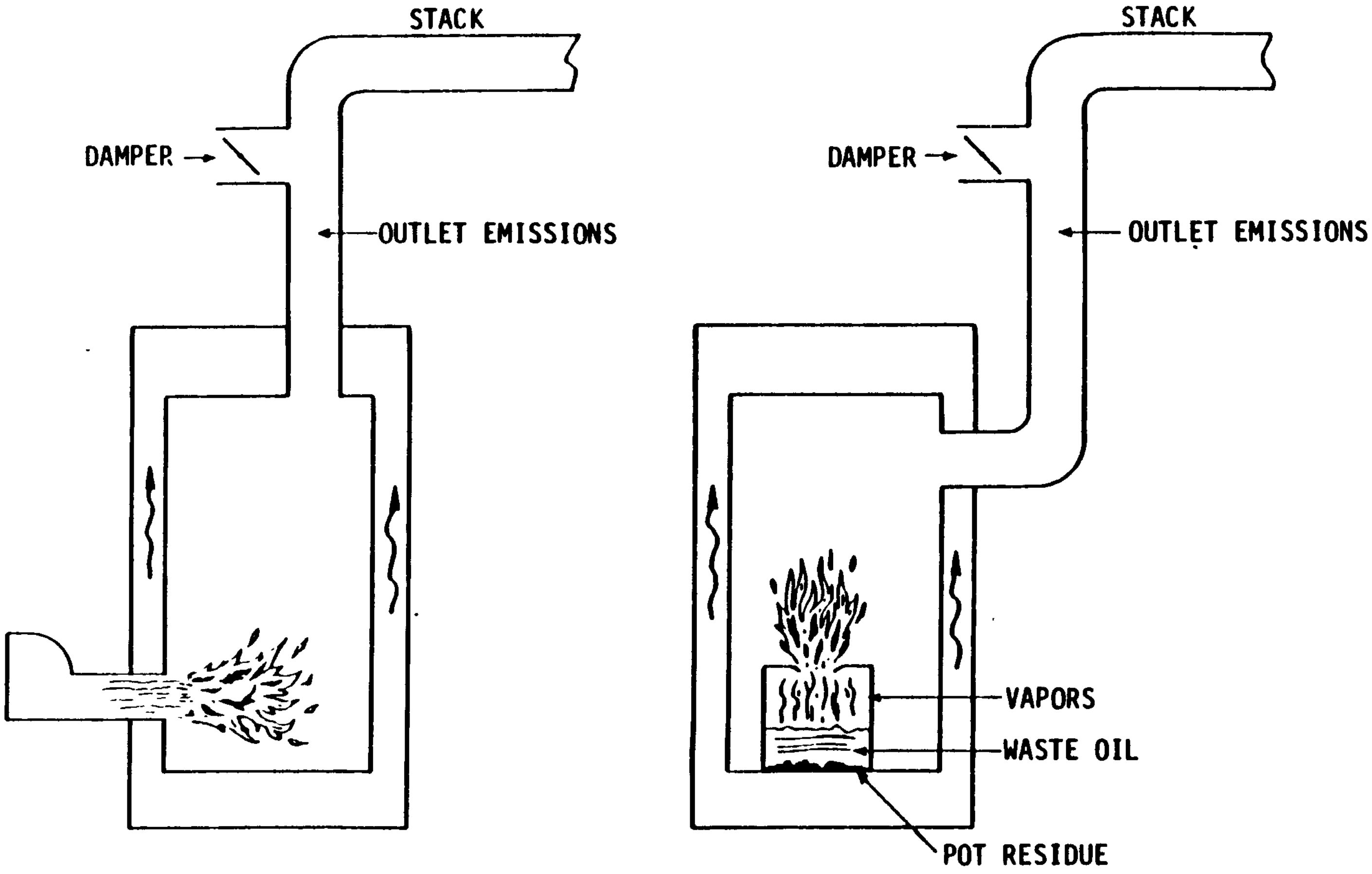
[a] Source: Ohio EPA Boiler Inventory (1982 retrieval).

[b] Assuming ~22.48 m^3/liter of oil burned. Calculated by use of North American Combustion Handbook, 1st edition, 1957 (average value for fuel oil).

$$\text{Exit velocity (m/s)} = \frac{4G}{60\ \pi\ d^2}$$

where G = gas flow, m^3/min

d = stack diameter, m



LOW-PRESSURE AIR
ATOMIZATION BURNER

VAPORIZING POT BURNER

Figure 3-2. Combustion principles of the low-pressure atomizing and vaporizing pot burners.

release to the air nearly all of the metal pollutants contained in the fuel.

Compared with most burning facilities, oil heaters consume relatively low volumes of waste oil; therefore, the overall absolute quantity of emitted metals is low. Because of the heaters' low stack heights and probable low gas emission velocities, however, little dispersion of the metallic contaminants occurs, so ground-level concentrations (particularly for atomizing burners) are relatively high.

Oil space heaters are easily adaptable to waste oil burning and are often designed exclusively for that purpose, particularly those used at facilities that generate waste oil (e.g., gas stations). If waste oil is burned, it is usually the only fuel; it is rarely blended with fuel oil.

A recently completed study of the waste oil space heater industry estimates that there are 10 manufacturers of waste-oil space heaters in the United States and that two brands are made in Europe and sold here.[4] Nearly 34,000 space heaters were sold in this country in the past 3 years; about 90 percent of these were vaporizing units and the other 10 percent were atomizing units. Average life expectancy on such units is believed to be about 10 years.

3.2.2 Oil Space Heater Parameters

Table 3-5 summarizes the parameters of oil heaters. Stack heights vary with the location of the heater. Because they are usually vented to the roof, stack heights can vary from 2 to 10 meters. Stack diameters are generally in the range of 15 to 25 centimeters. Stack temperatures vary with the unit: most are between 300° and 400°C, but some are as low as 165°C. Fuel feed rates vary from 0.4 to about 15 liters (0.1 to 4 gallons) per hour.

TABLE 3-5. OIL SPACE HEATER PARAMETERS

Stack temperature, °C	165-420
Stack diameter, cm	15-25
Stack height, m	2-10
Exit velocity, m/min	75-130
Volumetric flow rate at STP (20°C, 1 atm), m^3/s	0.014-0.025
Fuel feed rate, liters/h	0.4-15

Source: References 5 through 13.

3.3 MODELED POPULATION

3.3.1 Population Density and Distribution of Boilers

Most small residual-oil-fired boilers can be classified as industrial, commercial/institutional, or residential. Some information on the distribution of industrial and commercial/institutional boilers was obtained for this study and is presented in detail in Appendix B, along with some data on utility boilers. Only a brief summary is included here.

Nearly 90 percent of the U.S. industrial residual-oil-fired boilers have a heat input capacity of less than 10 million Btu/h; however, this group represents only 20 percent of the total industrial boiler capacity. Fifty percent of the capacity is generated by the larger boilers (in the 25 to 250 million Btu/h range). (See Appendix B for details.)

Another area of interest was the location of industrial boilers in densely populated urban areas versus nonurban areas. With the number of production employees used as an indicator of the number of boilers and data from 22 states, the following statistics were compiled:

- In the 22 states investigated, approximately 44 percent of all production workers are located in cities with populations of 25,000 or more and at least 450 manufacturing employees; 56 percent are located in nonurban areas. If this is used as an indicator of industrial boiler distribution, the same percentages would apply, which means that 44 percent of the industrial boilers are located in cities and 56 percent in nonurban areas.
- Based on a broader definition of urban and nonurban areas, about 78 percent of all production workers are located either within cities (same definition as above) or in Standard Metropolitan Statistical Areas (SMSA's), and the remaining 22 percent are located in nonurban areas. Again, if industrial boiler distribution correlates with production workers, then more than three-quarters of the industrial boilers are in urban areas, and a little less than one-fourth are in urban areas. (See Appendix A for details.)

Commercial/institutional oil-fired boilers are those used in hospitals, greenhouses, shopping malls, and similar applications. Because the nature of this type of boiler makes their distribution correlate well with population, no attempt was made to locate actual commercial/institutional boilers and categorize them as being in an urban or nonurban location.

Unlike industrial boilers, most commercial/institutional boilers are small: 88 percent (by number) have heat input capacities of less than 10 million Btu/h. Much of this heat input capacity (i.e., about 25 percent) is found in the range of 1.5 to 10 million Btu/h range. About half of the total generated capacity is represented by boilers with heat input capacities of less than 10 million Btu/h. Tables A-9 through A-14 in Appendix A provide more detailed data on the numbers and capacities of various sized commercial/institutional boilers by type of boiler (i.e., water-tube, fire-tube, etc.).

Although it was not an objective of this study to survey small boilers, it is useful to provide some indication of the relative potential use of waste oil across the nation. Two approaches to obtaining an estimate of the geographical distribution of small boilers were considered: 1) to base the distribution on residual fuel oil deliveries to the commercial sector in each state, and 2) to obtain data from a survey of states and waste oil collectors/processors. These approaches are discussed in detail in Appendix A. Based on the latter method of estimating the amount of waste oil generated and burned in each state (as presented in a survey by Franklin Associates, Ltd.[1]), the states with the greatest potential number of small boilers that burn waste oil are New York, New Jersey, Pennsylvania, Illinois, Michigan, Texas, and California. This is a reasonable estimate, but its accuracy is questionable. (See Appendix A.)

3.3.2 Population Density and Distribution of Oil Space Heaters

Actual data are not available on the population density and distribution of oil space heaters. Users of space heaters include service stations, automobile dealerships, trucklines, and farmers. The distribution of the population of about 34,000 space heaters is assumed to be similar to that of the general population except in very warm climates, where the need is limited.

3.4 EMISSIONS FROM BOILERS AND SPACE HEATERS

Emissions resulting from burning waste oil depend on the design of the combustion unit and control equipment, unit capacity, burner type, operating parameters, waste oil contaminants, and feed rate. Large water-tube boilers with firebox residence times of at least 1 second and firebox exit temperatures of higher than 1500°F provide more complete combustion than the smaller fire-tube boilers. Many of the factors that affect the quality of combustion (e.g., excess air, fuel homogeneity, firebox heat release rate, and on/off cycling) are not as carefully controlled in small boilers.[14]

In an oil-fired boiler, the four basic atomization methods are air, steam, mechanical, and rotary-cup atomization. The trend is toward mechanical atomization in small units, and toward air atomization in larger units.[15] Generally, rotary-cup burners are being phased out because of their high maintenance requirements; however, these burners are most adaptable to waste oil firing and continue to be used for that purpose. Small water-tube, fire-tube, and cast iron boilers that are fired by the same type of single burners have similar combustion characteristics and, consequently, similar emission factors. Small commercial/institutional boilers generally do not have air pollution equipment. When such boilers burn waste oil as fuel, however, the lack of controls becomes a concern because of the relatively high levels of lead and other heavy metals that can be emitted as particulates. The potential emissions of most concern are metals, halide acids, and organics (solvents and chlorinated organics).

3.4.1 Metals Emissions

Table 3-6 presents average physical and chemical properties of waste oil and residual fuel oil. Table 3-7 presents the average contaminant concentrations of nearly 400 waste oil samples.[16] The numbers represent median concentrations, 75th percentile concentrations, and 90th percentile concentrations. The metals of particular concern and interest are arsenic, barium, cadmium, chromium, lead, and zinc.

Some test data are available on emissions of metals from waste oil boilers, and calculations of a value for percent metals emitted was based on these data (total concentration in the feed, feed rate, and measured emission rates). Table 3-8 presents these values for the metals of interest. (Lead and zinc values represent an average of five data points; values of all other metals represent averages of two data points.) The average emission rates of these metals is 31 to 75 percent; individual emission rates ranged from 20 to 100 percent. As a maximum, worst-case conditions would be based on the assumption that all metals in the fuel are quantitatively emitted. A reasonably conservative, but more realistic, estimate would be 75 percent. Thus, if a facility were burning 100 percent waste oil at a feed rate of approximately 132 liters/h (35 gal/h), the estimated potential lead emission from this source would be 99 g/h or 0.028 g/s, calculated as follows:

TABLE 3-6. PROPERTIES OF WASTE OIL AND RESIDUAL FUEL OIL

Parameter	Estimated typical value of waste oil	Estimated typical value of residual fuel oil
Heat value, Btu/lb	18,500[a]	18,500[a]
Btu/gal	138,000[a]	149,000[a]
API gravity at 60°F	26[a]	13-16[b]
Density at 15°C, g/ml	0.8960[a]	
Viscosity at 40°C, cs	66.6[a]	350[b]
Water, %	2.4[a]	0.08[b]
Ash, %	1.16[a]	0.2-0.3[b]
Carbon, %	83.9[a]	86.4[b]
Hydrogen, %	13.2[a]	12.9[b]
Nitrogen, %	0.093[a]	0.3[b]
Sulfur, %	0.5[a]	0.2-5[b]
Chlorine, %	1.4[c]	
Arsenic, µg/g	11[c]	0.2-0.7[d]
Barium, µg/g	50[c]	0.3-5.0[d]
Cadmium, µg/g	1.1[c]	0.003-1[d]
Chromium, µg/g	10[c]	0.7-4[d]
Lead, µg/g	220[c,e]	1-4[d]
Zinc, µg/g	469[c]	0.4-2.0[d]

[a] Reference 17.

[b] Reference 18.

[c] Reference 16.

[d] Reference 19.

[e] This is an average of mixed oils containing both crankcase oil (high in lead) with industrial oils (no lead content).

TABLE 3-7. SUMMARY OF WASTE OIL CONCENTRATION AT THE 50TH, 75TH, AND 90TH PERCENTILE

	Number of samples	Median concentration at 50th percentile,[a] ppm	Concentration at 75th percentile,[b] ppm	Concentration at 90th percentile,[c] ppm
Metals				
Arsenic	17	11	14	16
Barium	159	50	200	485
Cadmium	189	1.1	1.3	4.0
Chromium	273	10	12	28
Lead[d]	227	220	420	1,000
Zinc	232	469	890	1,150
Chlorinated solvents				
Dichlorodifluoromethane	78	20	210	860
Trichlorotrifluoroethane	26	<1	33	130
1,1,1-trichloroethane	123	270	590	1,300
Trichloroethylene	126	60	490	1,049
Tetrachloroethylene	100	120	370	1,200
Total chlorine	62	1,400	2,600	6,150
Other organics				
Benzene	32	46	77	160
Toluene	30	190	490	1,200
Xylene	22	36	270	570
Benzo(a)anthracene	17	16	26	35
Benzo(a)pyrene	19	9	12	33
Naphthalene	15	290	490	580
PCB's	264	9	41	50

[a] At the median, 50 percent of the analyzed waste oil samples had contaminant concentrations below the given value.

[b] Seventy-five percent of the analyzed waste oil samples had contaminant concentrations below the given value.

[c] Ninety percent of the analyzed waste oil samples had contaminant concentrations below the given value.

[d] Values for lead were taken from 1979-1983 data only.

$$Q = (A)(F)(0.75)(\text{grams}/10^3\ \mu g)$$

where Q = lead emission rate in g/h

A = lead concentration in feed in ppm (assumed to be 1000 mg/liter)

F = feed rate in liters/h

0.75 = estimated percent of lead emitted to the air

$g/10^3\ \mu g$ = conversion factor

TABLE 3-8. CALCULATED EMITTED PORTION OF TOTAL INPUT OF SELECTED METALS

Metal	Percent emitted
Arsenic	70
Barium	58
Cadmium	40
Chromium	31
Lead	64
Zinc	75

Source: References 17 and 20.

3.4.2 Organics Emissions

Because organics such as polynuclear aromatics (PNA's) and polycyclic organic matter (POM's) may be found in all heavy fossil fuels, they do not represent a contaminant resulting from the use of waste oil. Polychlorinated biphenyls (PCB's), on the other hand, are not present in virgin fuel oil and therefore are a contaminant in waste oil. Other organics that may be present in waste oils are gasoline, glycol (from antifreeze), pesticides, and solvents. Nonhalide solvents, glycols, and gasoline are normally readily combustible. Table 3-7 shows concentrations of some organic contaminants found in waste oil.

Commercial/institutional boilers consume less fuel than the residential, industrial, and utility boilers and therefore are not major contributors to the total national emissions. Nevertheless, their environmental impact may be significant because of their high seasonal fuel consumption, their relative abundance and proximity to population centers, their almost total lack of pollution control equipment, and their release of emissions relatively close to ground level.[15] The same reasoning applies to waste oil space heaters, which have a significant potential impact because of their low stack height and proximity to populations.

In addition to the potential emissions resulting from contaminants in the waste oil, emissions could also arise from incomplete combustion (carbon monoxide, hydrocarbons, carbonaceous particles, and possibly other chemical species, such as dioxin). Very few emission test results are available, and it is difficult to make a quantitative estimate of these emissions, which often vary with operating conditions (i.e., temperature, residence time, excess air, etc.).

The limited test data available on organic emissions from burning waste oil indicate mostly nondetectable levels. For the purpose of the air dispersion modeling in this study, emissions of specific organic compounds were estimated based on the following assumptions:

- Organic compounds present in waste oil as potential hazardous air emissions are 1,1,1-trichloroethane, tetrachloroethylene, toluene, trichloroethylene, carbon tetrachloride, and polychlorinated biphenyl compounds.
- Each organic compound is present in waste oil at the concentration shown in Table 3-7 as the 90th percentile concentration. Some additional runs of one of the air

dispersion models were based on 1 percent levels of some organics in waste oil (10,000 ppm).

- Destruction removal efficiency for these specific organic compounds is assumed to be 97 or 99 percent for all sources modeled (space heaters, small boilers, and medium-sized boilers).

Calculated emissions used for the modeling are presented in Section 4.

3.4.3 Particle Size Distribution

Some available test data on particle size distribution of emissions from fuel oil and waste oil burning are presented in Tables 3-9 and 3-10. Table 3-9 gives the distribution, on a weight percent basis, for some major contaminants resulting from burning 100 percent waste oil in a small boiler. As the table shows, in most cases 90 percent or more of the particulate emissions are 10 µm or smaller in size. This is the respirable range, which is the most detrimental to human health. Table 3-10 gives the distribution, on a weight percent basis, for particulate from the combustion of No. 6 fuel oil in a 10-MW (30 x 10^6 Btu/h) industrial boiler. Here, 95 percent of the particulate was in the respirable range of 10 µm or smaller.

3.4.4 Atmospheric Half-Life

The organic waste oil contaminants have a finite life in the atmosphere. After a time, they transform into simpler compounds as a result of sunlight or because of chemicals in the atmosphere. Table 3-11 shows the approximate half-lives of the organic compounds of interest. Because carbon tetrachloride, toluene, and trichloroethylene are simpler compounds, their

TABLE 3-9. PARTICLE SIZE DISTRIBUTION OF SOME MAJOR CONTAMINANTS IN EMISSIONS FROM WASTE OIL COMBUSTION[a]
(wt. percent of the contaminant falling within the indicated particle size range)

Particle size	Lead	Calcium	Phosphorus	Zinc	Iron	Barium
<1 micrometer	76-79	10-19	23-42	56-73	2.7-36	3.3-51
1-10 micrometers	16-21	71-74	49-66	23-39	51-80	40-79
>10 micrometers	2.7-4.4	10-15	8.9-10	3.4-5.0	13-80	8.9-18

[a] Source: Reference 21.

TABLE 3-10. PARTICULATE SIZE DISTRIBUTION OF UNCONTROLLED EMISSIONS FROM AN OIL-FIRED BOILER[a]

Aerodynamic diameter size range, μm	Weight %
<1	20
1-3	1
3-10	74
>10	5

[a] Source: Reference 22.

half-lives are 5 to 12 hours. Tetrachloroethylene and 1,1,2-trichloroethane remain in the atmosphere between 20 and 40 hours before half of their original concentration is transformed; 1,1,1-trichloroethane, which is very persistent in the atmosphere, has a half-life in excess of 1700 hours (nearly 71 days).

TABLE 3-11. HALF-LIVES OF SELECTED WASTE OIL ORGANIC EMISSIONS IN AIR

Organic substance	Half-life, hours
Carbon tetrachloride	<8
Tetrachloroethylene	20-40
Toluene	5; 7
Trichloroethane	(1,1,1) >>1700 (1,1,2) 20-40
Trichloroethylene	5-12

3.4.5 Summary of Assumptions Used to Model Emissions

The assumed emissions of metals and organics used in the air dispersion modeling are shown in Table 3-12. For boilers, it is assumed that 75 percent of the metals in the waste oil are emitted. Additional analyses were conducted based on 50 percent of the metals being emitted. For space heaters, a range of emission rates of 5 to 95 percent is used. For both boilers and space heaters, destruction removal efficiencies of 97 and 99 percent are used, which result in respective emissions of 3 percent and 1 percent of the organics in the waste oil. Sensitivity analyses (described in Section 4) showed that particle deposition and half-life had negligible effects on dispersion modeling results.

Therefore, they are not included in the point source and urban area modeling.

TABLE 3-12. ASSUMED EMISSIONS OF METALS AND ORGANICS USED IN AIR DISPERSION MODELING

Source	Type of contaminant	Emissions,[a] %
Space heaters	Metals	5, 10, 15, 25, 50, 75, 85, 95
	Organics	3, 1[b]
Boilers (small and medium)	Metals	75, 50
	Organics	3, 1[b]

[a] Expressed as percent of contaminant in waste oil that is emitted.

[b] Corresponds to destruction removal efficiencies of 97 percent and 99 percent, respectively.

REFERENCES FOR SECTION 3

1. Recon Systems, Inc., and ETA Engineering, Inc. Used Oil Burned as a Fuel. Vols. 1 and 2. U.S. Environmental Protection Agency, Washington, D.C. October 1980.

2. Development Planning and Research Associates, Inc. Risk/Cost Analysis of Regulatory Options for the Waste Oil Management System. Vol. 1. U.S. Environmental Protection Agency, Washington, D.C. January 1982.

3. Devitt, T., et al. Population and Characteristics of Industrial/Commercial Boilers in the U.S. EPA-600/7-79-178a, August 1979.

4. Development Planning and Research Associates. Selected Characteristics of the Waste Oil Space Heater Industry. July 1983.

5. Barbour, R. L., and W. M. Cooke. Chemical Analysis of Waste Crankcase Oil Combustion Samples. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. May 1982.

6. Waite, D. A., et al. Waste Oil Combustion: An Environmental Case Study. APCA Paper No. 82-5.1. Presented at the Annual Meeting, Air Pollution Control Association, New Orleans, June 20-25, 1982.

7. Thomé-Kozmiensky, K. J. Report on Article 1, No. 7. of the First Regulation for the Implementation of the German Federal Emission Control Act of September 22, 1978. Berlin Technical University. December 15, 1980.

8. Brookes, B. I. Emissions From the Combustion of Waste Oil in a Space Heater. (Unpublished report) Glasgow, Strathclyde Regional Council, re. August 1981.

9. Interpoll, Inc. Results of the November 20 and 21, 1979, particulate emission compliance tests of the Kutrieb Corporation Chetek 500 and F.A.I. 70 incinerators. (Unpublished report) Chetek, Wisconsin, Kutrieb Corporation, December 17, 1979.

10. Personal communication from Timothy A. Vanderver, Jr., Patton, Boggs, and Blow, to Docket Clerk (Docket No. 3001), Office of Solid Waste, U.S. Environmental Protection Agency, August 14, 1980. Comments on EPA's proposal to designate waste oil as a hazardous waste and to regulate certain reuses of waste oil.

11. Rourke, J. Emission Test Results - Lanair Waste Oil Heater. Tests performed October 15, 1980.

12. Thomé-Kozmiensky, K. J. Comparison of the Environmental Effects of Different Waste Oil Recycling Methods. Berlin Technical University. December 1980.

13. Dravo/Hastings, Inc. P-50 Paraflow Waste Oil Heater Emission Test Report Project No. 78-152. Test date February 6-7, 1979.

14. Fred C. Hart Associates, Inc. Impact of Burning of Hazardous Waste in Boilers. (Unpublished report) SCA Chemical Services, Inc., Boston. August 1982.

15. Surprenant, N. F. Emissions Assessment of Conventional Stationary Combustion Systems, Vol. 4. National Technical Information Service, EPA-600/7-81-003b, January 1981.

16. Franklin Associates Limited and PEDCo Environmental, Inc. Survey of the Waste Oil Industry and Waste Oil Composition. Draft Report. April 1983.

17. American Petroleum Institute. Energy From Used Lubricating Oils. Prepared by the Task Force on Utilization of Waste Lubricating Oils. Publication No. 1588. October 1975.

18. Schmidt, P. F. Fuel Oil Manual. Industrial Press, Inc. New York. 1969.

19. Electric Power Research Institute. Study of Electrostatic Precipitators Installed on Oil-Fired Boilers. EPRI FP-792, Project 413-1, Task 1.4, Volume 2, Final Report. June 1978.

20. Hall, R., et al. Test Plan and Quality Assurance Plan for Emissions Characterization of Waste Oil Combustion. U.S. Environmental Protection Agency, Cincinnati. June 1982.

21. U.S. Environmental Protection Agency. Report to Congress; Waste Oil Study. Accession No. PB-257693. April 1974.

22. U.S. Environmental Protection Agency. Environmental Assessment of Coal- and Oil-Firing in a Controlled Industrial Boiler. Volume III. EPA-600/7-78-164c, August 1978.

SECTION 4

AIR DISPERSION MODELING

4.1 INTRODUCTION

The objective of this part of the analysis was to quantify the impacts of hazardous emissions from the combustion of waste oil on ambient air quality. The dispersion models provided a mechanism for assessing the air quality impact of a large number of sources under various scenarios and for predicting the concentrations of waste oil contaminants in ambient air.

Of primary concern was the combustion of waste oil in small commercial/industrial and residential boilers and space heaters ($<15 \times 10^6$ Btu/h). Secondary emphasis was the use of this oil in medium-sized boilers (50 to 100×10^6 Btu/h). Thus three source types were modeled: small boilers, medium-sized boilers, and space heaters. Preliminary investigations revealed several factors concerning the population of small boilers and space heaters:

- Emissions from these boilers are generally uncontrolled.
- The distribution of these boilers is much the same as population distribution.
- Stack heights are generally less than 30 meters.

The most reasonable analysis entails modeling the impacts of waste oil burning based on specific assumptions concerning the source types and the distribution of sources and emissions. Because little is known about the population of small boilers and space heaters that burn waste oil, individual and urbanwide emissions were modeled to identify problem areas. Although the air quality impact of an individual boiler may be minimal, when combined with that of many other small boilers in the same geographical area, the total impact may become significant. Such impact depends on boiler density, emissions, and source characteristics.

Two dispersion models were selected to estimate the air quality impacts of contaminant emissions from waste oil burning. The Industrial Source Complex Model[1] (which is recommended by the Guideline on Air Quality Models[2]) was chosen to model individual sources and small groups of multiple sources at distances up to 10 km. Ambient air concentrations due to individual boilers were estimated only for those waste oil contaminants that elicit a threshold response.

For a spatial scale of up to 50 km, the Hanna-Gifford Model[3] (a simplified, empirical model for areawide sources) was used. Waste oil burning over an urban area was estimated for a worst-case month and for the year. Total emissions were combined with derived constants and climatologically averaged meteorological conditions to determine monthly and annual pollutant concentrations. The urban modeling included estimates for both threshold and nonthreshold contaminants.

These two models are easily adaptable, they are accepted by the modeling community, and their uses and limitations are well documented. The simplified and generic application of these models is appropriate because of the hypothetical nature of the air quality analyses performed.

Table 4-1 describes the spatial and temporal scales used for the analysis. (Further details for each model are given in Appendix B.) The specific applications of these models are as follows:

- The short-range modeling concentrated on producing worst-case estimates resulting from individual or multiple point sources, assuming each source burned 100 percent waste oil; concentrations of contaminants eliciting a threshold response were of particular concern.
- The urban-wide modeling focused on the burning of all available waste oil in a given area; urban-wide impacts of contaminants eliciting a threshold response were of considerable concern; impacts of nonthreshold substances across the selected urban area were also studied, but these offer limited utility for assessing risk in other urban areas.

TABLE 4-1. MODEL SELECTION

Model	Spatial scale	Temporal scale	Pollutants
Industrial Source Complex (ISC)	0-5 km Individual or multiple-point sources	30-day	Threshold[a]
Hanna-Gifford	0-50 km Urban-wide area sources	30-day, annual	Threshold and nonthreshold[b]

[a] Threshold pollutants are those eliciting a threshold limit response.

[b] Nonthreshold pollutants are those causing excess cancers per a specified population over a lifetime.

4.2 POINT-SOURCE ANALYSIS WITH ISC MODEL

4.2.1 Overview

All modeling discussed in this section was done with an ISC model. Individual or small group sources were modeled to estimate the air quality impact provided by a threshold contaminants source burning 100 percent waste oil. From a regulatory standpoint, these estimates are of interest in the establisment of limitations for emissions and waste oil feed stock contaminants.

The ISC Model was used in its long-term mode. The meteorological input for this model is the STability ARray (STAR) data, a joint-frequency distribution of windspeed, wind direction, and atmospheric stability class. Meteorological data characteristic of an urban location (John F. Kennedy International Airport) for the years 1974 to 1978 were used. During this period, 3720 observations were tabulated for the month of January. Figure 4-1 presents a January wind rose combining all stability classes for JFK Airport. As this figure indicates, winds from the west and northwest were typical for this period.

January was selected for the analysis of pollutants with a threshold response because of high oil consumption during this coldest month. A monthly concentration was selected to give a worst-case example for contaminants with threshold responses when compared with lifetime or annual response limits. Short-term (1- to 24-hour averaging periods) estimates of concentration were judged to be too high for comparison with long-term environmental exposure. Such concentrations were not likely to

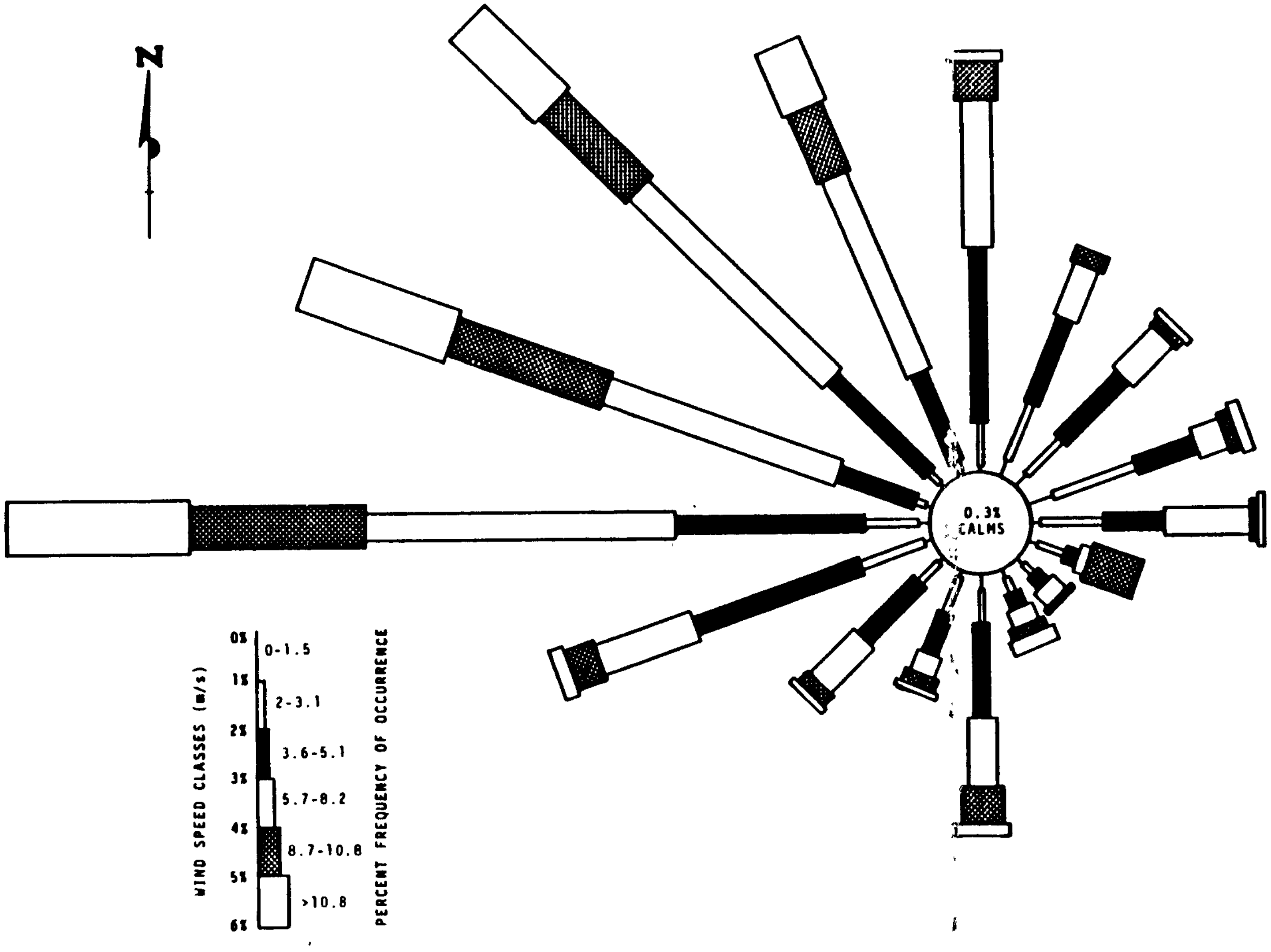


Figure 4-1. Wind rose for JFK International Airport, 1974-1978.

be sustained long enough or to occur frequently enough to provide representative estimates of environmental exposure limits.

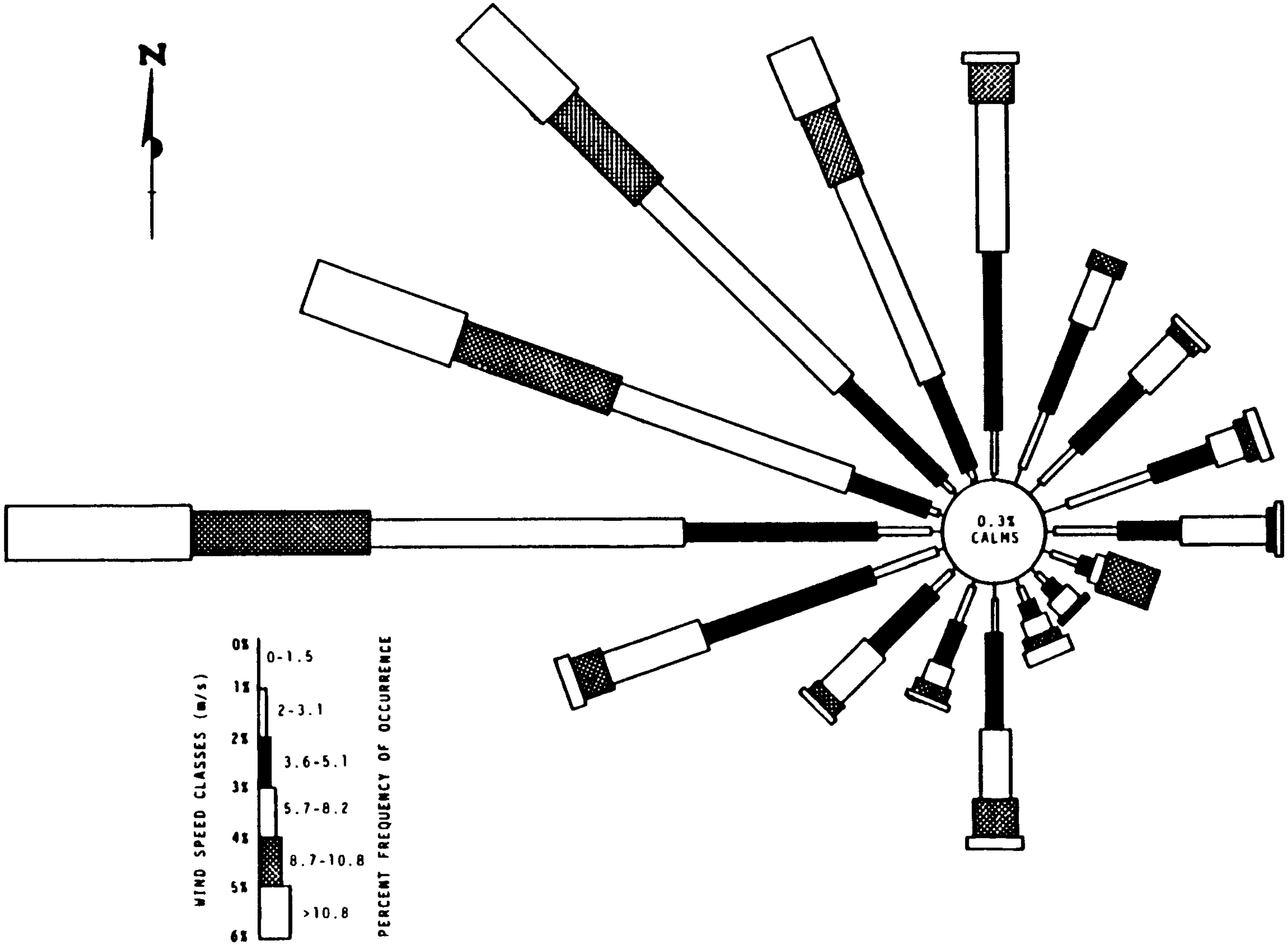
Other meteorological data used in this analysis included monthly average mixing heights and temperatures. These were estimated by using available mixing height climatologies[4] and Local Climatological Data summaries[5] for New York. All meteorological inputs are presented in Appendix B.

Because the analysis is assumed to take place in an urban area, the option that considers the atmospheric effects of the urban area was used. Essentially, the effect of this option on the ISC calculations is to treat very stable atmospheric conditions as neutral stability and thereby account for the effect of heat losses and gains in an urban area on local atmospheric stability.

After the modeling parameters had been specified, the ISC Model was used to perform calculations for individual small boilers and space heaters, medium-sized industrial boilers, and multiple small boilers and space heaters.

4.2.2 Small Boilers and Space Heaters

Table 4-2 presents the 13 point sources analyzed in the ISC Model, which represent typical small boilers and space heaters. As the table shows, these sources include a range of boiler sizes, feed rates, and stack heights. The invariability of other stack parameters was justified by the fact that the plume rise was small compared with physical stack height. Section 3 describes the sources reviewed in determining the representative sources in Table 4-2.



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After the modeling parameters had been specified, the ISC Model was used to perform calculations for individual small boilers and space heaters, medium-sized industrial boilers, and multiple small boilers and space heaters.

4.2.2 Small Boilers and Space Heaters

Table 4-2 presents the 13 point sources analyzed in the ISC Model, which represent typical small boilers and space heaters. As the table shows, these sources include a range of boiler sizes, feed rates, and stack heights. The invariability of other stack parameters was justified by the fact that the plume rise was small compared with physical stack height. Section 3 describes the sources reviewed in determining the representative sources in Table 4-2.

TABLE 4-2. SOURCE CHARACTERISTICS FOR SINGLE AND MULTIPLE SOURCE ANALYSIS: SMALL BOILERS AND SPACE HEATERS

Source identification number[a]	Source type	Capacity, 10^6 Btu/h	Feed rate, liters/h	Feed rate, gal/h	Stack height, m	Stack diameter, m	Stack gas temperature, K	Stack gas velocity, m/s
1	Boiler	0.7	19	5	5	0.5	420	0.5
2	Boiler	0.7	19	5	10	0.5	420	0.5
3	Boiler	2.1	57	15	10	0.6	420	1.2
4	Boiler	2.1	57	15	15	0.6	420	1.2
5	Boiler	2.1	57	15	20	0.6	420	1.2
6	Boiler	5.0	132	35	10	0.6	470	2.0
7	Boiler	5.0	132	35	15	0.6	470	2.0
8	Boiler	5.0	132	35	20	0.6	470	2.0
9	Boiler	9.3	246	65	10	0.6	520	4.5
10	Boiler	9.3	246	65	15	0.6	520	4.5
11	Boiler	9.3	246	65	20	0.6	520	4.5
12	Space heater	0.1	4	1	2	0.2	625	1.8
13	Space heater	0.1	4	1	5	0.2	625	1.8

[a] For identification in the ISC Model.

Emissions for the small boilers and space heaters were based on several factors:

- Only contaminants with a threshold reponse were considered in the single source analysis.
- Contaminant concentrations in the waste oil were assumed to be 90th percentile contaminant levels.
- January boiler usage was assumed to be at 50 percent of capacity for small boilers[6] and 100 percent of capacity for space heaters.
- Feed rates were assumed to be 4, 19, 57, 132, and 246 liters/hour at 100 percent boiler capacity. In all modeling, however, emission calculations are based on 50 percent boiler capacity, so actual feed rates are half of these values.
- Assumed emission rates of heavy metals were as follows:
    - Small boilers: 75 percent of input (50 percent of input for barium and lead)
    - Space heaters, atomizing: 5 to 95 percent of input.
- Organic emission rates
    - Small boilers and space heaters: 3 percent of input (i.e., 97% destruction removal efficiency)

Table 4-3 lists the emission factors used throughout the small boiler and space heater modeling analyses.

The results of modeling waste oil contaminants from individual small boilers and space heaters (described in Table 4-2) are presented in Table 4-4. The concentrations shown represent the maximum estimated for each single source case. These estimated concentrations are compared with the Environmental Exposure Limit (EEL) or National Ambient Air Quality Standard (NAAQS) for each contaminant. (The EEL's are described more fully in Section 5.) The comparison with the EEL's indicates that barium,

TABLE 4-3. CONTAMINANT EMISSION RATES USED IN ISC MODELING ANALYSIS: SMALL BOILERS AND SPACE HEATERS

Contaminant with threshold level, EEL[a]	Concentration in waste oil, ppm	Boiler capacity, 10^6 Btu/h	Source waste oil burn rates, liters/h	Contaminant input, µg/s	Emissions at 100% capacity, µg/s	Emissions in January at 50% capacity, µg/s
Barium	485[b]	0.1	4	512	384.	[c]
		0.7	19	2,560	1,920.	960.
		2.1	57	7,680	5,760.	2,880.
		5.0	132	17,900	13,400.	6,700.
		9.3	246	33,100	24,800.	12,400.
Cadmium	4[b]	0.1	4	4.21	3.16	[c]
		0.7	19	21.1	15.8	7.9
		2.1	57	63.3	47.5	23.8
		5.0	132	147.	110.	55.0
		9.3	246	273.	205.	103.
Chromium	28[b]	0.1	4	30.0	22.5	[c]
		0.7	19	148.	111.	55.5
		2.1	57	443	332.	166.
		5.0	132	1,031	773.	387.
		9.3	246	1,910	1,430.	715.
Lead	1000[b]	0.1	4	1,055	791.	[c]
		0.7	19	5,280	3,950.	1,980.
		2.1	57	15,800	11,900.	5,930.
		5.0	132	36,600	27,500.	13,750.
		9.3	246	68,400	51,300.	25,600.
Zinc	1150[b]	0.1	4	1,210	910.	[c]
		0.7	19	6,070	4,550.	2,275.
		2.1	57	18,200	13,700.	6,850.
		5.0	132	42,200	31,700.	15,850.
		9.3	246	78,600	59,000.	29,500.
Toluene[d]	1200	0.1	4	1,270	38.	[c]
		0.7	19	6,340	190.	95.
		2.1	57	19,000	570.	285.
		5.0	132	43,900	1,320.	666.
		9.3	246	82,000	2,460.	1,235.
1,1,1-Trichloroethane[d]	1300	0.1	4	1,370	41.1	[c]
		0.7	19	6,860	206.	103.
		2.1	57	20,590	618.	309.
		5.0	132	47,570	1,427.	721.
		9.3	246	88,530	2,856.	1,339.
Chlorinated organics[e]	6150	0.1	4	6,470	6,470.	[c]
		0.7	19	32,335	32,335.	16,170.
		2.1	57	97,000	97,000.	48,500.
		5.0	132	226,320	226,320.	113,160.
		9.3	246	420,250	420,250.	210,125.
Naphthalene[d]	580	0.1	4	610	18.3	[c]
		0.7	19	3,050	92.	45.9
		2.1	57	9,150	274.	137.
		5.0	132	21,350	640.	321.
		9.3	246	39,650	1,190.	595.

[a] See Environmental Exposure Level discussion.

[b] Weight per volume; metal emissions are assumed to equal 75% of input emissions.

[c] Space heaters only modeled at 100% capacity level for the January analysis.

[d] Destruction efficiency is assumed to be equal to 97%.

[e] Weight per volume; HCl emissions are assumed equal to 100% of input chlorinated organic levels.

TABLE 4-4. AMBIENT AIR IMPACT FROM COMBUSTION OF WASTE OIL CONTAINING CONTAMINANTS WITH A THRESHOLD RESPONSE IN INDIVIDUAL BOILERS AND SPACE HEATERS SMALLER THAN 15 x 10^6 Btu/h

	Maximum 30-day concentrations, μg/m³														
	Source number[a]														
Substance	1	2	3	4	5	6	7	8	9[d]	10	11	12	13	EEL,[b] μg/m³	Maximum percentage of EEL[b,c]
Barium	0.061	0.017	0.041	0.018	0.009	0.080	0.036	0.020	0.098	0.050	0.029	0.043	0.024	0.43	23[e]
Cadmium	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.34	<1
Chromium	0.004	0.001	0.002	0.001	0.001	0.005	0.002	0.001	0.006	0.003	0.002	0.003	0.001	4.32	<1
Lead	0.126	0.034	0.085	0.036	0.019	0.164	0.074	0.040	0.203	0.103	0.060	0.089	0.051	1.5	14[e]
Zinc	0.145	0.040	0.098	0.042	0.022	0.189	0.086	0.046	0.233	0.118	0.069	0.103	0.058	43.2	<1
Toluene[f]	0.006	0.001	0.005	0.001	<0.001	0.008	0.004	0.001	0.009	0.005	0.004	0.005	0.002	3240.	<1
Trichloroethane[f]	0.006	0.001	0.005	0.001	<0.001	0.009	0.004	0.001	0.010	0.005	0.004	0.005	0.002	16420.	<1
Hydrogen chloride	1.03	0.28	0.69	0.30	0.16	1.35	0.62	0.33	1.66	0.84	0.49	0.73	0.41	59.7	3
Napthalene[f]	0.003	< 0.001	0.002	< 0.001	< 0.001	0.003	0.002	0.001	0.004	0.003	0.002	0.002	0.001	432.	<1

[a] Identification in the ISC Model.

[b] Environmental Exposure Limits.

[c] The maximum pollutant concentration of the 13 sources is considered.

[d] Source giving maximum concentrations.

[e] At 50% emission, the maximum equals: barium - 0.065 μg/m³ and 15% of EEL; lead - 0.135 μg/m³, 9% of NAAQS.

[f] Destruction efficiency of 97% is assumed.

lead, and chlorinated organics are the major contaminants of concern; they contribute 23, 14, and 14 percent, respectively, of the EEL's at the worst-case receptors. At a rate of 50 percent of input, emissions levels of barium and lead drop to 15 and 9 percent of their respective EEL's. The impact of the other contaminants on the ambient air quality was no greater than 1 percent of their respective EEL's. Maximum concentrations were due to sources with the high emission rates (feed rates of 246 liters/h) and sources with 10-meter stack heights (Source No. 9). For each set of boilers or space heaters, the maximum concentration occurred with the lowest stack height.

Figures 4-2 and 4-3 present the isopleths of lead concentrations for two scenarios to illustrate how the maximum concentration and the overall concentration distribution depend on stack height and final plume height. Figure 4-2 shows that the maximum impact of a boiler with a feed rate of 19 liters/h and a 5-meter stack is within 200 meters east of the stack, primarily downwind of the predominant wind directions. Figure 4-3 indicates that with a taller stack (10 m) and slightly higher plume rise the impact is farther downwind (200 to 400 meters east of the source). Although the maximum concentration occurs farther downwind as stack height increases, the concentration does not necessarily decrease with distance because the larger boilers with the taller stacks also generate more emissions. In this and all subsequent tables, reported concentrations represent the maximum 30-day averages at the highest receptor for each case.

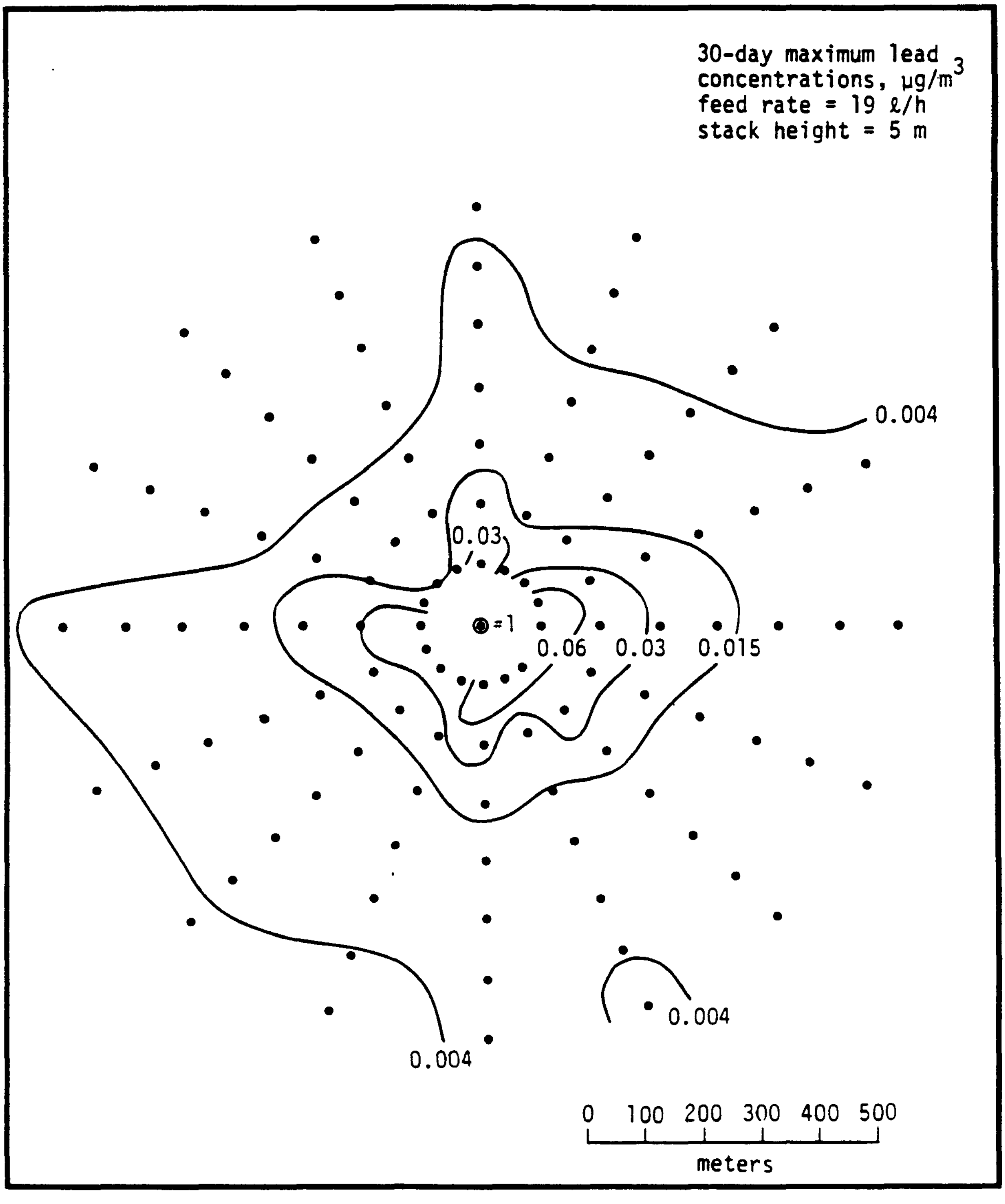


Figure 4-2. Isopleths of lead concentration over a 30-day averaging period for a 19 ℓ/h (5 gal/h) small boiler.

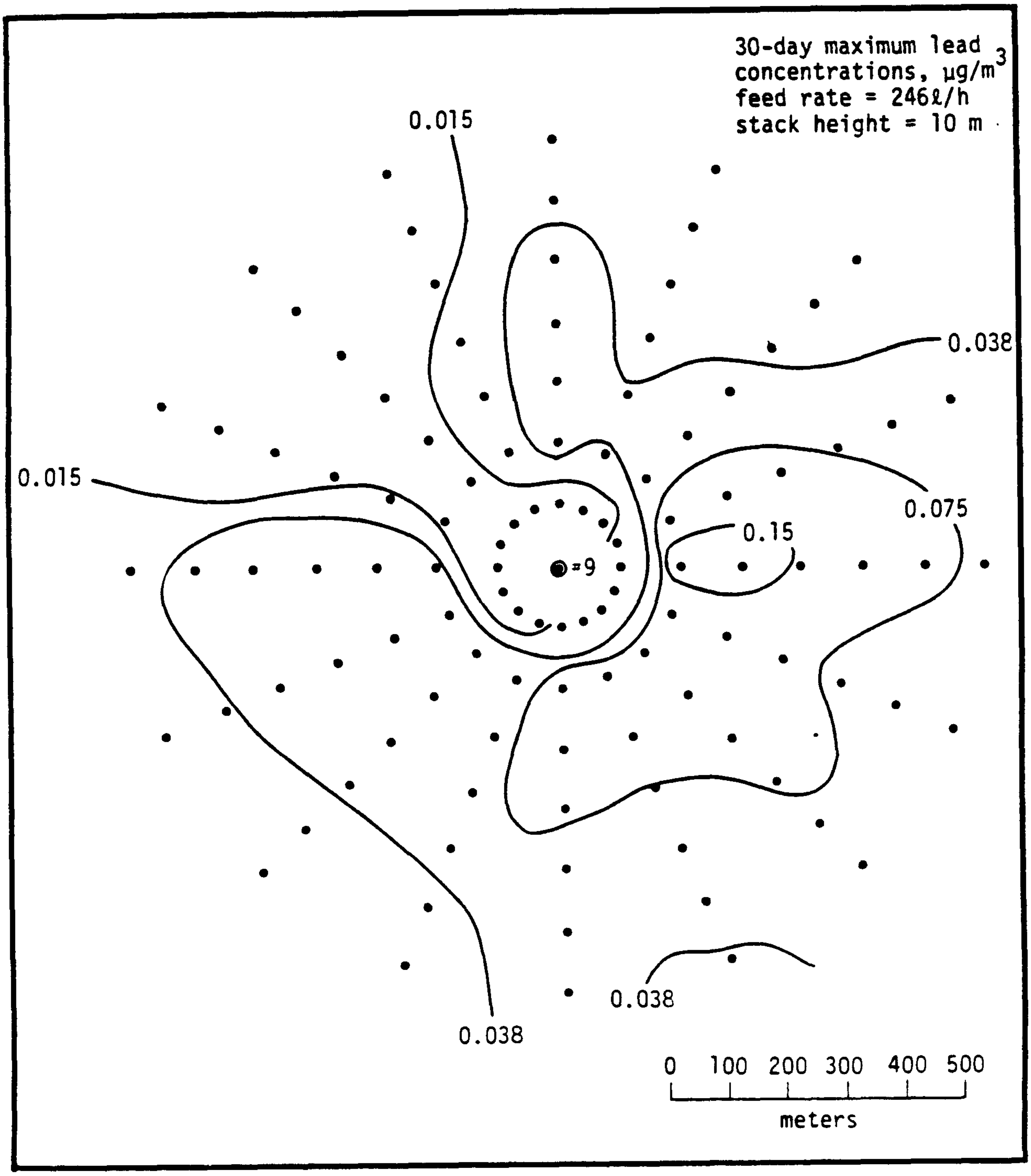


Figure 4-3. Isopleths of lead concentration over a 30-day averaging period for a 246 ℓ/h (65 gal/h) small boiler.

For determination of the levels of waste oil contaminants that would produce no significant impact at any individual source (here defined as a waste oil concentration resulting in ambient concentrations less than some specified percentage of the EEL), concentrations were estimated at variable waste oil levels of barium, lead, and chlorinated organics. Tables 4-5, 4-6, and 4-7 present these estimates for barium, lead, and hydrogen chloride, respectively. Table 4-5 shows that waste oil containing 50 ppm of barium produces ambient air concentrations at or below 3 percent of the EEL; at 10 ppm, concentrations fall below 1 percent. Table 4-6 shows that waste oil containing 100 ppm of lead produces ambient air concentrations at or below 1 percent of the NAAQS. Table 4-7 shows that waste oil with 3000 ppm of chlorinated organics results in ambient air quality concentrations of hydrogen chloride at or below 1 percent of the EEL.

As described in Section 3, several types of space heaters are commonly in current use. Because the firing mechanisms of space heaters may differ from those on small boilers, the impact of total metal emissions assumed in Tables 4-4 through 4-7 could differ somewhat. In these tables, the emission rate for metal contaminants was assumed to be 75 percent of the input contaminant levels (50 percent for selected barium and lead cases). For some types of space heaters this estimate is low, but for others it is high. In the subsequent analysis (represented by Tables 4-8 through 4-10), emissions of metals due to the combustion of waste oil in space heaters varied from 5 to 95 percent.

TABLE 4-5. AMBIENT AIR IMPACT FROM THE COMBUSTION OF WASTE OIL CONTAINING VARIOUS INPUT CONCENTRATIONS OF BARIUM IN INDIVIDUAL BOILERS AND SPACE HEATERS SMALLER THAN 15 x 10^6 Btu/h

Source No.[a]	Source type	Feed rate, ℓ/h[b]	Stack height, m	Barium concentrations in waste oil feed stock, ppm									
				485[c]		200		50		25		10	
				χ,[d] μg/m^3	% EEL[e]	χ, μg/m^3	% EEL	χ, μg/m^3	% EEL	χ, μg/m^3	% EEL	χ, μg/m^3	% EEL
1	Boiler	19	5	0.061	14	0.025	6	0.006	2	0.002	1	0.001	<1
2	Boiler	19	10	0.017	4	0.007	2	0.002	<1	0.001	<1	<0.001	<1
3	Boiler	57	10	0.041	10	0.017	4	0.004	1	0.002	<1	<0.001	<1
4	Boiler	57	15	0.018	4	0.007	2	0.002	<1	0.001	<1	<0.001	<1
5	Boiler	57	20	0.009	2	0.004	<1	0.001	<1	<0.001	<1	<0.001	<1
6	Boiler	132	10	0.080	19	0.033	8	0.008	2	0.004	1	0.002	<1
7	Boiler	132	15	0.036	8	0.015	3	0.004	1	0.002	<1	<0.001	<1
8	Boiler	132	20	0.020	5	0.008	2	0.002	<1	0.001	<1	<0.001	<1
9	Boiler	246	10	0.098	23[f]	0.040	10	0.010	3	0.005	2	0.002	<1
10	Boiler	246	15	0.050	12	0.021	5	0.005	1	0.003	<1	0.001	<1
11	Boiler	246	20	0.029	7	0.012	3	0.003	<1	0.002	<1	<0.001	<1
12	Space heater	4	2	0.043	10	0.018	4	0.005	1	0.003	<1	0.001	<1
13	Space heater	4	5	0.024	6	0.010	2	0.003	<1	0.002	<1	<0.001	<1

[a] For identification in the ISC Model.

[b] 19 liters/h = 5 gal/h; 57 liters/h = 15 gal/h; 132 liters/h = 35 gal/h; 246 liters/h = 65 gal/h; 4 liters/h = 1 gal/h.

[c] 90th percentile of barium concentrations in waste oil.

[d] χ = ambient concentration.

[e] Environmental Exposure Limit = 0.43 μg/m^3 for barium.

[f] At 50 percent emissions, the % EEL is 15% at 485 ppm, 7% at 200 ppm, 2% at 50 ppm, 1% at 25 ppm.

TABLE 4-6. AMBIENT AIR IMPACT FROM THE COMBUSTION OF WASTE OIL CONTAINING VARIOUS INPUT CONCENTRATIONS OF LEAD IN INDIVIDUAL BOILERS AND SPACE HEATERS SMALLER THAN 15 x 10^6 Btu/h

Source No.[a]	Source type	Feed rate, ℓ/h[b]	Stack height, m	Lead concentrations in waste oil, ppm									
				3000		1000[c]		500		100		25	
				χ,[d] $\mu g/m^3$	% NAAQS[e]	χ, $\mu g/m^3$	% NAAQS	χ, $\mu g/m^3$	% NAAQS	χ, $\mu g/m^3$	% NAAQS	χ, $\mu g/m^3$	% NAAQS
1	Boiler	19	5	0.378	25	0.126	8	0.063	4	0.013	1	0.002	<1
2	Boiler	19	10	0.103	7	0.038	2	0.019	1	0.004	<1	<0.001	<1
3	Boiler	57	10	0.254	17	0.085	6	0.042	3	0.009	1	0.002	<1
4	Boiler	57	15	0.109	7	0.036	2	0.018	1	0.004	<1	0.001	<1
5	Boiler	57	20	0.058	4	0.019	1	0.010	<1	0.002	<1	0.001	<1
6	Boiler	132	10	0.491	33	0.164	11	0.082	6	0.016	1	0.004	<1
7	Boiler	132	15	0.223	15	0.074	5	0.037	3	0.007	1	0.002	<1
8	Boiler	132	20	0.121	8	0.040	3	0.020	1	0.004	<1	0.001	<1
9	Boiler	246	10	0.608	41[f]	0.203	14	0.101	7	0.020	1	0.005	<1
10	Boiler	246	15	0.308	21	0.103	7	0.051	4	0.010	1	0.002	<1
11	Boiler	246	20	0.179	12	0.050	4	0.029	2	0.006	<1	0.001	<1
12	Space heater	4	2	0.267	18	0.089	6	0.044	3	0.009	1	0.002	<1
13	Space heater	4	5	0.152	10	0.051	3	0.026	2	0.005	<1	0.001	<1

[a] For identification in the ISC Model.

[b] 19 liters/h = 5 gal/h; 57 liters/h = 15 gal/h; 132 liters/h = 35 gal/h; 246 liters/h = 65 gal/h; 4 liters/h = 1 gal/h.

[c] Most representative in terms of recent measurements and estimates of lead in waste oil; 90th percentile.

[d] χ= ambient concentration.

[e] NAAQS = 1.5 $\mu g/m^3$ for lead.

[f] At 50 percent emissions, the % of NAAQS is 27% at 3000 ppm, 9% at 1000 ppm, 5% at 500 ppm, 1% at 100 ppm, <1% at 25 ppm.

TABLE 4-7. AMBIENT AIR IMPACT OF HCl FROM THE COMBUSTION OF WASTE OIL CONTAINING VARIOUS INPUT CONCENTRATIONS OF CHLORINATED ORGANICS IN INDIVIDUAL BOILERS AND SPACE HEATERS SMALLER THAN 15 x 10^6 Btu/h

Source No.[a]	Source type	Feed rate, ℓ/h[b]	Stack height, m	Chlorinated organic concentrations (ppm) in waste oil									
				30,000		10,000		6,150[c]		3,000		1,000	
				χ,[d] μg/m^3	% EEL[e]	χ, μg/m^3	% EEL	χ, μg/m^3	% EEL	χ, μg/m^3	% EEL	χ, μg/m^3	% EEL
1	Boiler	19	5	5.03	8	1.68	3	1.03	2	0.51	1	0.17	<1
2	Boiler	19	10	1.39	2	0.46	1	0.29	<1	0.14	<1	0.05	<1
3	Boiler	57	10	3.38	6	1.13	2	0.70	1	0.34	1	0.11	<1
4	Boiler	57	15	1.45	2	0.48	1	0.30	<1	0.15	<1	0.05	<1
5	Boiler	57	20	0.76	1	0.25	<1	0.15	<1	0.08	<1	0.03	<1
6	Boiler	132	10	6.58	11	2.19	4	1.34	2	0.66	1	0.22	1
7	Boiler	132	15	3.00	5	1.00	2	0.61	1	0.30	1	0.10	<1
8	Boiler	132	20	1.60	3	0.53	1	0.33	<1	0.16	<1	0.05	<1
9	Boiler	246	10	8.10	14	2.70	4	1.66	3	0.81	1	0.27	1
10	Boiler	246	15	4.10	7	1.37	2	0.84	1	0.41	1	0.14	<1
11	Boiler	246	20	2.40	4	0.80	1	0.49	<1	0.24	<1	0.08	<1
12	Space heater	4	2	3.57	6	1.19	2	0.73	1	0.36	1	0.12	<1
13	Space heater	4	2	2.01	3	0.67	1	0.41	<1	0.20	<1	0.07	<1

[a] For identification in the ISC Model.

[b] 19 liters/h = 5 gal/h; 57 liters/h = 15 gal/h; 132 liters/h = 35 gal/h; 246 liters/h = 65 gal/h; 4 liters/h = 1 gal/h.

[c] 90th percentile concentration.

[d] χ = ambient concentrations of HCl.

[e] Environmental Exposure Limit = 59.7 μg/m^3 for HCl.

TABLE 4-8. AMBIENT AIR IMPACTS FROM THE COMBUSTION OF WASTE OIL CONTAINING VARIOUS INPUT RATES OF METAL CONTAMINANTS IN SPACE HEATERS

Maximum 30-day average concentrations, µg/m³

	Percentage of waste oil contaminants emitted									
	5%		15%		25%		35%		45%	
	Stack ht., m[a]		Stack ht., m[a]		Stack ht., m[a]		Stack ht., m[a]		Stack ht., m[a]	
Pollutant	2	5	2	5	2	5	2	5	2	5
Barium	0.003	0.002	0.009	0.005	0.014	0.008	0.020	0.011	0.026	0.014
Cadmium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium	<0.003	<0.001	<0.004	<0.001	0.001	<0.001	0.002	<0.001	0.002	<0.001
Lead	0.006	0.003	0.018	0.010	0.030	0.017	0.042	0.024	0.054	0.030
Zinc	0.007	0.004	0.021	0.012	0.034	0.019	0.048	0.027	0.062	0.035

Maximum 30-day average concentrations, µg/m³

	Percentage of waste oil contaminants emitted									
	55%		65%		75%		85%		95%	
	Stack ht., m[a]		Stack ht., m[a]		Stack ht., m[a]		Stack ht., m[a]		Stack ht., m[a]	
Pollutant	2	5	2	5	2	5	2	5	2	5
Barium	0.031	0.017	0.037	0.021	0.043	0.024	0.049	0.027	0.054	0.030
Cadmium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium	0.002	<0.001	0.003	<0.001	0.003	0.001	0.003	0.001	0.004	0.001
Lead	0.065	0.037	0.077	0.044	0.089	0.051	0.101	0.057	0.113	0.064
Zinc	0.075	0.042	0.089	0.050	0.103	0.058	0.117	0.066	0.130	0.073

[a] These sources have stack characteristics corresponding to Sources 12 and 13 in previous tables.

TABLE 4-9. AMBIENT AIR IMPACT FROM THE COMBUSTION OF WASTE OIL CONTAINING VARIOUS INPUT CONCENTRATIONS OF BARIUM IN INDIVIDUAL SPACE HEATERS

Percent of metals emitted	Feed rate, ℓ/h	Stack height, m	Barium concentrations in waste oil feed stock, ppm									
			485[a]		200		100		25		10	
			χ, μg/m³	% EEL	χ, μg/m³	% EEL	χ, μg/m³	% EEL	χ, μg/m³	% EEL	χ, μg/m³	% EEL
5	4	2	0.003	<1	0.001	<1	<0.001	<1	<0.001	<1	<0.001	<1
5	4	5	0.002	<1	<0.001	<1	<0.001	<1	<0.001	<1	<0.001	<1
15	4	2	0.009	2	0.004	<1	0.002	<1	<0.001	<1	<0.001	<1
15	4	5	0.005	1	0.002	<1	0.001	<1	<0.001	<1	<0.001	<1
75	4	2	0.043	10	0.018	4	0.009	2	0.002	<1	<0.001	<1
75	4	5	0.024	6	0.010	2	0.005	1	0.001	<1	<0.001	<1
95	4	2	0.054	13[c]	0.022	5	0.011	3	0.003	<1	0.001	<1
95	4	5	0.030	7	0.012	3	0.006	1	0.002	<1	<0.001	<1

[a] Most representative in terms of recent measurements and estimates of barium in waste oil; 90th percentile.

[b] EEL = Environmental Exposure Limit.

[c] At 50 percent emissions, the % EEL at each contaminant level is: 485 ppm - 9%; 200 ppm - 3%; 100 ppm - 2% 25 ppm - <1%; 10 ppm - <1 ppm.

TABLE 4-10. AMBIENT AIR IMPACT FROM COMBUSTION OF WASTE OIL CONTAINING VARIOUS INPUT CONCENTRATIONS OF LEAD IN INDIVIDUAL SPACE HEATERS

Percent of metals emitted	Feed rate, gal/h	Stack height, m	Lead concentrations (ppm) in waste oil feed stock									
			3000		1000[a]		500		100		25	
			χ,[b] μg/m³	% NAAQS[c]	χ, μg/m³	% NAAQS	χ, μg/m³	% NAAQS	χ, μg/m³	% NAAQS	χ, μg/m³	% NAAQS
5	4	2	0.018	1	0.006	<1	0.003	<1	<0.001	<1	<0.001	<1
5	4	5	0.010	1	0.003	<1	0.002	<1	0.001	<1	<0.001	<1
15	4	2	0.054	4	0.018	1	0.009	<1	0.002	<1	<0.001	<1
15	4	5	0.030	2	0.010	1	0.005	<1	0.001	<1	<0.001	<1
75	4	2	0.267	18	0.089	6	0.044	3	0.009	1	0.002	<1
75	4	5	0.152	10	0.051	3	0.026	2	0.005	<1	0.001	<1
95	4	2	0.339	23[d]	0.113	8	0.057	4	0.011	1	0.003	<1
95	4	5	0.192	13	0.064	4	0.032	2	0.006	<1	0.002	<1

[a] Most representative in terms of recent measurements and estimates of lead in waste oil; 90th percentile.

[b] χ = ambient concentration of barium.

[c] NAAQS = 1.5 μg/m³ for lead.

[d] At 50 percent emissions, the % of NAAQS is 15% at 3000 ppm, 5% at 1000 ppm, 3% at 500 ppm, <1% at 100 ppm, <1% at 25 ppm.

Emissions of all threshold organic contaminants were assumed to be at the same levels as in the previous analysis, and thus were not remodeled.

Table 4-8 presents the dispersion modeling results for space heaters at varying emission levels. Two stack heights were modeled at each emission level. All other source characteristics were the same as those presented in Table 4-2. Modeling indicated that the maximum concentrations are found in emissions at the 95 percent level from the 2-meter stack height. Barium and lead had the greatest impacts on ambient air.

As a test of the sensitivity of air quality concentrations, alternative contaminant levels were estimated for barium and lead at selected emission rates (5, 15, 75, and 95 percent of input). Tables 4-9 and 4-10 present these results. As shown in Table 4-9, at levels of 100 ppm in waste oil feedstock, levels of barium in the ambient air concentrations fell to 3 percent or less of the EEL. Table 4-10 shows that the ambient concentrations of lead due to waste oil combustion in space heaters fell below 1 percent of the NAAQS of 1.5 $\mu g/m^3$ at a feedstock input of about 100 ppm. The 3000-ppm level was included to give an indication of the impact at high levels of lead in waste oil.

4.2.3 Multiple Small Sources

Except for barium and lead, ambient air impacts from the burning of waste oil in individual small boilers and space heaters were minimal compared with the EEL's. Because these sources are proximate to one another and have an additive ambient air impact, an entire urban area was modeled to assess the impact of multiple sources. The results of this modeling are discussed later (Section 4.3).

A limited group of multiple point sources was also modeled to ascertain the combined-source impact of the individual short-range maximum impacts of multiple point sources. Three groups of multiple point sources were selected from the 13 small boiler and space heater sources listed in Table 4-2. Each group consisted of four identical sources spaced at equal distances of 50 m apart, with one source located at each corner of a square. A receptor grid (similar to that in the single source analysis) was used, along with all other inputs specified in the single source analysis. The three source groups modeled were as follows:

Group 1: Four boilers with feed rates of 19 liters/h and 5-m stacks
Group 2: Four boilers with feed rates of 246 liters/h and 10-m stacks
Group 3: Four space heaters with feed rates of 4 liters/h and 2-m stacks

The metal contaminants were modeled at the 75 percent emission level for Groups 1 and 2 and at the 95 percent level for Group 3. The organics were modeled at the 3 percent emission level (97 percent destruction removal efficiency), and HCl was modeled at 100 percent emissions.

The results of this limited analysis showed that the combined-source impacts due to a group of small sources were greater than those from an individual source. This result was not unexpected because of the overlap of emission plumes in the atmosphere and the subsequent combined downwind impacts. Table 4-11 shows the concentration estimates for the three groups of sources modeled. In each case, the combined impact of the four boilers with the feed rate of 246 liters/h was greatest. For barium and lead, the combined impacts yielded concentration estimates that represented a significant percentage of the applicable EEL's. Maximum hydrogen chloride levels are 10 percent of the EEL. For all other contaminants with a threshold response, concentrations were less than 2 percent of the EEL.

Tables 4-12, 4-13, and 4-14 present estimates of ambient concentrations for each group of sources at various waste oil contaminant levels. At a barium level of 25 ppm, the combined source impact falls to 4 percent or less of the EEL. Similarly, at a lead level of 100 ppm, combined-source ambient concentrations are 5 percent or less of the NAAQS. At HCl levels of 1000 ppm, the combined-source concentration is 1 percent or less of the applicable EEL.

As would be expected, combined-source impacts can be minimized for any contaminant by reducing the level of that contaminant in the waste oil feed stock. The limited multiple-source modeling performed here, however, shows the impact of only four sources. Additional modeling of lead emissions from waste oil combustion was performed for 16 boilers located on a 50-m grid spacing over a 150-m by 150-m square. Estimates were made for 16 small boilers with feed rates of 19 liters/h and 16 small boilers with feed rates of 246 liters/h. This source configuration and the resulting estimates of ambient lead concentration

TABLE 4-11. AMBIENT AIR IMPACTS FROM MULTIPLE-SOURCE COMBUSTION OF WASTE OIL CONTAINING CONTAMINANTS WITH A THRESHOLD RESPONSE

Pollutant	Maximum 30-day concentrations, µg/m³ Source group number Group 1[a]	Group 2[b]	Group 3[c]	EEL concentration, µg/m³	Maximum percentage of EEL
Barium	0.1484	0.3424	0.0958	0.43	80[d]
Cadmium	0.0012	0.0028	0.0008	0.34	<1
Chromium	0.0086	0.0197	0.0056	4.32	<1
Lead	0.3059	0.7078	0.1975	1.5	47[e]
Zinc	0.3517	0.8145	0.2271	43.2	2
Toluene	0.0148	0.0341	0.0095	3,240.	<1
Trichloroethane	0.0159	0.0370	0.0102	16,420.	<1
Hydrogen chloride	2.50	5.80	1.61	59.7	10
Naphthalene	0.007	0.017	0.004	432.	<1

[a] Group 1 consists of four boilers with a feed rate of 5 gal/h and a 5-m stack height.

[b] Group 2 consists of four boilers with a feed rate of 65 gal/h and a 10-m stack height.

[c] Group 3 consists of four space heaters with a feed rate of 1 gal/h and a 2-m stack height.

[d] At 50 percent emissions, Group 2 yields 0.2283 µg/m^3 and 53% of the EEL for barium.

[e] At 50 percent emissions, Group 2 yields 0.4119 µg/m^3 and 31% of the EEL for lead.

TABLE 4-12. AMBIENT AIR IMPACTS FROM MULTIPLE SOURCE COMBUSTION OF WASTE OIL CONTAINING BARIUM AT VARIOUS INPUT CONCENTRATIONS

Source group No.	Barium concentrations in waste oil feed stock, ppm									
	485		200		50		25		10	
	χ,[d] µg/m^3	% EEL[e]	χ, µg/m^3	% EEL	χ, µg/m^3	% EEL	χ, µg/m^3	% EEL	χ, µg/m^3	% EEL
1[a]	0.148	35	0.061	14	0.015	4	0.008	2	0.003	<1
2[b]	0.342	80[f]	0.141	33	0.035	8	0.018	4	0.007	2
3[c]	0.076	18	0.031	7	0.008	2	0.004	1	0.002	<1

[a] Four boilers with a feed rate of 5 gal/h and 5-m stack heights.

[b] Four boilers with a feed rate of 65 gal/h and 10-m stack heights.

[c] Four space heaters with a feed rate of 1 gal/h and 2-m stack heights.

[d] Ambient air concentration of barium.

[e] Environmental Exposure Limit = 0.43 µg/m^3 for barium.

[f] At 50 percent emissions, the % EEL is 53% at 485 ppm, 22% at 200 ppm, 5% at 50 ppm, 3% at 25 ppm, 1% at 10 ppm.

TABLE 4-13. AMBIENT AIR IMPACTS FROM THE COMBUSTION OF WASTE OIL CONTAINING LEAD AT VARIOUS INPUT CONCENTRATIONS IN FOUR CLUSTERED SOURCES

Source group No.	Lead concentrations in waste oil feed stock, ppm									
	3000		1000		500		100		25	
	χ,[a] $\mu g/m^3$	% NAAQS[b]	χ, $\mu g/m^3$	% NAAQS	χ, $\mu g/m^3$	% NAAQS	χ, $\mu g/m^3$	% NAAQS	χ, $\mu g/m^3$	% NAAQS
1[c]	0.918	61	0.306	20	0.153	10	0.031	2	0.008	<1
2[d,e]	2.123	142	0.708	47	0.359	24	0.072	5	0.018	1
3[f]	0.468	31	0.156	10	0.078	5	0.016	1	0.004	<1

[a] Ambient air concentrations of lead.

[b] NAAQS = 1.5 $\mu g/m^3$ for lead

[c] Four boilers with feed rates of 5 gal/h and 5-m stack heights.

[d] Four boilers with feed rates of 65 gal/h and 10m stack heights.

[e] Assuming 50 percent of the lead is emitted, waste oil with 3000 ppm lead results in ambient air concentrations that are 95% of the NAAQS; for 1000 ppm, the result is 31% of the standard; for 500 ppm, the results 16% of the standard; for 100 ppm, the result is 3% of the standard; and for 25 ppm, the ambient air concentration is less than 1% of the NAAQS.

[f] Four space heaters with feed rates of 1 gal/h and 2-m stack heights.

TABLE 4-14. AMBIENT AIR IMPACTS OF HCl FROM MULTIPLE-SOURCE COMBUSTION OF WASTE OIL CONTAINING CHLORINATED ORGANICS AT VARIOUS INPUT CONCENTRATIONS

Source group No.	30,000		10,000		6,150[a]		3,000		1,000	
	χ,[b] $\mu g/m^3$	% EEL[c]	χ, $\mu g/m^3$	% EEL	χ, $\mu g/m^3$	% EEL	χ, $\mu g/m^3$	% EEL	χ, $\mu g/m^3$	% EEL
1[d]	12.19	20	4.06	7	2.44	4	1.22	2	0.41	1
2[e]	28.30	47	9.43	16	5.66	10	2.83	5	0.94	1
3[f]	7.87	13	2.66	4	1.55	3	0.78	1	0.26	<1

[a] 90th percentile concentration.

[b] χ = ambient air concentrations of HCl.

[c] Environmental Exposure Limit = 59.7 $\mu g/m^3$ for HCl.

[d] Four boilers with feed rates of 5 gal/h and 5-m stack heights.

[e] Four boilers with feed rates of 65 gal/h and 10-m stack heights.

[f] Four boilers with feed rates of 1 gal/h and 2-m stack heights.

are representative of several boilers located near one another, such as in a large apartment complex or a small industrial area.

Ambient air impacts of lead are presented in Table 4-15. At the 25-ppm input level, lead concentrations from the 19-liter/h sources are at or below 1 percent of the NAAQS. At the 5-ppm input level, lead concentrations in emissions from the 246-liter/h boilers are estimated to be below 1 percent of the NAAQS.

4.2.4 Medium-Size Boilers

Some waste oil burning also occurs in boilers with capacities of 50 to 100 x 10^6 Btu/h (in larger commercial/institutional or residential applications). For determination of the ambient air quality impact of burning 100 percent waste oil in these medium-size boilers, the meteorological data, model options, and the modeling receptor grid were the same as those for the small boiler analysis. Typical stack characteristics for these boilers were obtained by reviewing boiler population studies[7] and selecting representative values.

Table 4-16 presents the source characteristics chosen for analysis and the appropriate stack parameters. Concentrations of the contaminants eliciting a threshold response were based on the 90th percentile levels in waste oil. Emissions resulting from the burning of waste oil in these medium-size boilers are presented in Table 4-17. Because these boilers were assumed to be used primarily for heating, a load factor of 50 percent for January modeling applications was also assumed.

TABLE 4-15. AMBIENT AIR IMPACTS FROM SIXTEEN CLUSTERED SOURCES BURNING WASTE OIL CONTAINING LEAD AT VARIOUS INPUT CONCENTRATIONS

Concentration of lead in waste oil, ppm	Source group number			
	1[a]		2[b]	
	χ,[c] μg/m³	Percent NAAQS	χ,[c] μg/m³	Percent NAAQS
1000	0.755[d]	50	2.392[e]	159
500	0.378	25	1.196	80
250	0.189	13	0.598	40
100	0.076	5	0.239	15
75	0.057	4	0.179	12
50	0.057	3	0.120	8
25	0.019	1	0.060	4
10	0.008	<1	0.024	2
5	0.004	<1	0.012	<1

[a] Sixteen 5-gal/h boilers with 5-m stack heights on a 50-m grid spacing.

[b] Sixteen 65-gal/h boilers with 10-m stack heights on a 50-m grid spacing.

[c] Ambient concentrations of lead averaged over a 30-day period.

[d] Emission rate from a 5-gal/h boiler is 1,980 μg/s at 1000 ppm lead in waste oil.

[e] Emission rate from a 65-gal/h boiler is 25,680 μg/s at 1000 ppm lead in waste oil.

TABLE 4-16. SOURCE CHARACTERISTICS FOR SINGLE SOURCE ANALYSIS: MEDIUM-SIZE BOILERS

Source identification number[a]	Capacity, 10^6 Btu/h	Feed rate,[a] liters/h	Stack height, m	Stack diameter, m	Stack gas temperature, K	Stack gas velocity, m/s
14	50	1330	10	0.7	450	18.3
15	50	1330	15	0.7	450	18.3
16	50	1330	20	0.7	450	18.3
17	100	2660	20	1.0	450	18.3
18	100	2660	25	1.0	450	18.3
19	100	2660	30	1.0	450	18.3

[a] 1330 liters/h = 350 gal/h; 2660 liters/h = 700 gal/h.

TABLE 4-17. CONTAMINANT EMISSIONS USED IN SINGLE SOURCE ISC MODELING ANALYSIS: MEDIUM-SIZE BOILERS

Threshold contaminant	Concentration in waste oil, ppm	Source waste oil burn rates,[a] liters/h	Contaminant input, μg/s x 10^3	Emissions at 100% capacity,[b] μg/s x 10^3	Emissions in January at 50% capacity, μg/s x 10^3
Barium	485 [c]	1330 2660	178. 356.	134. 268.	67. 134.
Cadmium	4 [c]	1330 2660	1.47 2.94	1.10 2.20	0.55 1.10
Chromium	28 [c]	1330 2660	10.3 20.6	7.73 15.46	3.87 7.73
Lead	1000 [c]	1330 2660	366. 732.	275. 550.	138. 275.
Zinc	1150 [c]	1330 2660	422. 844.	317. 634.	159. 317.
Toluene	1200 [d]	1330 2660	439. 878.	13.1 26.3	6.57 13.1
1,1,1-Trichloroethane	1300 [d]	1330 2660	476. 951.	14.3 28.5	7.15 14.3
Chlorinated organics [d]	6150	1330 2660	2272. 4544.	2272. 4544.	1136. 4544.
Naphthalene	580	1330 2660	213. 426	6.40 12.8	3.18 6.40

[a] Liters/hour waste oil input (gal/hour) = 350 (700).

[b] Assume 75% of metals and 3% of organics (97% destruction rate efficiency) are emitted.

[c] Assume ppm = mg/liter.

[d] HCl emissions are assumed equal to 100% of input chlorinated organic levels.

The climatological mode of the ISC model was applied to obtain 30-day average ambient air concentrations of all contaminants with a threshold response. Table 4-18 presents the results for six medium-size boilers. Source 14 generates the maximum concentration in each case, primarily because of its low stack height. Sources 17, 18, and 19 had much higher emissions, but have a lesser ground-level impact because they have higher stacks. Figures 4-4 and 4-5 compare the ambient concentration patterns of lead from a boiler with a feed rate of 1330 liters/h and a 10-m stack with those from one with a feed rate of 2660 liters/h and a 20-m stack. Maximum concentrations for the 1330-liter/h boiler were estimated at 400 to 500 meters east of the source (Figure 4-4). Because of its higher stack, the impact of the 2660-liter/h boiler was much farther downwind, at receptors 800 to 1000 meters east and east-southeast of the source. Even at twice the lead emissions, a lower maximum ground-level concentration resulted from the larger boiler because of transport and dilution that result from release from the higher stack.

Most of the pollutants from the burning of waste oil in medium-size boilers (Table 4-17) amounted to less than 1 percent of the corresponding EEL's. The impacts of barium, lead, and HCl concentrations, however, amounted to 36, 21, and 4 percent of their respective EEL's or AAQS. The sensitivity of lower levels of lead, HCl, and barium in waste oil burned in medium-size boilers was tested by performing additional dispersion modeling. Table 4-19 (barium), Table 4-20 (lead) and Table 4-21

TABLE 4-18. AMBIENT AIR IMPACTS FROM THE COMBUSTION OF WASTE OIL CONTAINING ALL CONTAMINANTS WITH A THRESHOLD RESPONSE IN MEDIUM-SIZE BOILERS

	Maximum 30-day concentrations, $\mu g/m^3$						EEL concentration, $\mu g/m^3$	Maximum percentage of EEL
	Source number							
Substance	14[a]	15[a]	16[a]	17[b]	18[b]	19[b]		
Barium	0.153	0.102	0.071	0.087	0.067	0.053	0.43	36[c]
Cadmium	0.002	0.001	<0.001	<0.001	<0.001	<0.001	0.34	<1
Chromium	0.009	0.006	0.004	0.005	0.004	0.003	4.32	<1
Lead	0.314	0.210	0.146	0.178	0.137	0.108	1.5	21[d]
Zinc	0.361	0.242	0.168	0.205	0.158	0.124	43.2	1
Toluene	0.015	0.010	0.007	0.009	0.007	0.006	3240	<1
Trichloroethane	0.016	0.0011	0.007	0.010	0.007	0.006	16420	<1
HCl	2.58	1.73	1.20	1.47	1.13	0.89	59.7	4
Naphthalene	0.007	0.005	0.003	0.004	0.003	0.003	4320	<1

[a] 1330 liters/hour.

[b] 2660 liters/hour.

[c] At 50 percent emissions, Source 14 yields barium concentrations of 0.102 $\mu g/m^3$ and 24% of EEL.

[d] At 50 percent emissions, Source 14 yields lead concentrations of 0.209 $\mu g/m^3$ and 14% of NAAQS.

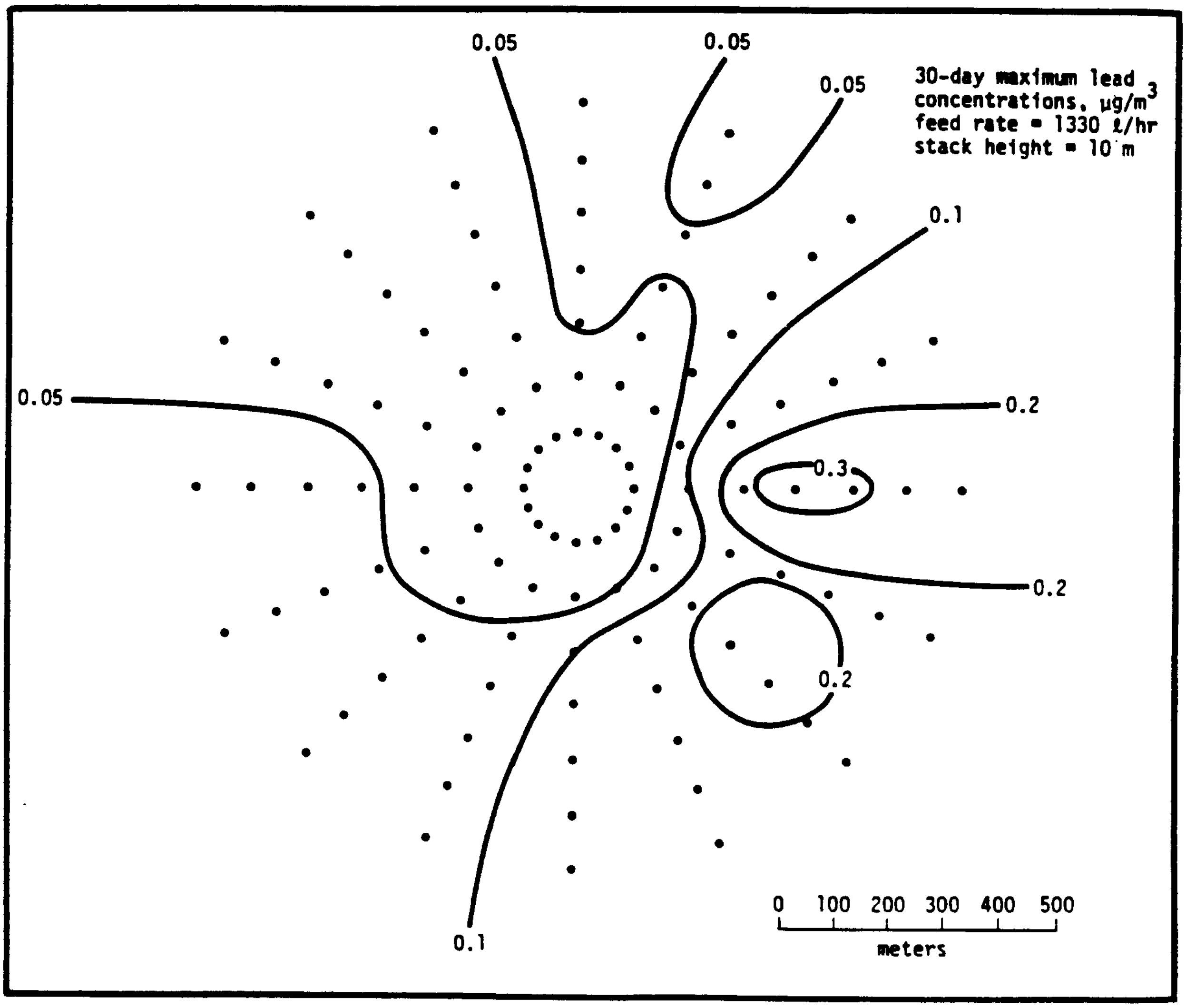


Figure 4-4. Isopleths of lead concentration over a 30-day averaging period for a 1330 ℓ/h (350 gal/h) medium boiler.

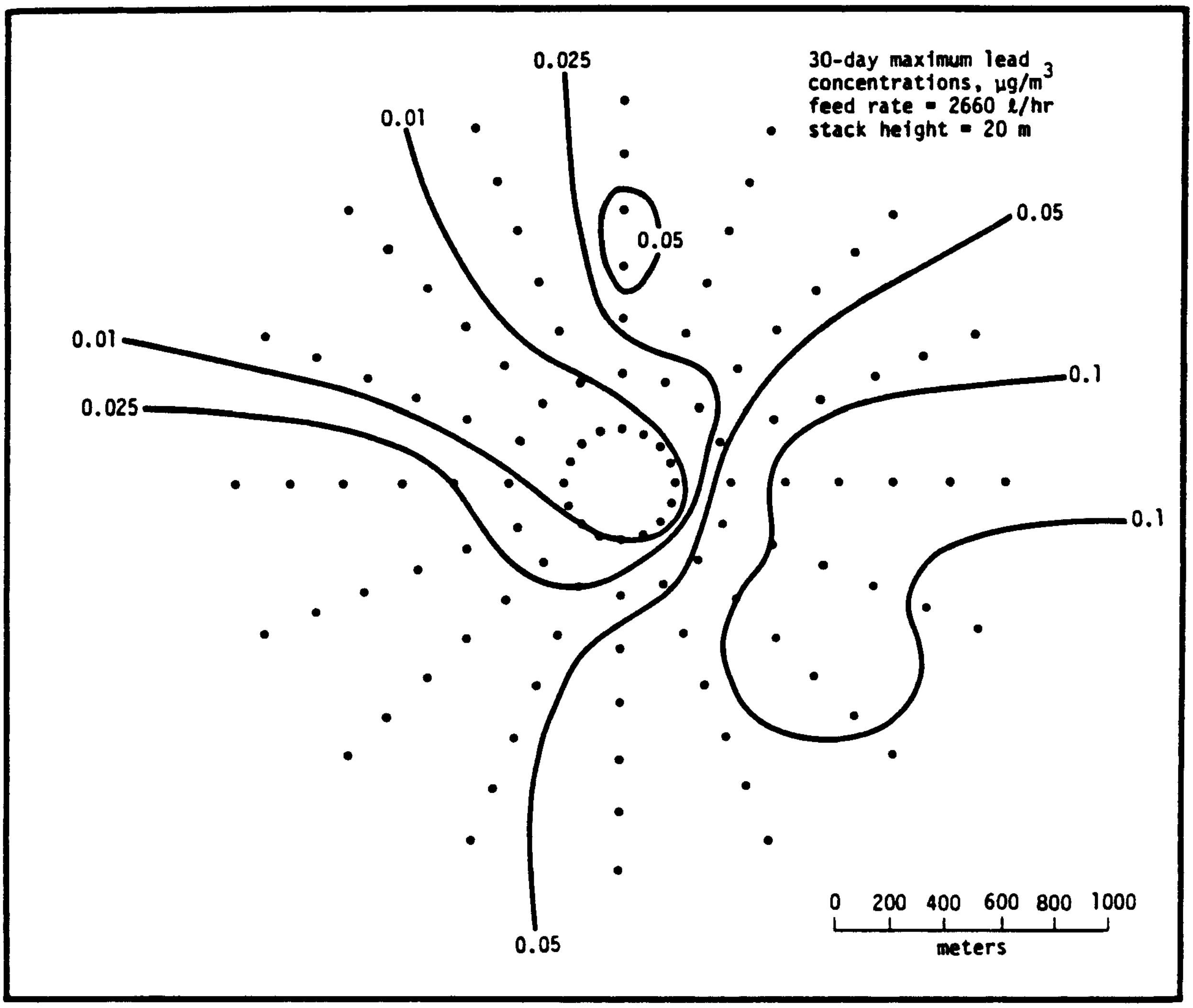


Figure 4-5. Isopleths of lead concentration over a 30-day averaging period for a 2660 ℓ/h (700 gal/h) medium boiler.

TABLE 4-19. AMBIENT AIR IMPACT FROM THE COMBUSTION OF WASTE OIL CONTAINING VARIOUS INPUT CONCENTRATIONS OF BARIUM IN MEDIUM-SIZE BOILERS

Source No.[a]	Feed rate,[b] ℓ/h	Stack height, m	Barium concentrations in waste oil, ppm									
			485[c]		200		50		25		10	
			χ,[d] μg/m^3	% EEL[e]	χ, μg/m^3	% EEL	χ, μg/m^3	% EEL	χ, μg/m^3	% EEL	χ, μg/m^3	% EEL
14	1330	10	0.153	36 [f]	0.063	15	0.016	4	0.008	2	0.003	<1
15	1330	15	0.102	24	0.042	10	0.011	3	0.006	2	0.002	<1
16	1330	20	0.071	17	0.030	7	0.008	4	0.004	1	0.002	<1
17	2660	20	0.087	20	0.036	9	0.009	2	0.005	1	0.002	<1
18	2660	25	0.067	16	0.028	7	0.007	2	0.004	1	0.002	<1
19	2660	30	0.053	12	0.022	5	0.006	2	0.003	<1	0.001	<1

[a] For identification in ISC Model.

[b] 1330 liters/h = 350 gal/h; 2660 liters/h = 700 gal/h.

[c] 90th percentile concentration.

[d] Ambient air concentrations of barium.

[e] Environmental Exposure Limit = 0.43 μg/m^3 for barium.

[f] At 50 percent emissions, the % EEL is 24% at 485 ppm, 10% at 200 ppm, 3% at 50 ppm, 2% at 25 ppm, <1% at 10 ppm - <1%.

TABLE 4-20. AMBIENT AIR IMPACT FROM THE COMBUSTION OF WASTE OIL CONTAINING VARIOUS INPUT CONCENTRATIONS OF LEAD IN MEDIUM-SIZE BOILERS

Source No.[a]	Feed rate,[b] ℓ/h	Stack height, m	Lead concentrations in waste oil, ppm									
			3000		1000[e]		500		100		25	
			χ,[c] μg/m^3	% NAAQS[d]	χ, μg/m^3	% NAAQS	χ, μg/m^3	% NAAQS	χ, μg/m^3	% NAAQS	χ, μg/m^3	% NAAQS
14	1330	10	0.94	63	0.314	21	0.157	11	0.032	2	0.008	<1
15	1330	15	0.63	42	0.210	14	0.105	7	0.021	2	0.005	<1
16	1330	20	0.437	29	0.146	10	0.073	5	0.015	1	0.004	<1
17	2660	20	0.590	36	0.178	12	0.089	6	0.018	1	0.005	<1
18	2660	25	0.411	28	0.137	9	0.069	5	0.014	1	0.004	<1
19	2660	30	0.323	21	0.108	7	0.054	4	0.011	<1	0.003	<1

[a] For identification in ISC Model.

[b] 1330 liters/h = 350 gal/h; 2660 liters/h = 700 gal/h.

[c] Ambient air concentration of lead.

[d] NAAQS = 1.5 μg/m^3 for lead.

[e] 90th percentile concentration.

TABLE 4-21. AMBIENT AIR IMPACT OF HCl FROM THE COMBUSTION OF WASTE OIL CONTAINING VARIOUS INPUT CONCENTRATIONS OF CHLORINATED ORGANICS IN MEDIUM-SIZE BOILERS

Source No.[a]	Feed rate,[b] ℓ/h	Stack height, m	Chlorinated organics concentrations in waste oil, ppm									
			30,000		10,000		6,150[c]		3,000		1,000	
			χ,[d] μg/m³	% EEL[e]	χ, μg/m³	% EEL	χ, μg/m³	% EEL	χ, μg/m³	% EEL	χ, μg/m³	% EEL
14	1330	10	12.58	21	4.16	7	2.52	4	1.26	2	0.42	1
15	1330	15	8.43	14	2.81	5	1.69	3	0.84	1	0.28	1
16	1330	20	5.86	10	1.95	3	1.17	2	0.59	1	0.20	<1
17	2660	20	7.17	12	2.39	4	1.43	2	0.72	1	0.24	<1
18	2660	25	5.52	9	1.84	3	1.10	2	0.55	1	0.18	<1
19	2660	30	4.34	7	1.45	2	0.87	1	0.43	1	0.15	<1

[a] For identification in ISC Model.

[b] 1330 liters/h = 350 gal/h; 2660 liters/h = 700 gal/h.

[c] 90th percentile concentration.

[d] Ambient air concentrations of HCl.

[e] Environmental Exposure Limit = 59.7 μg/m³ for HCl.

(HCl) indicate the change in ambient impacts at variable contaminant input levels. Barium input levels of 25 ppm decreased medium-size boiler impacts to 2 percent or less of the EEL in all six of the cases analyzed (Table 4-19). Lead input levels of 100 ppm produced ambient lead concentrations from medium-size boilers of less than 2 percent of the NAAQS (Table 4-20). A chlorinated organics input level of 1000 ppm results in medium-size boiler impacts of less than a 1 percent of the EEL for HCl (Table 4-21).

Although not necessarily indicative of every possible boiler in the 50 to 100 x 10^6 Btu/h range, this ambient air analysis demonstrates the potential impact of boilers of this size. Further detailed analyses of individual boilers is required to improve the results. In lieu of modeling every boiler that could possibly burn waste oil, this analysis provides an estimate of the impact of the important threshold contaminants of concern.

4.2.5 Lead Concentrations at Elevated Receptors

Of particular concern in this analysis is the concentration of lead at receptors at or near the stack height of small and medium-size individual and multiple sources. To obtain estimates of the maximum 30-day concentrations of lead from such sources, several source configurations were modeled with the ISC Model in its long-term mode. The sources modeled were as follows:

10^6 Btu/h:	1 source
	4 sources in a 2 x 2 grid 50 m apart
	16 sources in a 4 x 4 grid 50 m apart

10 x 10^6 Btu/h: 1 source
4 sources in a 2 x 2 grid 50 m apart
16 sources in a 4 x 4 grid 50 m apart

50 x 10^6 Btu/h: 1 source
4 sources in a 2 x 2 grid 100 m apart

Stack parameters for the 10^6 Btu/h boilers are those shown for Source 1 in Table 4-2; for the 10 x 10^6 Btu/h boilers, those for Source 9 in Table 4-2; and for the 50 x 10^6 Btu/h boilers, those for Source 14 in Table 4-16. Emissions of lead in each case are similar to those in Tables 4-3 and 4-17 at the appropriate boiler size, except in this case the concentration of lead in the feed waste oil is fixed at 250 ppm (rather than 1000 ppm), which results in lower lead emissions.

All meteorological and modeling inputs are as described in previous sections. A 200-m interval grid of receptors was used for the 50 x 10^6 Btu/h boilers and a 100-m interval grid for the 10^6 and 10 x 10^6 Btu/h boilers. Because of the source configuration, the closest source/receptor distance is generally 100 m. All receptors are located at stack heights that give the worst-case concentrations because they are very close to the plume centerlines.

Table 4-22 shows the maximum 30-day lead concentrations for the various individual and multiple-source configurations. Concentrations of lead in emissions from the small boilers (10^6 Btu/h) are all less than the NAAQS for lead (1.5 $\mu g/m^3$). In emissions from the 10 x 10^6 Btu/h boilers, however, concentrations exceed the NAAQS for the 16-source array. Lead concentrations in emissions from the medium-size boilers were less than

TABLE 4-22. AMBIENT AIR LEAD IMPACTS AT ELEVATED RECEPTORS RESULTING FROM THE COMBUSTION OF WASTE OIL CONTAINING LEAD

Boiler size, 10^6 Btu/h	Boiler configuration	Maximum 30-day concentration, μg/m^3
1	1	0.067
1	2 x 2	0.092
1	4 x 4	0.244
10	1	0.443
10	2 x 2	0.773
10	4 x 4	1.993
50	1	0.263
50	2 x 2	0.674

the NAAQS for the two cases modeled, even though emissions were greater. The lower concentrations were due primarily to higher plume rise. The 16-source array of medium-size boilers was not analyzed because of the low probability that this many 50 x 10^6 Btu/h boilers would be clustered so closely together.

4.2.6 Lead Concentrations at Close Receptors

Calculations were made to account for concentrations at receptors closer than 100 m (the minimum allowable source-receptor distance in the ISC Model). These calculations involved the use of Gaussian plume equations. The plume heights and receptor heights were equal, and the estimates were made at the plume centerline. The following equation resulted:

$$\chi = \frac{Qf}{\pi \ \sigma y \ \sigma_z u}$$

where χ = ambient concentration

Q = local emissions in μg/s at 250 ppm in the feedstock

f = frequency of occurrence of specific windspeed, wind direction, and stability class categories

σy = horizontal standard deviation of the plume

σ_z = vertical standard deviation of the plume

u = windspeed

Concentrations were estimated for a receptor 25 m downwind of a source. At this distance, the σy and σ_z parameters are 2.1 and 1.4 m, respectively, for a neutral stability class (D). A January average windspeed (see Table B-6 in Appendix B) of 5.8 m/s was used in the calculations. Because previous sections indicate the maximum concentrations to the east of the sources, the frequency of occurrence toward 67.5, 90.0, and 112.5 degrees was compiled, which yielded a combined frequency under all stability classes (D stability accounted for over 90 percent of the total) of 0.043 or 4.3 percent.

The impact of multiple sources was determined by modeling two sources separated by 50 m; i.e., the impact of the first at 25 m and the second at 75 m, to determine the combined source impact at one downwind receptor. Only two sources were modeled (in contrast to the modeling described in Section 4.2.6) because distances between receptors indicate little contribution from off-axis sources. The results of this analysis for the combustion of waste oil with a lead content of 250 ppm were single-source lead concentrations of 0.395, 5.10, and 27.5 $\mu g/m^3$ in emissions from the 1, 10, and 50 x 10^6 Btu/h boilers; and concentrations of 0.45, 5.76, and 31.0 $\mu g/m^3$ for the two-source 1, 10, and 50 x 10^6 Btu/h cases, respectively. Concentrations of lead at these close-in receptors are therefore estimated to be higher than the NAAQS for sources larger than 10^6 Btu/h.

4.2.7 Increased Organic Levels

The dispersion modeling presented so far focuses on a 90th percentile level of organic contaminants in the composite waste oil. Mixing of individual or composite organic solvents into waste oil is not uncommon, however. For an evaluation of the potential increased ambient air quality impact of single sources burning waste oil high in organic compounds, concentrations of toluene and 1,1,1-trichloroethane were increased to the 10,000-ppm level (1%) in the waste oil feed stock. These levels of contaminants were considered in further analysis of the 13 small boilers and space heaters described earlier in Table 4-2.

The results of previous analyses showed concentrations to be much less than the applicable EEL's for toluene and trichloroethane. Even at almost 10 times the original contaminant levels of 1200 and 1300 ppm for toluene and trichloroethane, respectively, the air quality impacts are insignificant. Table 4-23 presents the results of the dispersion modeling for the 13 small boilers and space heaters. In all cases, the 30-day maximum concentrations of contaminants in ambient air are much less than 1 percent of the applicable EEL. The primary reasons for the insignificant air quality impacts are the destruction efficiencies of organics in waste oil and the high threshold response concentrations required to elicit a health-related response.

4.3 URBAN-SCALE ANALYSIS WITH THE HANNA-GIFFORD MODEL

4.3.1 Overview

The urban-scale analysis examines the contaminant levels that may occur over a broad urban scale area (50 to 100 km). All modeling in this section was performed with a Hanna-Gifford model.

Based on the following constraints, a simplified modeling procedure was selected for this analysis:

- Waste oil is burned primarily in a large number of small boilers and space heaters.
- These sources are distributed evenly across an urban area.

TABLE 4-23. MAXIMUM 30-DAY CONCENTRATIONS ASSUMING 1 PERCENT LEVELS OF TWO ORGANICS IN WASTE OIL AND 97 PERCENT DESTRUCTION REMOVAL EFFICIENCIES ($\mu g/m^3$)

Source No.[a]	Concentration of waste oil contaminant	
	Toluene	1,1,1-Trichloroethane
1	0.051	0.050
2	0.014	0.013
3	0.035	0.034
4	0.015	0.015
5	0.008	0.007
6	0.066	0.066
7	0.030	0.030
8	0.016	0.016
9[b]	0.082	0.082
10	0.042	0.042
11	0.024	0.024
12	0.036	0.036
13	0.023	0.021
EEL,[c] $\mu g/m^3$	3,240	16,420
Maximum percentage of EEL	<1	<1

[a] Identification in ISC model.

[b] Source giving maximum concentrations.

[c] EEL = Environmental Exposure Limit.

- State and national inventories and summaries of sources do not contain records of small sources.

The EPA has used the Hanna-Gifford Model, which was developed by the Air Resource Atmospheric Turbulence and Diffusion Laboratory at Oak Ridge, Tennessee, for previous hazardous pollutant analyses.[8] This simple but realistic dispersion model has proved to be adequate for estimating pollutant concentrations resulting from area source emissions in urban areas. It has performed best in large urbanwide applications,[7,9,10] especially in the modeling of low-level sources that are distributed fairly evenly across such an area.

The Hanna-Gifford Model entails the use of emissions averaged over time and space rather than those from specific individual sources. The emissions due to waste oil burning were estimated over an urban study area and distributed evenly across the study grids in a manner consistent with the model requirements. Additional inputs were:

- The windspeed for the averaging time of interest.
- A specific constant calculated on the basis of study area grid size.
- The number of grids and grid size.
- Two atmospheric stability constants.

For this analysis, an urban area was selected where a large number of residential/commercial small boilers and space heaters were believed to be in use. The study area was broken into five subareas based on population density, urban-versus-rural land use, and distance from the urban core. The area selected for analysis is situated within Air Quality Control Region 43 on the eastern coastline of the United States. The study area and subareas are shown in Figure 4-6. Concentric rings at 5, 10, 15, 25, and 50 km were used to differentiate subareas for study. For this analysis, each area bounded by the concentric rings was treated as a separate calculation in the model. This approach was considered reasonable because a receptor located at some midpoint in each subarea was affected primarily by emissions in that area or those immediately adjacent.

The model was applied in an iterative fashion by first calculating the value of the constant in the model, then estimating the appropriate seasonal or annual windspeeds, and finally, estimating the subarea emissions due to waste oil burning. The concentration estimate made for each contaminant in each subarea was assumed to apply over that whole subarea. All model inputs are discussed in Appendix B.

4.3.2 Urban Emissions

Different concentric circle subareas were assigned different emission rates, depending on population, total area of subarea, and availability of waste oil for burning. The area of each subarea shown in Figure 4-6 was calculated to determine the extent over which subarea-specific emissions were distributed. The area of each subarea (bounded by the distances specified in Figure 4-6) is shown in Table 4-24.

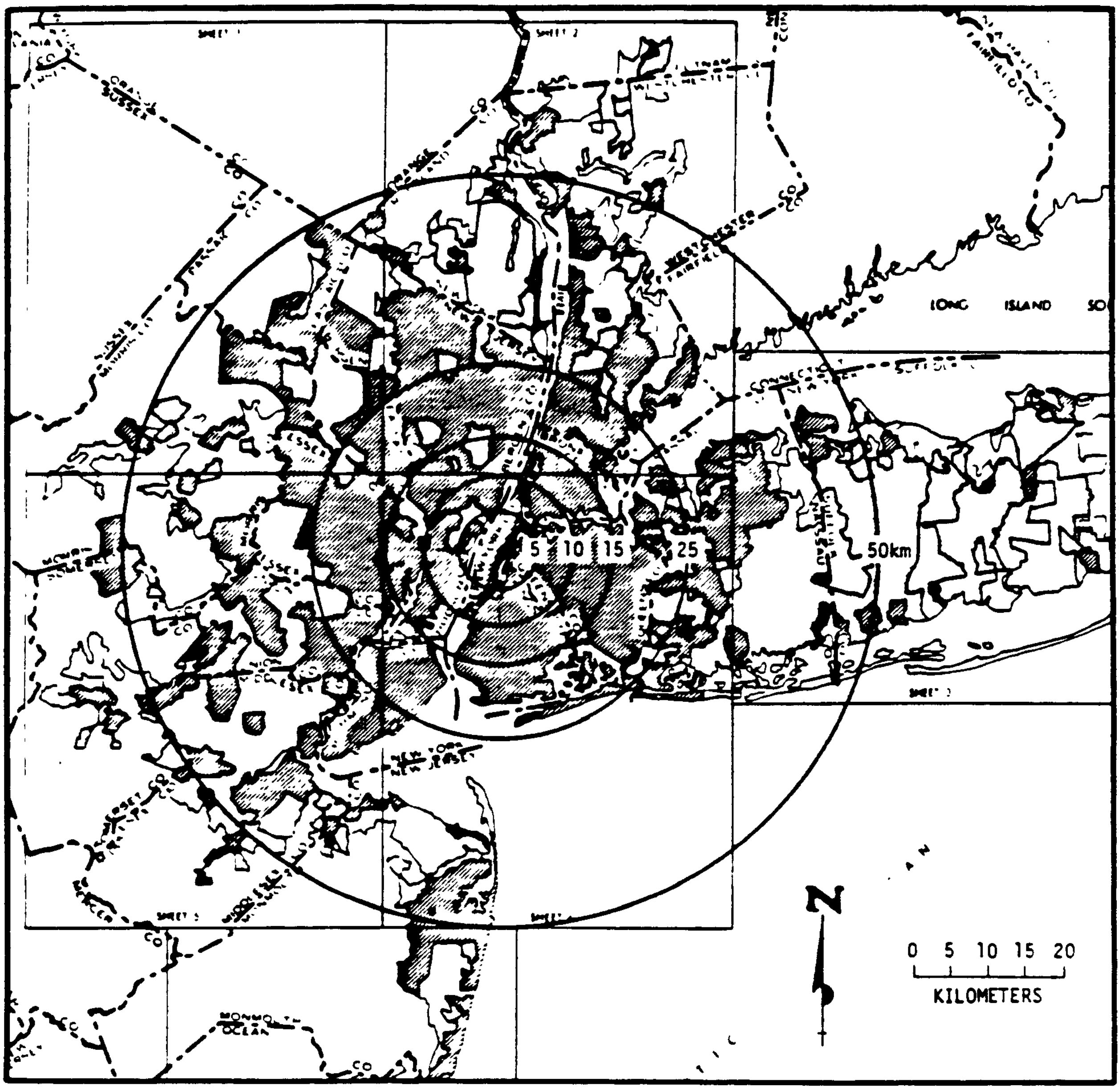


Figure 4-6. Urban area and associated study grid used in the Hanna-Gifford Model analyses.

TABLE 4-24. AREAS OF EACH STUDY SUBAREA

Distance from study area centroid, km	Area of subarea, 10^7 m^2
0-5	7.85
5-10	23.6
10-15	39.3
15-25	134.
25-50	589.

The emissions of contaminant per liter of waste oil burned were calculated and are presented in Table 4-25. These emission estimates were used together with the estimates of waste oil burned in each subarea to calculate the emission rates for each contaminant. Table 4-26 presents the estimates of waste oil generated, the combustion factors, the study period use factors, and the calculated amounts of waste oil burned in each subarea.

For this urban-scale analysis, all waste oil contaminants eliciting a threshold level response were modeled over a 30-day averaging time. All carcinogenic contaminants were modeled over an annual averaging time. So that the ambient air concentrations would be expressed in a format consistent with model specifications, the emission factors were determined for the appropriate averaging time and expressed in mass per area per time period.

The urban-scale subarea emission rates for threshold and nonthreshold contaminants due to waste oil burning are presented in Tables 4-27 and 4-28. The subareas are expressed in terms of distance of the boundaries from the centroid of the urban study area. These emission rates per unit area provided the necessary

TABLE 4-25. ESTIMATED CONTAMINANT EMISSION RATES PER LITER OF WASTE OIL BURNED

Waste oil contaminant	Concentration in waste oil, ppm[a]	Emissions per waste oil burned,[b] g/liter
Arsenic	16[c]	0.012[c]
Barium	485	0.364
Cadmium	4	0.003
Chromium	28	0.021
Lead	1000	0.750
Zinc	1150	0.863
Trichloroethane	1300	0.039
Tetrachloroethylene	1200	0.036
Toluene	1200	0.036
Trichloroethylene	1050	0.031
Carbon tetrachloride	1000	0.030
PCB's	50	0.001
Chlorinated organics[d]	6150	6.15
Benzene	160	0.005
Naphthalene	580	0.018

[a] Weight/volume.

[b] Metal emissions are assumed at 75 percent of input metal rates and organics at 3 percent of organic input rates.

[c] At 5 ppm concentration, arsenic emissions equal 0.004 g/liter.

[d] HCl emissions are assumed equal to 100 percent of input rates of chlorinated organics.

TABLE 4-26. WASTE OIL BURNING CHARACTERISTICS DERIVED FOR THE URBAN-SCALE DISPERSION MODELING ANALYSIS

Distance from study area centroid, km	Waste oil generated, 10^7 liters/yr	Combustion factor	January		Annual	
			Monthly use factor	Waste oil burned, 10^6 liters/mo	Annual use factor	Waste oil burned, 10^7 liters/yr
0-5	1.94	0.7	0.21	2.85	1.0	1.36
5-10	2.35	0.7	0.21	3.45	1.0	1.65
10-15	3.32	0.7	0.21	4.88	1.0	2.32
15-25	4.29	0.7	0.20	6.31	1.0	3.00
25-50	1.94	0.7	0.20	2.85	1.0	1.36

TABLE 4-27. AREA SOURCE JANUARY EMISSIONS FROM THE COMBUSTION OF WASTE OIL CONTAINING CONTAMINANTS WITH A THRESHOLD RESPONSE

Distrance from study area centroid, km	January emissions of threshold contaminants, 10^9 g/s-m^2								
	Barium	Cadmium	Chromium	Lead	Zinc	Toluene	1,1,2-Trichloroethane	Chlorinated organics	Naphthalene
0-5	4.94	0.041	0.285	10.2	11.7	0.48	0.523	83.4	0.237
5-10	2.00	0.017	0.115	4.11	4.73	0.20	0.211	33.6	0.096
10-15	1.69	0.014	0.098	3.49	4.01	0.16	0.179	28.5	0.079
15-25	0.609	0.0050	0.035	1.26	1.45	0.060	0.064	11.	0.030
25-50	0.062	0.00052	0.0036	0.129	0.149	0.0060	0.0070	1.1	0.0030

TABLE 4-28. AREA SOURCE ANNUAL EMISSIONS FROM THE COMBUSTION OF WASTE OIL FOR NONTHRESHOLD CONTAMINANTS

Distance from study area centroid, km	Annual emissions of nonthreshold contaminants, 10^{-11} g/s-m^2							
	Arsenic[a]	Chromium	Carbon tetrachloride	PCB's	Tetrachloro-ethylene	Trichloro-ethylene	1,1,2-Tri-chloroethane	Benzene
0-5	6.58	11.6	16.4	0.828	19.7	17.1	21.2	2.50
5-10	2.66	4.66	6.59	0.333	7.95	6.91	8.52	1.01
10-15	2.55	3.95	5.60	0.282	6.72	5.87	7.25	0.856
15-25	0.855	1.49	2.12	0.107	2.54	2.22	2.74	0.324
25-50	0.088	0.154	0.218	0.011	0.262	0.228	0.282	0.033

[a] At 5 ppm input, arsenic emissions equal 2.06, 0.83, 0.70, 0.267, and 0.028 x 10^{-11} g/s-m^2 per study grid.

emissions input in all subsequent urban-scale modeling calculations. These rates were considered best estimates of possible urbanwide emissions when all available waste oil was utilized. The derivation of windspeeds, which was based on local data summaries, is presented in Appendix B.

4.3.3 Urban-Scale Air Quality Impacts

For threshold contaminants, the results of applying the Hanna-Gifford Model to the subject urban area are expressed in terms of monthly averaged concentrations. Nonthreshold contaminants are calculated on an annual basis, based on the assumption that year-to-year variations are not significant and that the average subarea and urbanwide concentrations and exposures are comparable to lifetime exposures.

Table 4-29 presents estimated monthly emission concentrations of threshold contaminants. A review of the ratio of the highest concentrations to the applicable EEL's or NAAQS shows that barium, lead, and HCl are of primary significance, at 77, 44, and 9 percent of their respective EEL's or NAAQS. All other contaminants are 2 percent or less.

Because the levels of chlorinated organics in waste oil were assumed, alternative emission levels of HCl were analyzed. Table 4-30 presents the ambient concentrations of HCl at several concentrations of chlorinated organics in the waste oil. At the 1000-ppm level, emission concentrations of HCl fall to 1 percent of the applicable EEL in the innermost study area (0 to 5 km).

TABLE 4-29. AMBIENT AIR IMPACTS FROM THE COMBUSTION OF WASTE OIL CONTAINING ALL CONTAMINANTS WITH A THRESHOLD RESPONSE IN THE URBAN STUDY AREA

Pollutant	Study area monthly average concentrations, μg/m³					EEL concentration μg/m³	Maximum percentage of EEL
	Distance from study area centroid, km						
	0-5	5-10	10-15	15-25	25-50		
Barium	0.323[a]	0.108	0.091	0.033	0.003	0.43	77
Cadmium	0.003	0.001	0.001	<0.001	<0.001	0.34	1
Chromium	0.019	0.062	0.005	0.002	<0.001	4.32	<1
Lead	0.665[b]	0.222	0.189	0.068	0.007	1.5	44
Zinc	0.765	0.256	0.217	0.078	0.008	43.2	2
Toluene	0.024	0.008	0.007	0.002	<0.001	3,240.0	<1
1,1,1-Trichloroethane	0.026	0.009	0.007	0.003	0.001	16,420.0	<1
HCl	5.45	1.83	1.55	0.56	0.06	59.7	9
Naphthalene	0.016	0.005	0.004	0.002	<0.001	432.	<1

[a] At 50 percent emissions (rather than the assumed 75 percent) the maximum concentration of barium is 0.215 μg/m³ or 50 percent of EEL.

[b] At 50 percent emissions (rather than the assumed 75 percent) the maximum concentration of lead is 0.443 μg/m³ or 30% of NAAQS.

TABLE 4-30. AMBIENT AIR IMPACTS FROM THE COMBUSTION OF WASTE OIL CONTAINING CHLORINATED ORGANICS AT VARIOUS PLANT INPUT CONCENTRATIONS IN THE URBAN STUDY AREA

Distance from study area centroid, km	Chlorinated organics concentrations (ppm) in the waste oil feed stock									
	30,000		10,000		6,150[c]		3,000		1,000	
	χ,[a] μg/m³	% EEL[b]	χ, μg/m³	% EEL	χ, μg/m³	% EEL	χ, μg/m³	% EEL	χ, μg/m³	% EEL
0-5	26.6	145	8.87	15	5.45	9	2.66	4	0.89	1
5-10	8.91	15	2.97	5	1.82	3	0.89	1	0.30	1
10-15	7.55	13	2.52	4	1.55	3	0.76	1	0.25	<1
15-25	2.71	4	0.90	1	0.55	<1	0.27	<1	0.09	<1
25-50	0.28	1	0.09	<1	0.06	<1	0.03	<1	0.01	<1

[a] Ambient air concentration of HCl.

[b] EEL = 59.7 μg/m³ for HCl.

[c] 90th percentile concentration.

Similar concentration estimates were made for each subarea for the nonthreshold contaminants associated with waste oil burning. Tables 4-31 and 4-32 present these estimates. Table 4-31 shows annual ambient air concentrations of nonthreshold contaminants based on an assumed 97 percent destruction removal efficiency for organics and the emission of 75 percent of the metals in the oil. Table 4-32 shows annual ambient air concentrations for the same contaminants in the innermost ring of the urban area, based on an assumed 99 percent destruction removal efficiency for organics and the emission of 50 percent of the metals in the oil. In each case, the highest concentrations occur in the 0- to 5-km area. Cancer risks associated with the modeled concentrations are presented in Section 5. In each case, the highest concentrations occurred in the 0- to 5-km area.

TABLE 4-31. CONCENTRATIONS OF NONTHRESHOLD CONTAMINANTS FROM WASTE OIL COMBUSTION IN THE URBAN AREA, BASED ON 97 PERCENT DESTRUCTION REMOVAL EFFICIENCIES OF ORGANICS AND EMISSION OF 75 PERCENT OF THE METALS IN THE OIL

	Annual concentrations, µg/m³ Distance from study area centroid, km				
Pollutant	0-5	5-10	10-15	15-25	25-50
Arsenic	0.0050	0.0016	0.0013	0.0005	<0.0001
Benzene	0.0018	0.0008	0.0007	0.0002	<0.0001
Cadmium	0.0010	0.0003	0.0003	0.0001	<0.0001
Chromium	0.0086	0.0027	0.0023	0.0009	<0.0001
Carbon tetrachloride	0.0122	0.0038	0.0033	0.0013	0.0001
PCB's	0.0006	0.0002	0.0001	0.0001	<0.0001
Tetrachloroethylene	0.0147	0.0046	0.0036	0.0015	0.0001
Trichloroethylene	0.0128	0.0040	0.0034	0.0013	0.0001
1,1,2-Trichloroethane	0.0158	0.0050	0.0042	0.0016	0.0001

[a] At the 5-ppm arsenic level (rather than the 16-ppm level assumed), the concentration in the 0- to 5-km area equals 0.0016 µg/m³

TABLE 4-32. CONCENTRATIONS OF NONTHRESHOLD CONTAMINANTS IN THE URBAN AREA, BASED ON 99 PERCENT DESTRUCTION REMOVAL EFFICIENCIES AND EMISSION OF 50 PERCENT OF THE METALS IN THE OIL

Contaminant	Maximum concentration in 0- to 5-km area, $\mu g/m^3$
Arsenic	0.0033
Benzene	0.0006
Cadmium	0.0007
Carbon tetrachloride	0.0041
Chromium	0.0057
PCB's	0.0002
Tetrachloroethylene	0.0049
Trichloroethylene	0.0043
1,1,2-Trichloroethane	0.0053

REFERENCES FOR SECTION 4

1. Bowers, J. F., J. R. Bjorkland, and C. S. Cheny. Industrial Source Complex (ISC) Dispersion Model User's Guide. Vols. 1 and 2. EPA-450/4-79-030 and EPA-450/4-79-031, December 1979.

2. U.S. Environmental Protection Agency. Guideline on Air Quality Models. EPA-450/2-78-027, April 1978.

3. Gifford, F. A., and S. R. Hanna. Modeling Urban Air Pollution. Atmos. Environment, 7:131-136, 1973.

4. Holzworth, G. C. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. AP-101, 1972.

5. U.S. Department of Commerce. Local Climatological Data. J. F. Kennedy International Airport, National Oceanic and Atmospheric Administration, New York, New York, National Climatic Center. Asheville, North Carolina. 1979.

6. PEDCo Environmental, Inc. Program Office Support: Environmental Impacts of Fossil Fuel Utilization. Prepared for U.S. Environmental Protection Agency under Contract 68-02-3173, Task Order 5. (No date.)

7. Miller, C. W. An Application of the ATDL Simple Dispersion Model. JAPCA, 28:(8), August 1978.

8. Anderson, G. E., C. S. Liu, H. Y. Holman, and J. P. Killus. Human Exposure to Atmospheric Concentrations of Selected Chemicals. U.S. Environmental Protection Agency. March 1980.

9. Hanna, S. R. A Simple Method of Calculating Dispersion From Urban Area Sources. JAPCA, 21:(8), December 1971.

10. Hanna, S. R. Urban Diffusion Problems. Presented at the AMS Workshop of Meteorology and Environmental Assessment. Boston, Massachusetts.

SECTION 5

ENVIRONMENTAL IMPACT AND HEALTH RISKS FROM WASTE OIL BURNING

5.1 ENVIRONMENTAL IMPACT AND HEALTH CONSEQUENCE OF THRESHOLD CONTAMINANTS

This section presents an assessment of the impact on air quality and the risk to human health posed by airborne concentrations of threshold (noncarcinogenic) contaminants from the combustion of waste oil through a comparison of these concentrations with both EEL's and existing air quality.

Two atmospheric dispersion models were used to estimate the contribution of waste oil combustion to air quality, the ISC Model (point-source emissions) and the Hanna-Gifford model (area emissions). Table 5-1 presents the results that reflect the greatest ambient air impacts from all of the modeling runs. A review of these modeling results indicates that three waste oil constituents (barium, hydrogen chloride, and lead) may have a substantial impact on air quality when viewed in relation to their corresponding environmental exposure limits.

The magnitude of impact can be further assessed by comparing airborne concentrations with existing air quality measurements, as discussed in the following subsections.

TABLE 5-1. A COMPARISON OF ESTIMATED MAXIMUM EXPOSURE CONCENTRATIONS FROM WASTE OIL BURNING WITH ENVIRONMENTAL EXPOSURE LIMITS

	Ambient air concentration, µg/m³	Waste oil contribution, percent of the EEL[a]
Barium	0.098[b]	23
	0.15[c]	36
	0.34[d]	79
	0.323[e]	75
Cadmium	<0.001[b]	<1
	0.002[c]	<1
	0.0028[d]	1
	0.003[e]	1
Chromium (II and III)	0.006[b]	<1
	0.009[c]	<1
	0.0197[d]	<1
	0.062[e]	<1
HCl	1.66[b]	3
	2.58[c]	4
	5.80[d]	10
	5.45[e]	9
Lead	0.203[b]	14
	0.314[c]	21
	0.708[d]	47
	0.665[e]	44
Zinc	0.233[b]	<1
	0.361[c]	1
	0.814[d]	2
	0.765[e]	2
Naphthalene	0.004[b]	<1
	0.007[c]	<1
	0.017[d]	<1
	0.016[e]	<1
Toluene	0.009[b]	<1
	0.015[c]	<1
	0.0341[d]	<1
	0.024[e]	<1
1,1,1-Trichloroethane	0.010[b]	<1
	0.016[c]	<1
	0.0370[d]	<1
	0.026[e]	<1

[a] See Appendix C, Table C-4.

[b] Estimated contribution from Source 9 (a single small residential boiler) as determined by the ISC Model. See Table 4-4.

[c] Estimated contribution from Source 14 (a single medium-size commercial boiler) as determined by the ISC Model. See Table 4-18.

[d] Estimated contribution from Source 2 (four 5-gal/h boilers) as determined by the ISC Model. See Table 4-11.

[e] Estimated contribution from urban study Subarea 1 (0-5 km) as determined by the Hanna-Gifford Model. See Table 4-28.

5.1.1 Barium Impact

Dispersion modeling of barium emissions from single point sources indicates that local airborne concentrations of barium compounds can reach 0.098 to 0.153 $\mu g/m^3$ or 23 to 36 percent of the EEL. The EEL is derived from a TLV designed to protect against excitability. Barium increases the excitability of the muscles, particularly cardiac muscle. Modeling results of barium emissions from multiple point sources and high-density urban areas indicate that airborne concentrations of barium from waste oil burning may reach 75 to 79 percent of the EEL. Airborne concentrations of barium in the northeastern United States are reported to range from a high of 2.0 $\mu g/m^3$ to a low of 0.005 $\mu g/m^3$ (mean concentration of 0.25 $\mu g/m^3$). Based on these ambient concentrations, barium emissions from waste oil burning appear to account for at least 16 percent of the airborne concentration in high-density urban areas.

5.1.2 Hydrogen Chloride Impact

The dispersion modeling of hydrogen chloride emissions from single point sources indicates that airborne hydrogen chloride concentrations could occur at 1.66 to 2.58 $\mu g/m^3$, or between 3 and 4 percent of the EEL. The main health effect from exposure to hydrogen chloride is irritation. Hydrogen chloride emissions from multiple point sources and high-density urban areas indicate that 5.45 to 5.80 $\mu g/m^3$ or 9 to 10 percent of the hydrogen chloride EEL may be reached as a result of waste oil burning. Airborne ambient concentrations of 2 to 8 $\mu g/m^3$ (1.3 to 5 ppb) chlorine (as HCl) were measured at 10 m above the surface of the North Atlantic.[1] Cholak[2] and Katz[3] have indicated chloride concentrations in American cities ranging from 0.016 to 0.095 ppm, or 24 to 140 μg/m³; however, these data are from the 1950's. As indicated by the air dispersion modeling of multiple sources and urban areas, concentrations of HCl from waste oil burning in some cities can still be as high as those measured. More recent ambient HCl data are not available.

5.1.3 Lead Impact

Lead emissions resulting from the burning of waste oil at single point sources are believed to account for local airborne concentrations from 0.203 to 0.314 μg/m³, or 14 to 21 percent of the National Ambient Air Quality Standard. The lead standard is designed to protect against encephalopathy (brain disease) and renal damage. Emissions from multiple sources or high-density urban areas may produce airborne lead concentrations of 0.665 to 0.708 μg/m³, or 44 to 47 percent of the NAAQS. Measured ambient air concentrations of lead in the northeastern United States range from a high of 3.6 μg/m³ to a low of 0.06 μg/m³ (mean concentration of 0.79 μg/m³). Based on these values, emissions from waste oil burning could account for at least 10 percent of the airborne lead concentrations in high-density urban areas.

5.1.4 Summary

In summation, the modeling results show that concentrations of barium, hydrogen chloride, and lead from the burning of waste oil in small or medium-size boilers or space heaters has a measurable impact on air quality and that waste oil burning may account for a significant portion of the existing ambient airborne concentrations of each of these substances. The other threshold pollutants (cadmium, chromium, zinc, naphthalene, toluene, and 1,1,1-trichloroethane) do not have a serious impact on air quality near single or multiple sources or in high-density urban areas.

5.2 ENVIRONMENTAL IMPACT AND HEALTH CONSEQUENCE OF NONTHRESHOLD CONTAMINANTS

Potential cancer risks associated with waste oil combustion were calculated by comparing the estimated airborne concentrations previously presented (in Tables 4-30 and 4-31) with the reference concentrations presented in Appendix C, Table C-7. Tables 5-2 and 5-3 present the results of this comparison.

Based on the estimated ambient concentrations and the reference concentrations, a cancer risk estimate was determined for each waste oil constituent being emitted into the atmosphere. Cancer risk is calculated as a ratio of the modeled airborne concentration to the reference concentration. The resulting value, which is expressed in scientific notation, represents the frequency of cancers per a given population; e.g., the cancer risk from exposure to airborne arsenic is 2.0×10^{-5} or two incidences of cancer per 100,000 population.

Another means of expressing cancer risk is to present the value in terms of risk to a single individual; e.g., the cancer

TABLE 5-2. LIFETIME CANCER RISK ASSOCIATED WITH WASTE OIL BURNING IN A HIGH-DENSITY URBAN STUDY AREA, BASED ON 97 PERCENT DESTRUCTION REMOVAL EFFICIENCY FOR ORGANICS AND THE EMISSION OF 75 PERCENT OF THE METALS IN THE OIL

Substance	Airborne annual concentration[a], μg/m³	Cancer risk	Approximate risk to an individual
Arsenic[b]	0.0050	2.0×10^{-5}	1:50,000
Benzene	0.0018	2.7×10^{-8}	1:37,000,000
Cadmium	0.001	1.9×10^{-6}	1:530,000
Chromium	0.0086	1.1×10^{-4}	1:9,100
Carbon tetrachloride	0.0122	4.5×10^{-7}	1:2,200,000
Polychlorinated biphenols (PCB's)	0.0006	7.4×10^{-7}	1:1,300,000
Tetrachloroethylene	0.0147	2.2×10^{-7}	1:4,500,000
Trichloroethylene	0.0128	4.6×10^{-8}	1:22,000,000
1,1,2-Trichloroethane	0.0158	2.6×10^{-7}	1:3,800,000

[a] See Table 4-30. This is based on concentrations in the 0- to 5-km innermost ring; thus, risk represents the worst case for the most exposed individuals.

[b] At the 5-ppm arsenic level (rather than the assumed 16-ppm level), the concentration in the 0- to 5-km area equals 0.0016 μg/m³, which reduces the individual risk to 6.4×10^{-6}.

TABLE 5-3. LIFETIME CANCER RISK ASSOCIATED WITH WASTE OIL BURNING IN A HIGH-DENSITY URBAN STUDY AREA, BASED ON 99 PERCENT DESTRUCTION REMOVAL EFFICIENCY OF ORGANICS AND THE EMISSION OF 50 PERCENT OF THE METALS IN THE OIL

Substance	Airborne annual concentration,[a] $\mu g/m^3$	Cancer risk	Approximate risk to an individual
Arsenic	0.0033	1.3×10^{-5}	1:77,000
Benzene	0.0006	8.9×10^{-9}	1:110,000,000
Cadmium	0.0007	1.3×10^{-6}	1:760,000
Carbon tetrachloride	0.0041	1.5×10^{-7}	1:6,600,000
Chromium	0.0057	7.1×10^{-5}	1:14,000
PCB's	0.0002	2.5×10^{-7}	1:4,000,000
Tetrachloroethylene	0.0049	7.4×10^{-8}	1:13,000,000
Trichloroethylene	0.0043	1.5×10^{-8}	1:65,000,000
1,1,2-Trichloroethane	0.0053	8.7×10^{-8}	1:12,000,000

[a] See Table 4-31.

risk from arsenic (2.0×10^{-5}) can be expressed as the risk to a single individual in terms of 1 chance in 50,000 (1:50,000).

The significance of the results in Tables 5-2 and 5-3 depend on the level of risk considered to be acceptable. For either set of conditions (97% or 99% DRE's of organics and the emission of 75% or 50% of the metals in the ore), if a risk level of 10^{-5} is established as acceptable, the risk to health from chromium and arsenic would then be considered significant. On the other hand, should a lower risk level of 10^{-6} be established as acceptable, chromium, arsenic, and cadmium would then be considered to be presenting a significant health problem. Table 5-4 identifies the waste oil constituents of concern for three levels of risk 10^{-4}, 10^{-5}, and 10^{-6}.

TABLE 5-4. WASTE OIL CONSTITUENTS PRESENTING A POTENTIALLY UNACCEPTABLE CANCER RISK[a]

Acceptable risk level	Assuming 97 percent DRE of organics and emission of 75 percent of metals	Assuming 99 percent DRE of organics and emissions of 50 percent of metals
10^{-4}	Chromium	-
10^{-5}	Chromium, arsenic	Chromium, arsenic
10^{-6}	Chromium, arsenic, cadmium	Chromium, arsenic, cadmium

[a] See Tables 5-2 and 5-3.

REFERENCES FOR SECTION 5

1. U.S. Environmental Protection Agency. Hydrochloric Acid and Air Pollution: An Annotated Bibliography. Environmental Protection Agency, Research Triangle Park, North Carolina. AP-100, 1971.

2. J. Cholak (ed.) In: Proceedings of the National Air Pollution Symposium, 2nd, 1952, p. 6.

3. Katz, M. Air Repair, 4:176, 1955.

SECTION 6

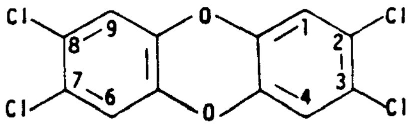
CHLORINATED DIBENZODIOXINS AND DIBENZOFURANS

Polychlorinated dibenzodioxins (PCDD's) are a subset of a larger group of related organic compounds collectively referred to in the literature as polyhalogenated aromatic hydrocarbons. Other members of the group include polychlorinated dibenzofurans (PCDF's), polychlorinated biphenyls (PCB's), polybrominated biphenyls (PBB's), polychlorinated naphthalenes (PCN's), and polychlorinated terphenyls (PCT's). The PCDD subset alone has 75 individual cogeners. One of these, 2,3,7,8-tetrachlorodibenzodioxin (2,3,7,8-TCDD), is of special concern because of its extreme toxicity and potentially widespread exposure. This and other PCDD's occur as unwanted byproducts of the manufacture and combustion of certain chemicals, most notably the chlorophenols and their derivatives.

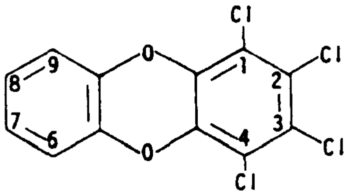
6.1 HEALTH EFFECTS

The most acutely toxic halogenated aromatic compound known is 2,3,7,8-TCDD. Laboratory studies have shown that less than 1 μg/kg is lethal to at least half of a test population of guinea pigs. No other synthetic chemical is known to be so toxic. This lethal effect has been observed to vary in intensity among different animal species. Though all species are adversely affected, some are more tolerant of the chemical than others. Monkeys, mice, rabbits, frogs, and dogs for example, survive equivalent exposures to 2,3,7,8-TCDD much better than guinea pigs. Also, although humans have been both inadvertantly and accidentally exposed to 2,3,7,8-TCDD, not one death has been directly attributed to acute poisoning by this substance. The extent of human exposure is not well known. Thus, it is unclear whether 2,3,7,8-TCDD, which is so lethally toxic to some laboratory animals, is also highly toxic to humans.

The acute toxicity of other PCDD's varies according to the number and placement of chlorine atoms on the basic dioxin triple-ring molecule. For example, dioxins with a more-or-less symmetrical distribution of chlorines (i.e., chlorines laterally placed on both benzene rings of the molecule) and in which at least three of the four positions (2, 3, 7, and 8) are occupied tend to be much more toxic than those with asymmetrical distribution. For example, 2,3,7,8-TCDD is highly toxic (rat oral LD_{50} 40 µg/kg), whereas 1,2,3,4-TCDD is nearly nontoxic (rat oral LD_{50} >1000 µg/kg).[1]



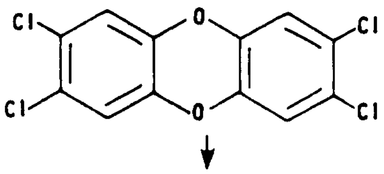
2,3,7,8-TCDD



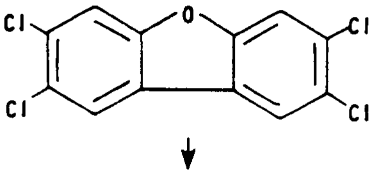
1,2,3,4-TCDD

Furthermore, the degree of chlorination also affects toxicity. Dioxins with three to six chlorine substituents symmetrically distributed tend to be quite toxic, whereas dioxins with either no substituents (i.e., no chlorine atoms) or dioxins that are totally substituted (i.e., with eight chlorines) exhibit little or no toxicity.

The toxicity of PCDF's has not been studied to the extent of PCDD's. From what has been learned so far, however, it appears that structurally analogous PCDF's may exhibit toxic effects similar to--though less potent than--the corresponding PCDD's. For example, the acute oral toxicity of 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF) is within an order of magnitude of 2,3,7,8-TCDD, as shown below:[2]



2,3,7,8-TCDD



2,3,7,8-TCDF

Species	LD$_{50}$, µg/kg	LD$_{50}$, µg/kg	$\frac{LD_{50}\ TCDF}{LD_{50}\ TCDD}$
Guinea pig	0.5-1.5	5-10	4
Monkey	30-70	1000	20
Mouse	150-300	6000	25

As with 2,3,7,8-TCDD, the toxicity of 2,3,7,8-TCDF varies in intensity by animal species, and the acute effect level for humans remains an unknown. Both molecules elicit chloracne, thymus atrophy, weight loss, and liver effects, but the dose of 2,3,7,8-TCDF needed to produce a given effect is often many times (30 to 100x) higher than that for 2,3,7,8-TCDD. The observed similarity between the toxic properties of 2,3,7,8-TCDD and those of 2,3,7,8-TCDF appears to be closely linked to the similar geometric dimensions and chlorine substitution patterns of the two molecules.

Apart from its well-documented acute toxic effects in animals, there is growing evidence that 2,3,7,8-TCDD is carcinogenic in animals and possibly in humans. An increased incidence of liver and lung/upper airway cancers has been described in one study where rats were fed 2,3,7,8-TCDD.[3] In another more recent study in rats, tumors of a variety of organs were produced.[4] Experimental data concerning other dioxins are limited. Recently (July 1983), a panel of some 50 scientists from around the world, all of whom are experts on the chemistry and toxicology of 2,3,7,8-TCDD and other dioxins, met with EPA's Environmental Criteria and Assessment Office staff in Cincinnati, Ohio, to review available data on dioxin health effects. In particular, they were asked to evaluate the compound's potential as a human carcinogen. The panel discussed at length the results of the animal studies mentioned above, and considered additional recent and admittedly limited epidemiological data on the incidence of soft tissue sarcoma in exposed populations in Europe and the United States (i.e., Midland, Michigan). At the meeting's conclusion, the panel endorsed a statement to the effect that "2,3,7,8-TCDD is probably carcinogenic for humans on the basis of animal carcinogenicity studies which were positive in multiple species and organs."

In addition to its acutely toxic and cancer-producing properties, 2,3,7,8-TCDD has been observed to elicit the following toxic and biologic responses in <u>humans</u>:[2,5]

Dermatological

> Severe and persistent chemically induced acne known as chloracne. Characterized by many blackheads, cysts, pustules, papules, and abscesses.

Blistering and scarring of the skin believed to be due to increased light sensitivity, known as porphyria cutanea tarda.

Darkened skin areas/blotches, known as hyperpigmentation.

Excessive growth of hair of normal or abnormal distribution, known as hirsutism.

Internal

Liver damage
Raised serum hepatic enzyme levels
Disorders of fat metabolism
Disorders of carbohydrate metabolism
Cardiovascular disorders
Urinary tract disorders
Respiratory tract disorders
Pancreatic disorders

Neurological

Peripheral

Multiple sites of abnormal nerve degeneration (polyneuropathies)
Sensory impairments (sight, hearing, smell, taste)

Central

Fatigue, weakness, impotence
Loss of sexual drive or libido

Psychiatric

Depression

The following additional responses have been observed in monkeys and/or other nonhuman animals exposed to 2,3,7,8-TCDD:

1) A wasting syndrome manifested by a progressive weight loss and decreased food consumption by treated animals.

2) Skin disorders, especially acneform eruptions or chloracne, alopecia, edema (swelling), hyperkeratosis (thickened and hardened, crusty skin), and hypertrophy of Meibomian glands.

3) Progressive decline of the thymus gland (lymphoid involution and atrophy).

4) Porphyria resembling porphyria cutanea tarda (an abnormal metabolism condition characterized by excess blood metabolites--porphyrins--in the urine, and extreme sensitivity to light).

5) Endocrine and reproductive disorders including abnormal and toxic effects on the fetus (teratogenic and fetotoxic effects).

6) Adverse effects on the immune system (immunotoxicity).

7) Abnormal induction of numerous enzymes.

Weight loss, chloracne, liver effects, and thymus atrophy have also been observed in animals treated with 2,3,7,8-TCDF.[6] The two effects of exposure to TCDD's that occur at the lowest doses and therefore represent the greatest concern to public health are carcinogenic (10 ng/Kg/day) and reproductive effects.

6.2 POTENTIAL FOR DIOXIN AND DIBENZOFURAN FORMATION FROM THE COMBUSTION OF WASTE OIL IN BOILERS

The PCDD's (and PCDF's) emitted to the air from combustion processes are associated primarily with (i.e., sorbed to) air particulate matter.[7]

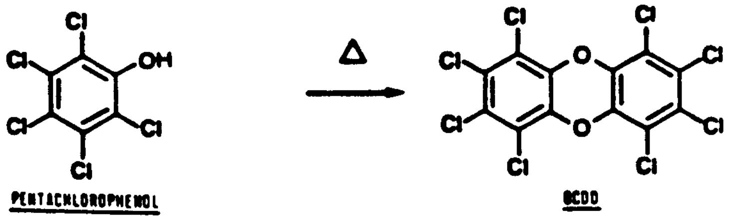
Several investigators have reported finding TCDD's and other dioxins in both the particulate emissions and fly ash of municipal incinerators. For example, fly ash from several such incinerators in Canada, Europe, and the United States has been found to contain the following range of dioxin concentrations:[8]

Dioxin	Concentration, ng/g
Total TCDD's	3.2 - 110
PeCDD's*	3.4 - 488
HxCDD's*	2.2 - 1200

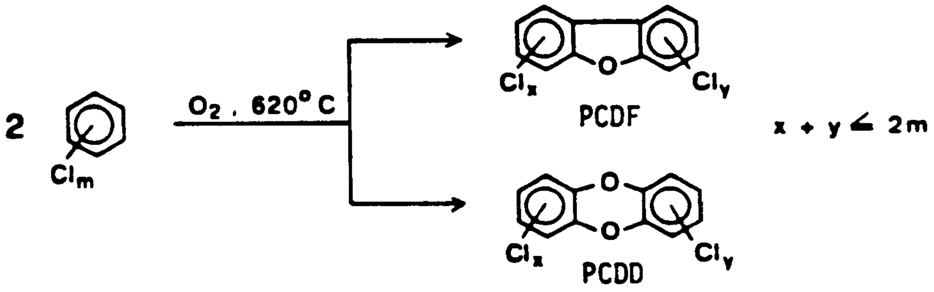
* Pentachlorodibenzo-p-dioxin or hexachlorodibenzo-p-dioxin.

The formation of PCDD's during combustion of fuels (including waste oil) is a controversial subject. One theory holds that precursors (e.g., chlorinated phenols[9] and chlorinated benzenes[10]) must be available in the fuel feed before PCDD's can be formed. Dioxins can be formed from these precursors, as shown by the following.

From chlorinated phenols:[1]



From chlorinated benzenes:[9]



Another possible precursor is polyvinyl chloride, a compound that produces chlorobenzenes during pyrolysis.[11,12]

Another theory, developed by Dow and others, proposes that low concentrations of either inorganic or organic chlorides in the fuel can be expected to produce traces of PCDD.[13] This hypothesis, which has been called "trace chemistries of fire," is based on the following:[13]

(1) Combustion processes are seldom more than 99.9 percent efficient in converting the carbon content of fuel to carbon dioxide.

(2) The remaining 0.1 percent of the fuel is converted to a large number of trace organic chemicals, including chlorinated hydrocarbons, only a few of which have been identified.

(3) Fossil fuels are extremely complex mixtures of many chemicals and compounds, some of which are present at low concentrations.

(4) The chlorine content of fuels can range from 1000 to 5000 ppm.

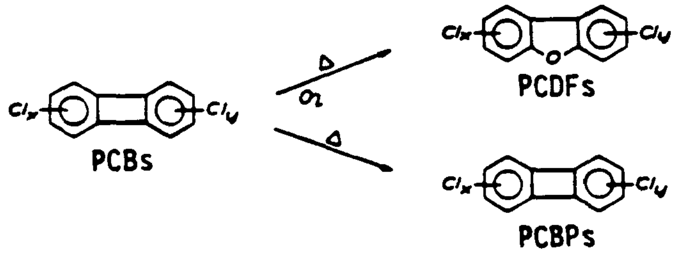
(5) Particles emitted from the combustion of oil contain vanadium and nickel. These, together with silicon and unburned carbon, can serve as catalysts in the combustion process.

(6) Chemical reactions that occur in flames include pyrolysis, oxidation, reduction, and acidolysis. Ions, electrons, free radicals, and free atoms interact in a continuously changing environment.

(7) In the Dow study, PCDD's were reportedly found in all particulate matter taken from areas close to combustion processes.

A significant criticism of the two theories discussed is that often the fuel that is combusted is not well characterized chemically. Thus, while dioxins may be detected in the combustion products, it is usually not known whether dioxins are present in the fuel itself; this makes it impossible to rule out still another "theory": dioxins in, dioxins out. Although this may not be true in all instances, it cannot be ignored.

Theories similar to those regarding PCDD's (i.e., precursor and trace chemistries of fire hypotheses) can be developed for the formation of PCDF's during combustion, with PCB as the major precursor. This can be shown as follows:[14]



These theories can be used to predict that small quantities of PCDD and PCDF may be formed during waste oil combustion. The chemical reaction sequence involved in the combustion of organic constituents present in waste oil is a complex process. This sequence consists of a series of decomposition, polymerization, and free radical reactions. The presence of chlorobenzene, chlorinated phenols, and other chlorinated hydrocarbons (aromatics and alphatics) appears to promote the formation of products of incomplete combustion, such as PCDD and PCDF. These unwanted byproducts of combustion have been detected in some fly ash and flue gas samples from the combustion of waste oil, traditional fossil fuels, and municipal refuse. The EPA has analyzed at least seven coal-fired power plants, however, and has not detected any PCDD's or PCDF's, which suggests that the general contamination of coal by PCDD's and PCDF's is not likely.

Analyses of waste oil samples have shown the presence of inorganic and organic constituents that may serve as precursors to PCDD and PCDF. Although data on chlorophenols are not available, a recent composition survey of 49 waste oil samples from a wide variety of sources showed a median phenol content of 18 ppm, and 90 percent of the samples had less than 110 ppm.[15]

It is not known, however, whether nonchlorinated phenols can serve directly as dioxin precursers. Another set of 62 waste oil samples had a median total chlorine value of 1400 ppm, and 90 percent of these samples had less than 6150 ppm.[15] Other precursors for PCDD's (e.g., chlorinated benzenes) were not included in the statistical analysis. Preliminary findings from a second set of waste oil samples revealed detectable concentrations of chlorobenzene in 5 out of 24 samples analyzed.[16] The detectable chlorobenzene concentrations ranged between 2 and 78 ppm.

Based on a set of 264 waste oil samples from a wide variety of sources, the median PCB concentration was 9 ppm, and 90 percent of the samples had less than 50 ppm PCB.[15] The presence of PCB, chlorine, and other chlorinated organics in waste oil, creates a potential for formation of PCDF. Yields of PCDF were 1 to 5 percent during laboratory pyrolysis of known PCB isomers.[14] The presence of PCDF's was also detected in the ash from PCB fires in Skovke, Sweden, and Stockholm, Sweden.[14]

A PCDD concentration of 640 ppb and a TCDD concentration of 100 ppb were measured in fly ash from an industrial heating facility burning large quantities of waste oils.[17] Unfortunately, samples of the waste oil feed were not analyzed during these tests.

More recent emission tests were performed at four boiler facilities burning waste oil spiked with trichlorophenol, trichlorobenzene, and other organic chlorides (possible PCDD precursors).[18] Species of PCDD's were detected in 6 of the 25 flue gas samples analyzed. The detectable concentrations of these compounds ranged from 0.18 to 17 μg/m³. Bulk samples of fly ash collected at one site contained four species of PCDD with detectable concentrations ranging between 33 and 230 μg/kg. Although the results of these tests show that PCDD's were formed under the test conditions, it is not known whether they would be formed without the additions of the PCDD precursors.

The formation of PCDF's during waste oil combustion has not been studied in detail. Data on the emission of PCDF's from waste oil combustion are even more limited than the data for PCDD's. GCA analyzed samples collected at four waste oil boiler facilities for the presence of PCDF.[18] The waste oil feed apparently was not analyzed for PCB's. [The waste oil analysis did include six organics (chloroform, trichloroethane, trichloroethylene, tetrachloroethylene, trichlorobenzene, and dichloronaphthalene) and six inorganics (chlorine, arsenic, cadmium, chromium, lead, and zinc).] Analyses of flue gas samples revealed PCDF concentrations ranging between 0.07 and 62 μg/m³.[18] Bulk samples of fly ash collected at one site contained seven species of PCDF with detectable concentrations in the range of 11 to 1000 μg/kg.[18]

In summary, some limited evidence seems to suggest that small amounts of PCDD's and PCDF's may be formed by the burning of waste oils in some boilers. The temperatures in a typical small, oil-fired, 15 million Btu/h boiler [i.e., a 4.4-MW boiler with a flue gas temperature of approximately 1315°C (2400°F) exiting the combustion zone at 100 percent load[19]] are sufficient to initiate a wide variety of reactions such as those suspected of forming PCDD's and PCDF's.[13] The destruction of these compounds, however, depends on such factors as the location in the combustion chamber where the compounds are formed, turbulence in the combustion chamber, and the temperature profile of the chamber.[20] Further research and test data are required to attempt to correlate the concentrations of PCDD's and PCDF's in the flue gas with waste oil composition and boiler operating conditions.

6.3 AIR DISPERSION MODELING OF DIOXINS

Atmospheric transport of PCDD's and PCDF's from point-source emissions can be predicted from dispersion modeling equations. For example, when a chemical cloud containing small amounts of TCDD's was accidentally emitted from a trichlorophenol manufacturing plant in Italy, it was experimentally demonstrated that the TCDD deposition from air to soil followed an exponential decay pattern along the downward wind direction.[21] Therefore, TCDD, other PCDD's, and PCDF's sorbed to particulate matter and emitted from combustion sources can be expected to be dispersed and deposited in the surrounding local area in a pattern reflecting local wind patterns, stack height, and terrain.

Only limited test data are available on TCDD's emissions from the combustion of waste oils. GCA reported measuring flue gas concentrations of 1.4 μg/m³ in 1 of 25 samples.[18] (This is for all TCDD isomers, not just 2,3,7,8-TCDD.) The remaining 24 flue gas samples fell below the detection limit of 0.10 μg/m³. The fly ash samples that GCA analyzed for TCDD's were also below the detection limit of 0.5 μg/kg (ppb). In addition to the GCA test data, TCDD concentrations of 100 ppb have been measured in fly ash from an industrial facility burning waste oils.[17]

These data can be used to estimate reasonable flue gas concentrations for ambient air modeling of TCDD emissions. The GCA flue gas data indicate TCDD concentrations generally fall below 0.10 μg/m³, with high concentrations in the magnitude of 1.0 μg/m³.

This range can be substantiated by converting the reported fly ash concentrations of 100 ppb[17] into approximate flue gas concentrations. Because particulate concentrations for the industrial heating facility were not reported, the particulate concentration was assumed to be 180 mg/dsm³, which is the allowable particulate emission rate from municipal and hazardous waste incinerators.

Conversion of the 180 mg/dsm³ (standard temperature, 70°F, and standard pressure, 1 atm) into an actual emission concentration (reported stack gas temperature of 392°F and pressure equal to 1 atm) yields 113 mg/m³, assuming constant moisture content. Based on a TCDD fly ash concentration of 100 ppb and assuming a particulate concentration of 113 mg/m³, the estimated flue gas TCDD concentration would be 0.011 μg/m³.

The test data and calculations just discussed indicate that TCDD flue gas concentrations fall within an order of magnitude of

0.01 and 1.0 μg/m³ and the majority of TCDD concentrations fall below the detection limit of 0.10 μg/m³. Therefore, a TCDD concentration range of 0.001 and 10 μg/m³ has been selected for air quality modeling purposes. On a volume-per-volume basis, this range corresponds to the following:

TCDD flue gas concentrations, μg/m³	TCDD flue gas concentrations, ppt
10	1000
1	100
0.1	10
0.01	1
0.001	0.1

The selected range reflects the probable levels of TCDD concentrations in waste oil boiler flue gases.

Dispersion modeling was performed for dioxin emissions resulting from the combustion of waste oil in space heaters and small and medium-size boilers. A complete discussion and the rationale of the modeling methodology and models selected for this analysis are presented in Section 4.1 and Appendix B. This analysis is based on the same assumptions concerning individual boilers and source characteristics as those presented in Sections 3 and 4. The specific models used in this analysis were the Industrial Source Complex (ISC) Model for short-range air impacts and the Hanna-Gifford Model for urban-wide impacts. The specific applications of these models were:

- The short-range modeling concentrated on worst-case estimates resulting from individual or multiple point sources, assuming each source burned 100 percent waste oil; concentrations of contaminants eliciting a threshold response were of particular concern.

- The urban-wide modeling focused the area-wide dispersion of emissions from the burning of all waste oil generated in that area; urban-wide impacts of contaminants eliciting a threshold response were of considerable concern.

6.3.1 Point Source Analysis

Individual or small group source modeling was performed to estimate the possible air quality impact from a particular source of dioxin emissions during the burning of 100 percent waste oil. From a potential regulatory standpoint these estimates are of interest in establishing emission limitations and waste oil feed stock contaminant limitations. The ISC Model was used in conjunction with meteorological data to estimate concentrations of dioxins in the ambient air resulting from various size boilers and space heaters.

Small Boilers and Space Heaters--

Table 4-2 (Section 4) presented the 13 point sources analyzed in the ISC Model that represent typical small boilers and space heaters (as discussed in Section 3). As the table shows, these sources represented a range of boiler sizes, feed rates, and stack heights. The invariability of other stack parameters was justified by the fact that plume rise was small compared with physical stack height.

Emissions of dioxins from small boilers were based on measured levels in fly ash from an industrial heating facility burning large quantities of waste oil. Because quantifiable levels of dioxin emissions are not available over many types of small boilers at variable feed rates, several levels of TCDD emissions in flue gas were analyzed, including 1000, 100, 10, 1, and 0.1 ppt. Table 6-1 presents the emission factors used throughout this analysis of small boilers and space heaters.

Table 6-2 presents the results of modeling dioxins from the burning of waste oil in individual small boilers and space heaters for each source scenario described in Table 4-2. These concentrations represent the maximum estimated for each single source case. Obviously, as stack emissions decrease from the 1000 ppb level to the 0.1 ppt level, concentrations also decrease.

Medium-Size Boilers--

Some waste oil also may be burned in commercial/institutional boilers with capacities of 50 to 100 x 10^6 Btu/h. An analysis (similar to that described in Section 4.3.4) was performed with the ISC Model to examine the air quality impacts of dioxin emissions from waste oil burning in medium-size boilers. Typical source characteristics chosen for this analysis are presented in Table 4-6 (Section 4). Dioxin emissions resulting from the burning of waste oil in these medium-size boilers are presented in Table 6-3, and the results of the dispersion analysis are presented in Table 6-4. As shown in Table 6-4, the maximum concentrations for a given source occur at the 1000 ppt dioxin level. Source 14 always has the maximum ground-level (ambient air) concentration because it has the lowest stack height.

TABLE 6-1. CONTAMINANT EMISSIONS USED IN SINGLE-SOURCE ISC MODELING ANALYSIS: SMALL BOILERS AND SPACE HEATERS

TCDD flue gas concentration, ppt	Source waste oil burn rates, liters/h	Emissions at 100% capacity, 10^{-4} µg/s	Emissions in January at 50% capacity, 10^{-4} µg/s
1000	4	10.6	5.3
	19	52.8	26.4
	57	158.0	78.9
	132	366.0	183.0
	346	684.0	342.0
100	4	1.06	0.53
	19	5.28	2.64
	57	15.80	7.89
	132	36.60	18.30
	346	68.40	34.20
10	4	0.11	0.05
	19	0.53	0.26
	57	1.58	0.79
	132	3.66	1.83
	346	6.84	3.42
1	4	0.011	0.005
	19	0.053	0.026
	57	0.158	0.079
	132	0.366	0.183
	346	0.684	0.342
0.1	4	0.001	0.001
	19	0.005	0.003
	57	0.016	0.008
	132	0.037	0.018
	346	0.069	0.034

TABLE 6-2. AMBIENT AIR IMPACT FROM WASTE OIL COMBUSTION IN INDIVIDUAL BOILERS AND SPACE HEATERS (<15 x 10^6 Btu/h) FOR VARIABLE TCDD CONCENTRATIONS

Dioxin (TCDD) flue gas concentrations, ppt	Maximum 30-day concentrations, $\mu g/m^3 \times 10^{-8}$ Source number[a]												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1000	12.600	3.400	8.500	3.600	1.900	16.400	7.400	4.000	20.303	10.300	6.000	8.900	5.100
100	1.260	0.340	0.850	0.360	0.190	1.640	0.740	0.400	2.030	1.030	0.600	0.890	0.510
10	0.126	0.034	0.085	0.036	0.019	0.164	0.074	0.040	0.203	0.103	0.060	0.089	0.051
1	0.013	0.003	0.009	0.004	0.002	0.016	0.007	0.004	0.020	0.010	0.006	0.009	0.005
0.1	0.001	0.000	0.001	0.000	0.000	0.002	0.001	0.000	0.002	0.001	0.001	0.001	0.001

[a] Identification in ISC Model.

TABLE 6-3. DIOXIN EMISSIONS USED IN SINGLE-SOURCE ISC MODELING ANALYSIS: MEDIUM-SIZE BOILERS

TCDD concentration, ppt	Source waste oil burn rates, liters/h	Emissions at 100% capacity, 10^{-4} μg/s	Emissions in January at 50% capacity, 10^{-4} μg/s
1000	1330	3661	1830
	2660	7320	3661
100	1330	366	183
	2660	732	366
10	1330	36.6	18.3
	2660	73.2	36.6
1	1330	3.7	1.8
	2660	7.3	3.7
0.1	1330	0.4	0.2
	2660	0.7	0.4

TABLE 6-4. MAXIMUM 30-DAY DIOXIN CONCENTRATIONS IN AMBIENT AIR AS A RESULT OF WASTE OIL COMBUSTION IN MEDIUM-SIZE BOILERS (10^{-8} μg/m³)

TCDD flue gas concentration, ppt	Source number					
	14	15	16	17	18	19
1000	31.392	21.000	14.600	17.800	13.700	10.800
100	3.139	2.100	1.460	1.780	1.370	1.080
10	0.314	0.210	0.146	0.178	0.137	0.108
1	0.031	0.021	0.015	0.018	0.014	0.011
0.1	0.003	0.002	0.002	0.002	0.001	0.001

6.3.2 Urban Scale Analysis

A dispersion modeling analysis based on the same assumptions and methodology as presented in Section 4.4 was performed to estimate the urban-wide impact of dioxins generated by waste oil burning. Estimated dioxin concentrations in waste oil combustion emissions were used to estimate dioxin emissions per liter of fuel burned (Table 6-5). These dioxin emissions were used in conjunction with estimates of waste oil burned in each subarea of the urban study area to calculate the rate of emissions at each dioxin concentration level in waste oil.

Emissions were estimated for a 30-day averaging period [consistent with the short-term (30-day) maximum waste oil impacts] and for an annual averaging period (consistent with long-term impacts from nonthreshold substances. Tables 6-6 and 6-7 present estimates of dioxin emissions over each subarea at each dioxin level in the waste oil combustion effluents.

The results of applying the Hanna-Gifford Model over the study area (Tables 6-6, 6-7, and 6-8) show that 30-day average concentrations are higher than those averaged over a whole year. These higher concentrations result from the higher emission rates averaged over a winter month rather than over a whole year (because emissions are low in the summer).

6.4 RISK ASSESSMENT

The risk associated with human exposure to dioxins in particulate matter resulting from combustion is not yet known. The National Research Council of Canada[8] has estimated that limiting

TABLE 6-5. DIOXIN EMISSION RATES PER WASTE OIL BURNED USED IN URBAN SCALE MODELING

TCDD concentration in flue gas, ppt	TCDD concentration in flue gas, μg/m³	Emissions per waste oil burned, ng/liter
1000	10	1.0
100	1.0	0.10
10	0.1	0.01
1	0.01	0.001
0.1	0.001	0.0001

TABLE 6-6. AREA SOURCE 30-DAY-AVERAGED EMISSIONS FOR TCDD IN WASTE OIL (JANUARY) (10^{-17} g/s-m²)

Distance from study area centroid, km	TCDD flue gas concentration, ppt				
	1000	100	10	1	0.1
0-5	1360.0	136.00	13.600	1.360	0.13
5-10	548.0	54.80	5.480	0.548	0.055
10-15	465.4	46.54	4.654	0.465	0.047
15-25	168.0	16.80	1.680	0.168	0.017
25-50	17.2	1.72	0.170	0.017	0.002

TABLE 6-7. AREA SOURCE ANNUAL-AVERAGED EMISSIONS FOR TCDD IN WASTE OIL (10^{-17} g/s-m²)

Distance from study area centroid, km	TCDD flue gas concentration, ppt				
	1000	100	10	1	0.1
0-5	552.3	55.23	5.523	0.552	0.055
5-10	222.0	22.20	2.220	0.222	0.022
10-15	188.0	18.80	1.880	0.188	0.019
15-25	70.9	7.09	0.709	0.071	0.007
25-50	7.3	0.73	0.073	0.007	0.001

TABLE 6-8. AVERAGE ANNUAL TCDD CONCENTRATIONS FOR WASTE OIL BURNING IN THE URBAN AREA
(10^{-8} μg/m³)

TCDD flue gas concentration, ppt	Distance from study area centroid, km				
	0-5	5-10	10-15	15-25	25-50
1000	30.714	9.643	8.214	3.214	0.357
100	3.071	0.964	0.821	0.321	0.036
10	0.307	0.096	0.082	0.032	0.004
1	0.031	0.010	0.008	0.003	0.0004
0.1	0.003	0.001	0.001	0.0003	<0.0001

ingestion of TCDD's to no more than 2.1 to 6.3 pg/day should be sufficient to reduce the cancer risk to the 10^{-6} risk level (i.e., 1 cancer in 1,000,000 people). The virtually safe dose for HxCDD's is estimated at about twice that calculated for TCDD's.[22] The EPA's Carcinogen Assessment Group has estimated that lifetime oral exposure to 1.6 pg/day TCDD's may pose a human cancer risk of 10^{-5} (1 in 100,000 people).[22] This is the best estimated value currently available for estimating a reference concentration. Assuming that the body uptake by inhalation corresponds to uptake by oral exposure, and assuming a daily breathing volume of 20 m³ (Appendix E, Equation 2), the reference concentration for TCDD's is:

$$(1.6\ \frac{\text{pg}}{\text{day}})(\frac{1}{20\ \text{m}^3}) = 0.08\ \text{pg/m}^3 = 8 \times 10^{-8}\ \mu\text{g/m}^3$$

Tables 6-1 through 6-8 presented the results of air dispersion modeling. The point-source modeling of small boilers (Sources 1 through 11), space heaters (Sources 12 and 13), and medium-size boilers (Sources 14 through 19) was based on TCDD concentrations in the particulate emissions of 1000, 100, 10, 1, and 0.1 parts per trillion from waste oil burning. The available data suggest that actual values are in the middle of this range. This section presents an estimate of cancer risk from exposure to the modeled point-source emissions.

It should be noted that for all the other waste oil contaminants modeled (metals and organics), cancer risk was calculated only for urban-scale (area) modeling and not for point-source modeling. Health effects (and therefore risk) from nonthreshold substances should be calculated for long-term exposure rather than for short-term (30-day average) maximums around a point source. The point-source modeling was added to this section on dioxins, however, because of the widespread attention now being focused on dioxins.

Table 6-9 presents the maximum ground-level (ambient air) concentrations of dioxin (TCDD) obtained in the point-source and urban area modeling. Of the 19 point sources modeled, the two resulting in the greatest ambient air impacts (Sources 9 and 14, a small and a medium-size boiler) are included in the risk assessment in Table 6-9. Also included are the modeled annual concentrations from the innermost ring of the urban area (0 to 5 km), the portion with the greatest ambient air impact.

As the modeling results show, ground-level concentrations from the small boiler, from the medium-size boiler, and within the urban area core are all comparable in magnitude. Variation resulting from the dioxin concentration in the particulate emissions is far greater than that resulting from the source configuration. The uncertainty of selecting numbers for the dioxin concentration results in comparable uncertainty in estimating risk.

The last two columns in Table 6-9 show the cancer risk expressed both as a risk level to a population as a whole (i.e., 2.54×10^{-5}) and as a risk to the individual (i.e., 1 in 39,400 or 1:39,400). The cancer risk number is obtained by dividing the ground-level concentration by the reference concentration, and

TABLE 6-9. ESTIMATED RISK FROM DIOXIN EMISSIONS

Modeled source	Dioxin (TCDD) flue gas concentrations, ppt	Maximum ground level concentration, 10^{-8} $\mu g/m^3$	Cancer risk	Lifetime cancer risk to an individual
Single-source small boiler (Source 9)	1000	20.303	2.54×10^{-5}	1:39,400
	100	2.030	2.54×10^{-6}	1:394,000
	10	0.203	2.54×10^{-7}	1:3,940,000
	1	0.020	2.54×10^{-8}	1:39,400,000
	0.1	0.002	2.54×10^{-9}	1:394,000,000
Single-source medium-size boiler (Source 14)	1000	31.393	3.93×10^{-5}	1:25,400
	100	3.139	3.93×10^{-6}	1:254,000
	10	0.314	3.93×10^{-7}	1:2,540,000
	1	0.031	3.93×10^{-8}	1:25,400,000
	0.1	0.003	3.93×10^{-9}	1:254,000,000
Urban-scale area source (annual concentrations in 0-5 km area)	1000	30.714	3.84×10^{-5}	1:26,000
	100	3.071	3.84×10^{-6}	1:260,000
	10	0.307	3.84×10^{-7}	1:2,600,000
	1	0.031	3.84×10^{-8}	1:26,000,000
	0.1	0.003	3.84×10^{-9}	1:260,000,000

multiplying that number by 10^{-5} (because the reference concentration is based on a risk level of 10^{-5}). Its inverse is the lifetime cancer risk to an individual.

Cancer risks from the modeled dioxin ground-level concentrations range from 10^{-9} to 10^{-5} or one cancer in 254 to 394 million to one in 25,400 to 39,400. The dioxin concentrations at the lower end of the modeled range result in risks that are at acceptable levels according to criteria most commonly applied to risk assessment (i.e., risks less than 1 cancer in a million). Concentrations in the upper end of the modeled range, however, do result in risks that are potentially significant (i.e., in the area of 10^{-5} and 10^{-6}). The results cannot be accurately quantified to any greater precision at this time because very limited data are available.

These results should be interpreted with the modeling limitations in mind. Several of the assumptions could contribute to erring on the safe side, i.e., overestimating the risk. The urban-area modeling assumes that dioxins are formed and emitted in 100 percent of the sources. Actual formation varies with precursors in the waste oil, with combustion time, and with temperature. It is likely, however, that dioxins are not always formed. If they were formed 75 percent of the time rather than 100 percent of the time, concentrations would be 25 percent less than those shown in Table 6-8. The corresponding risks would decrease to 2.9×10^{-5}, 2.9×10^{-6}, 2.9×10^{-7}, 2.9×10^{-8}, and 2.9×10^{-9} for the five concentrations modeled. In terms of risk, the reduced concentrations do not change the order of magnitude of risk. If TCDD's were formed 10 percent of the time, the concentrations would be only 10 percent of those shown in Table 6-8. The corresponding risks would decrease for the four urban scale modeling concentrations by one order of magnitude, and range from 3.84×10^{-6} to 3.84×10^{-10}.

Finally, it should be kept in mind that the numbers included in Table 6-9 are for the greatest concentrations calculated in the models. Much lower concentrations result in slightly lower risks. The methodology used to generate the figures involves "upper limit" numbers; i.e., the risks are not likely to be any higher than these figures, and they may be much lower. Sufficient data are not available at this time to improve the range of risk estimates.

In summary, the modeling indicates that if the underlying assumptions are correct, cancer risk from dioxin formation during combustion of waste oil may be potentially significant in some cases. The data base for the assumptions is extremely limited, however.

REFERENCES FOR SECTION 6

1. Esposito, M. P., T. O. Tiernan, and F. E. Dryden. Dioxins. EPA 600/2-80-197, 1980.

2. Reggiani, G. Toxicology of TCDD and Related Compounds. In: Workshop on the Impact of Chlorinated Dioxins and Related Compounds in the Environment, Rome, Italy, October 22-24, 1980.

3. Van Miller, J. J. Lalich, and J. R. Allen. Increased Incidence of Neoplasms in Rats Exposed to Low Levels of 2,3,7,8-Tetrachlorodibenzo-p-dioxin. Chemosphere, 6:537-544, 1977.

4. Kociba, R. J., et al. Results of a Two-Year Chronic Toxicity and Oncogenicity Study of 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) in Rats. Toxicology and Applied Pharmacology, 46:279-303, 1978.

5. Homberger, E., et al. The Seveso Accident: Its Nature, Extent and Consequences. Annals of Occupational Hygiene, 22:3272-80, 1979.

6. U.S. Environmental Protection Agency. PCB Disposal by Thermal Destruction. Appendix H: Consideration of Risks and Benefits/Alternatives Concerning PCB Incineration in Region VI. EPA-906/9-82-003, PB82-241860, 1982.

7. National Research Council of Canada (NRCC). Polychlorinated Dibenzo-p-dioxins: Limitations to Current Analytical Techniques. Publication No. 18576. NRCC/NRC, Ottawa, Canada. 1981.

8. National Research Council of Canada. Polychlorinated Dibenzo-p-dioxins: Criteria for Their Effects on Man and His Environment. Publication No. 18574, 1981.

9. Rappe, C., et al. Formation of Polychlorinated Dibenzo-p-dioxins (PCDD's) and Dibenzofurans (PCDF's) by Burning or Heating Chlorophenates. Chemosphere, 7:269-281, 1978.

10. Buser, H. R. Formation of Polychlorinated Dibenzofurans (PCDF's) and Dibenzo-p-dioxins (PCDD's) From the Pyrolysis of Chlorobenzenes. Chemosphere, 8:415-424, 1979.

11. Iida, I., M. Nakoshini, and R. Goto. Evolution of Aromatics on Pyrolysis of Poly(vinylchloride) and Its Mechanism. J. Polym. Sci. Chem. Ed., 12:737, 1964.

12. O'Mara, M. M. J. Polym. Sci., A1(8):1887, 1970.

13. Crummett, W. G. Environmental Chlorinated Dioxins From Combustion--The Trace Chemistries of Fire Hypothesis. Michigan Division Analytical Laboratories, Dow Chemical USA, Midland, Michigan. Pergamon Press. 1982.

14. Rappe, C., et al. Polychloronated Dioxin (PCDDs), Dibenzofurans (PCDFs) and Other Polynuclear Aromatics (PCPNA's) Formed During PCB Fires. Chemica Scripta, 20:56-61, 1982.

15. Franklin Associates Limited and PEDCo Environmental, Inc. Survey of the Waste Oil Industry and Waste Oil Composition. (Draft report) April 1983.

16. Personal communication from B. Bider, Franklin Associates Limited, October 3, 1983.

17. Buser, H. R., H-P. Bösshardt, and C. Rappe. Identification of Polychlorinated Dibenzo-p-dioxin Isomers Found in Fly Ash. Chemosphere, 7:165-172, 1978.

18. GCA Corporation. Draft Data Summary Waste Oil Incineration Study - Sites A, C, E, F. GCA 1-619-068, June 1983.

19. Castaldini, C., et al. A Technical Overview of the Concept of Disposing of Hazardous Wastes in Industrial Boilers. Prepared by Acurex Corporation, Mountain View, California, for U,.S. Environmental Protection Agency, Cincinnati, Ohio. January 1981. pp. 5-36, 5-37.

20. Arthur D. Little, Inc. Study on State of the Art of Dioxin From Combustion Sources. Prepared for American Society of Mechanical Engineers. New York, New York. 1981.

21. U.S. Environmental Protection Agency. Health Assessment Document for Dioxins. Research and Development Peer Review Workshop Draft document prepared by EPA Environmental Criteria and Assessment Office, Cincinnati, Ohio. ECAO-CIN-302A, July 1983.

22. U.S. Environmental Protection Agency. Health and Environmental Effects Profile for Tetra-, Penta- and Hexachlorodibenzo-p-dioxins. Research and Development Peer Review Draft Document prepared by Environmental Criteria and Assessment Office, Cincinnati, Ohio. ECAO-CIN-P004, July 1983.

APPENDIX A

OIL-FIRED BOILER CHARACTERIZATION

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OIL-FIRED BOILER CHARACTERIZATION

One of the approaches to the regulation of waste oil is to limit the number, types, and locations of boilers allowed to burn waste oil as fuel. For example, one possibility would be to allow the use of waste oil as fuel only in oil-fired utility boilers equipped with air pollution control devices. Since this approach is under consideration, it is necessary to gather some information on numbers, types, and locations of boilers (particularly utility, industrial, and commercial/institutional boilers). The figures and tables in this appendix summarize the data gathered on boilers in these three classes.

Utility Residual-Oil-Fired Boilers

Table A-1 summarizes the utility boiler population for which residual oil is the primary fuel in 10 states (California, Florida, Illinois, Louisiana, New Jersey, New York, Ohio, Pennsylvania, Texas, and Virginia). The source of data was "Power Directory, 1981, An Environmental Directory of U.S. Steam Electric Power Plants."[1] This directory was prepared for the Edison Electric Institute by the Utility Data Institute, Inc. The data presented in the "Power Directory" are based on the Edison Electric Institute's POWER Data Base as of January 1981.

TABLE A-1. POPULATION OF UTILITY BOILERS WITH RESIDUAL OIL AS THE PRIMARY FUEL IN URBAN AND RURAL AREAS OF TEN STATES

	Number of boilers[a]	Capacity, MWe[a]	Number of boilers with particulate controls[b]	Capacity of boilers with particulate controls, MWe[b]
Urban I	257 (66.4)	44,460.1 (64.8)	91[c] (35.4)	14,717.2[c] (33.1)
Rural I	130 (33.6)	24,197.9 (35.2)	57[d] (43.8)	13,524.4[d] (55.9)
Urban II	357 (92.2)	63,842.9 (93.0)	141[e] (39.5)	26,134.6[e] (40.9)
Rural II	30 (7.8)	4,815.1 (7.0)	7 (23.3)	2,107.0 (43.8)
Totals	387 (100.0)	68,658.0 (100.0)	148 (38.2)[a]	28,241.6 (41.1)[a]

[a] Numbers in parentheses are percentages of ten-state totals.

[b] Numbers in parentheses are percentages of group totals.

[c] Forty-one boilers with a capacity of 8,483.3 MWe are believed to have electrostatic precipitators.

[d] Fifteen boilers with a capacity of 2,197.8 MWe are believed to have electrostatic precipitators.

[e] Fifty-six boilers with a capacity of 10,681.1 MWe are believed to have electrostatic precipitators.

The 1980-1981 "Electrical World Directory of Electric Utilities" provided supplemental information on the location of some power plants.[2]

The data on the boiler populations of these 10 states were reviewed. For each unit in which residual or No. 6 fuel oil was indicated as the primary fuel, the following data were compiled: company, plant name, unit number, county, town, capacity (MWe), and pollution control device information.

Each plant was categorized into one of four groups. Any city listed in the "1977 Census of Manufacturers, Volume III, Geographic Area Statistics, Parts 1 and 2, General Summary," which provides manufacturing data for cities with 450 manufacturing employees or more,[3] was considered appropriate for our classification. State maps contained in the 1977 Census of Manufacturers were used to determine whether a plant was located in a Standard Metropolitan Statistical Area (SMSA). The four groups defined for this effort are:

Group A - In an SMSA and in a city
Group B - In an SMSA but not in a city
Group C - In a city outside of an SMSA
Group D - Not in a city or an SMSA

Further categories were established to indicate the number of plants in urban or rural areas. In the first of two definitions, it was decided that the Urban I classification would include all plants located within a city; thus, Urban I includes the plants in Group A plus Group C, and Rural I includes the plants in Groups B and D. In the second broader definition, it was decided that Urban II would include all plants in cities or SMSA's; thus, Urban II includes the plants in Groups A, B, and C, and Rural II includes only Group D.

Table A-1 summarizes the total population of utility boilers using residual oil as primary fuel in the 10 states examined. The 10-state population of residual oil utility boilers is 387, representing a capacity of 68,658.0 MWe. Of this total, 148 boilers (41 percent of the total capacity) are equipped with particulate control devices. Two hundred and fifty-seven boilers (nearly 65 percent of the total capacity) fall into the Urban I classification, and particulate emissions from 33 percent of this capacity are controlled by some type of device. In the broader Urban II classification, there are 357 boilers (92% of the total), representing a capacity of 63,842.9 MWe (93% of the total); particulate emissions from 40.9 percent of this capacity are controlled. Thus, nearly all (92%) of the oil-fired utility boilers are located in a city or SMSA. Less than half of these boilers are equipped with pollution control devices. Of the total population, only 56 boilers (14% of the number), representing a capacity of 10,681.1 MWe, appear to have electrostatic precipitators. Many of these boilers are probably former coal-fired units that have been converted to residual-oil-fired units.

Industrial Residual-Oil-Fired Boilers

The population of industrial boilers is presented graphically in Figures A-1 and A-2. Nearly 90 percent of the total

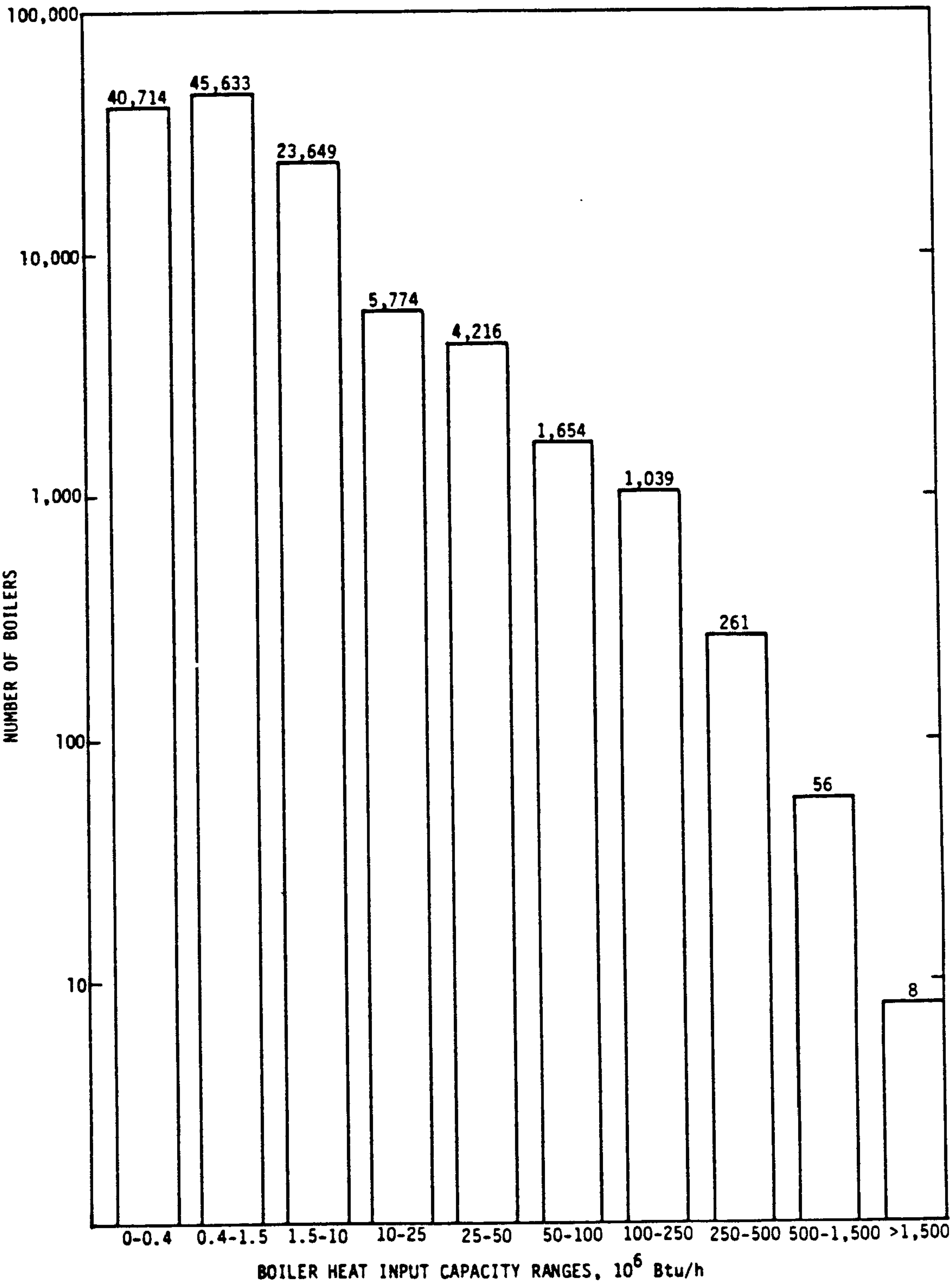


Figure A-1. Number of industrial, residual-oil-fired boilers.

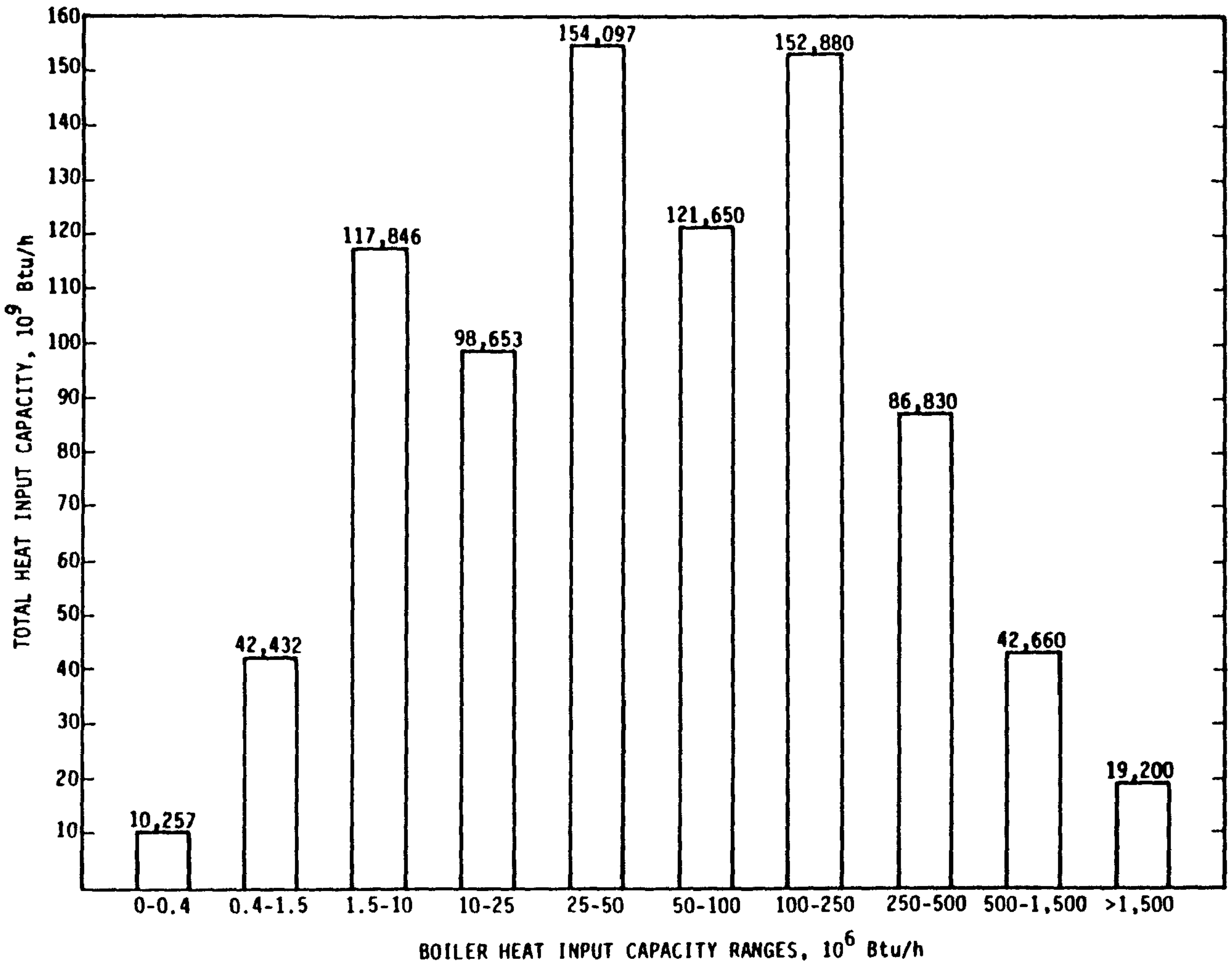


Figure A-2. Heat input capacity of industrial, residual-oil-fired boilers.

number of industrial boilers have a heat input capacity of less than 10 million Btu/h. As shown in Figure A-2, however, this group represents only 20 percent of the total industrial boiler capacity. Fifty percent of the capacity is generated by boilers in the 25 to 250 million Btu/h range, and 82 percent of the capacity is generated by boilers with heat input capacities of less than 250 million Btu/h. Tables A-2 through A-7 provide detailed data on the numbers and capacities of the various sized industrial boilers by type (i.e., water-tube, fire-tube, etc.).

Because of their large number, characterizing the distribution of industrial boilers according to urban vs. nonurban locations would be a formidable and time-consuming task. The number of hours required to complete such an inventory was beyond the scope of this task; therefore, we looked for another parameter that could be used to indicate fuel oil use (and ultimately boiler distribution) by capacity. The parameters considered for estimating boiler distribution were 1) number of manufacturing employees, 2) number of manufacturing establishments, and 3) number of production employees.

The first parameter includes sales and management employees as well as workers, and the second parameter includes brokers or sales establishments as well as actual manufacturers. Therefore, it was decided that the third parameter, number of production employees, would be the least biased of the three because it includes only those employees actually involved with production. The number of production employees was believed to be

TABLE A-2. THE 1977 POPULATION OF INDUSTRIAL WATER-TUBE BOILERS FIRING RESIDUAL OIL

	Number	Capacity, 10^6 Btu/h
Class population	11,872	601,160
Distribution by capacity ranges, 10^6 Btu/h		
0 to 0.4	0	
Over 0.4 to 1.5	744	920
Over 1.5 to 10	2,443	12,540
Over 10 to 25	2,021	32,860
Over 25 to 50	3,616	131,620
Over 50 to 100	1,654	121,650
Over 100 to 250	1,039	152,880
Over 250 to 500	261	86,830
Over 500 to 1,500	56	42,660
Over 1,500	8	19,200

TABLE A-3. THE 1977 POPULATION OF INDUSTRIAL SCOTCH FIRE-TUBE BOILERS FIRING RESIDUAL OIL

	Number	Capacity, 10^6 Btu/h
Class population	18,268	85,805
Distribution by capacity ranges, 10^6 Btu/h		
0 to 0.4	0	
Over 0.4 to 1.5	9,445	9,455
Over 1.5 to 10	6,955	37,867
Over 10 to 25	1,580	27,704
Over 25 to 50	288	10,789
Over 50 to 100	0	
Over 100 to 250	0	
Over 250 to 500	0	
Over 500 to 1,500	0	
Over 1,500	0	

TABLE A-4. THE 1977 POPULATION OF INDUSTRIAL FIREBOX FIRE-TUBE BOILERS FIRING RESIDUAL OIL

	Number	Capacity, 10^6 Btu/h
Class population	24,171	87,283
Distribution by capacity ranges, 10^6 Btu/h		
0 to 0.4	0	
Over 0.4 to 1.5	15,833	15,831
Over 1.5 to 10	6,682	36,671
Over 10 to 25	1,368	23,992
Over 25 to 50	288	10,789
Over 50 to 100	0	
Over 100 to 250	0	
Over 250 to 500	0	
Over 500 to 1,500	0	
Over 1,500	0	

TABLE A-5. THE 1977 POPULATION OF INDUSTRIAL HRT FIRE-TUBE BOILERS FIRING RESIDUAL OIL

	Number	Capacity, 10^6 Btu/h
Class population	5,371	24,873
Distribution by capacity ranges, 10^6 Btu/h		
0 to 0.4	0	
Over 0.4 to 1.5	2,953	2,953
Over 1.5 to 10	1,731	9,907
Over 10 to 25	687	12,013
Over 25 to 50	0	
Over 50 to 100	0	
Over 100 to 250	0	
Over 250 to 500	0	
Over 500 to 1,500	0	
Over 1,500	0	

TABLE A-6. THE 1977 POPULATION OF OTHER INDUSTRIAL FIRE-TUBE BOILERS FIRING RESIDUAL OIL

	Number	Capacity, 10^6 Btu/h
Class population	3,428	10,678
Distribution by capacity ranges, 10^6 Btu/h		
0 to 0.4	0	
Over 0.4 to 1.5	2,305	2,304
Over 1.5 to 10	981	5,391
Over 10 to 25	118	2,084
Over 25 to 50	24	899
Over 50 to 100	0	
Over 100 to 250	0	
Over 250 to 500	0	
Over 500 to 1,500	0	
Over 1,500	0	

TABLE A-7. THE 1977 POPULATION OF INDUSTRIAL CAST IRON BOILERS FIRING RESIDUAL OIL

	Number	Capacity, 10^6 Btu/h
Class population	59,894	36,706
Distribution by capacity ranges, 10^6 Btu/h		
0 to 0.4	40,714	10,257
Over 0.4 to 1.5	14,323	10,979
Over 1.5 to 10	4,857	15,470
Over 10 to 25	0	
Over 25 to 50	0	
Over 50 to 100	0	
Over 100 to 250	0	
Over 250 to 500	0	
Over 500 to 1,500	0	
Over 1,500	0	

roughly indicative of the percentage of fuel burned in urban and nonurban areas. These numbers were taken from the Census of Manufacturers, which lists people according to where they work, rather than from the Census of Population, which lists people according to where they live.

Another note of explanation is necessary. The Census of Manufacturers defines a city as a political division with 450 or more manufacturing employees. This very inclusive definition results in many relatively small towns being defined as cities. For this reason, we have used a combination of that definition and the Bureau of Census definition of a city (i.e., population of 25,000 or more). Thus, a city is defined as having a population of 25,000 or more and 450 or more manufacturing employees.

Table A-8 summarizes the number of production workers in urban and nonurban areas for selected states.[3,4] As requested by EPA, we have included two definitions of an urban area. Urban I includes all cities having a population greater than or equal to 25,000 and at least 450 manufacturing employees; urban II includes all SMSA's and those cities (as defined above) not located in SMSA counties.

As shown in Table A-8, the number of production workers in urbanized areas varies significantly from state to state. California, New York, and Pennsylvania are predominantly urban in character; whereas Maine, Vermont, Georgia, and South Carolina are predominantly nonurban.

In the 22 states investigated, approximately 43.7 percent

TABLE A-8. SUMMARY OF PRODUCTION WORKERS IN URBAN AND NONURBAN AREAS.

		URBAN I[a]		RURAL		URBAN II[b]		RURAL II	
STATE	PRODUCTION WORKERS IN STATE	# OF PRODUCTION WORKERS	PERCENT	# OF PRODUCTION WORKERS	PERCENT	# OF PRODUCTION WORKERS	PERCENT	# OF PRODUCTION WORKERS	PERCENT
ALABAMA	273.00	86.10	31.54	186.90	68.46	150.40	55.09	122.60	44.91
CALIFORNIA	1142.60	783.30	68.55	359.30	31.45	1091.90	95.56	50.70	4.44
CONNECTICUT	255.30	106.80	41.83	148.50	58.17	236.00	92.44	19.30	7.56
DELAWARE	32.30	3.90	12.07	28.40	87.93	20.70	64.09	11.60	35.91
FLORIDA	249.20	109.00	43.74	140.20	56.26	224.00	89.89	25.20	10.11
GEORGIA	376.20	66.90	17.78	309.30	82.22	154.60	41.10	221.60	58.90
ILLINOIS	857.80	456.30	53.19	401.50	46.81	736.00	85.80	121.80	14.20
LOUISIANA	145.20	49.90	34.37	95.30	65.63	94.10	64.81	51.10	35.19
MAINE	84.20	11.40	13.54	72.80	86.46	22.90	27.20	61.30	72.80
MARYLAND	162.90	58.40	35.85	104.50	64.15	128.80	79.07	34.10	20.93
MASSACHUSETTS	407.90	224.20	54.96	183.70	45.04	362.50	88.87	45.40	11.13
NEW HAMPSHIRE	72.00	23.40	32.50	48.60	67.50	31.10	43.19	40.90	56.81
NEW JERSEY	489.60	178.80	36.52	310.80	63.48	477.70	97.57	11.90	2.43
NEW YORK	958.10	555.80	58.01	402.30	41.99	857.40	89.49	100.70	10.51
N. CAROLINA	611.30	123.70	20.24	487.60	79.76	260.00	42.53	351.30	57.47
OHIO	924.40	398.20	43.08	526.20	56.92	753.80	81.54	170.60	18.46
PENNSYLVANIA	934.10	282.80	30.28	651.30	69.72	759.30	81.29	174.80	18.71
RHODE ISLAND	94.70	60.20	63.57	34.50	36.43	92.90	98.10	1.80	1.90
S. CAROLINA	299.80	37.00	12.34	262.80	87.66	139.40	46.50	160.40	53.50
TEXAS	600.70	360.30	59.98	240.40	40.02	509.10	84.75	91.60	15.25
VERMONT	28.70	0.00	0.00	28.70	100.00	0.00	0.00	28.70	100.00
VIRGINIA	302.00	107.40	35.56	194.60	64.44	153.40	50.79	148.60	49.21
W. VIRGINIA	89.20	21.30	23.88	67.90	76.12	56.50	63.34	32.70	36.66
TOTAL	9391.20	4105.10	43.71	5286.10	56.29	7312.50	77.87	2078.70	22.13

[a] PRODUCTION WORKERS IN CITIES WITH A POPULATION OF 25,000 OR MORE AND 450 MANUFACTURING EMPLOYEES

[b] PRODUCTION WORKERS IN SMSA'S AND CITIES (AS DEFINED ABOVE) NOT LOCATED IN SMSA COUNTIES

of all production workers are located in cities having a population of 25,000 or more and at least 450 manufacturing employees, and 56.3 percent are in rural areas. In the second definition of urban areas (SMSA's and cities not in SMSA counties), about 77.9 percent of all production workers are in urban areas and 22.1 percent in rural areas. Thus, assuming that boiler capacity distribution is directly proportional to the number of production workers, the boilers generating a little more than three-quarters of the industrial boiler capacity are located in cities or SMSA's; the remainder are in rural locations.

Commercial/Institutional Residual-Oil-Fired Boilers

Commercial/institutional oil-fired boilers are those used in hospitals, greenhouses, shopping malls, and similar applications. The very nature of this type of boiler makes their distribution correlate well with population. No attempt was made to locate actual commercial/institutional boilers and categorize them as being in an urban or rural location.

Figures A-3 and A-4 present data on the distribution of commercial/institutional boilers by number and by heat input capacity. Most commercial boilers are small: 88 percent (by number) have heat input capacities of less than 1.5 million Btu/h, and 98 percent have heat input capacities of less than 10 million Btu/h. Much of the heat input capacity of commercial/institutional boilers (i.e., about 25 percent) is found in the 1.5 to 10 million Btu/h range. About half of the total generated capacity is represented by boilers with heat input capacities of less than 10 million Btu/h. Tables A-9 through A-14 provide

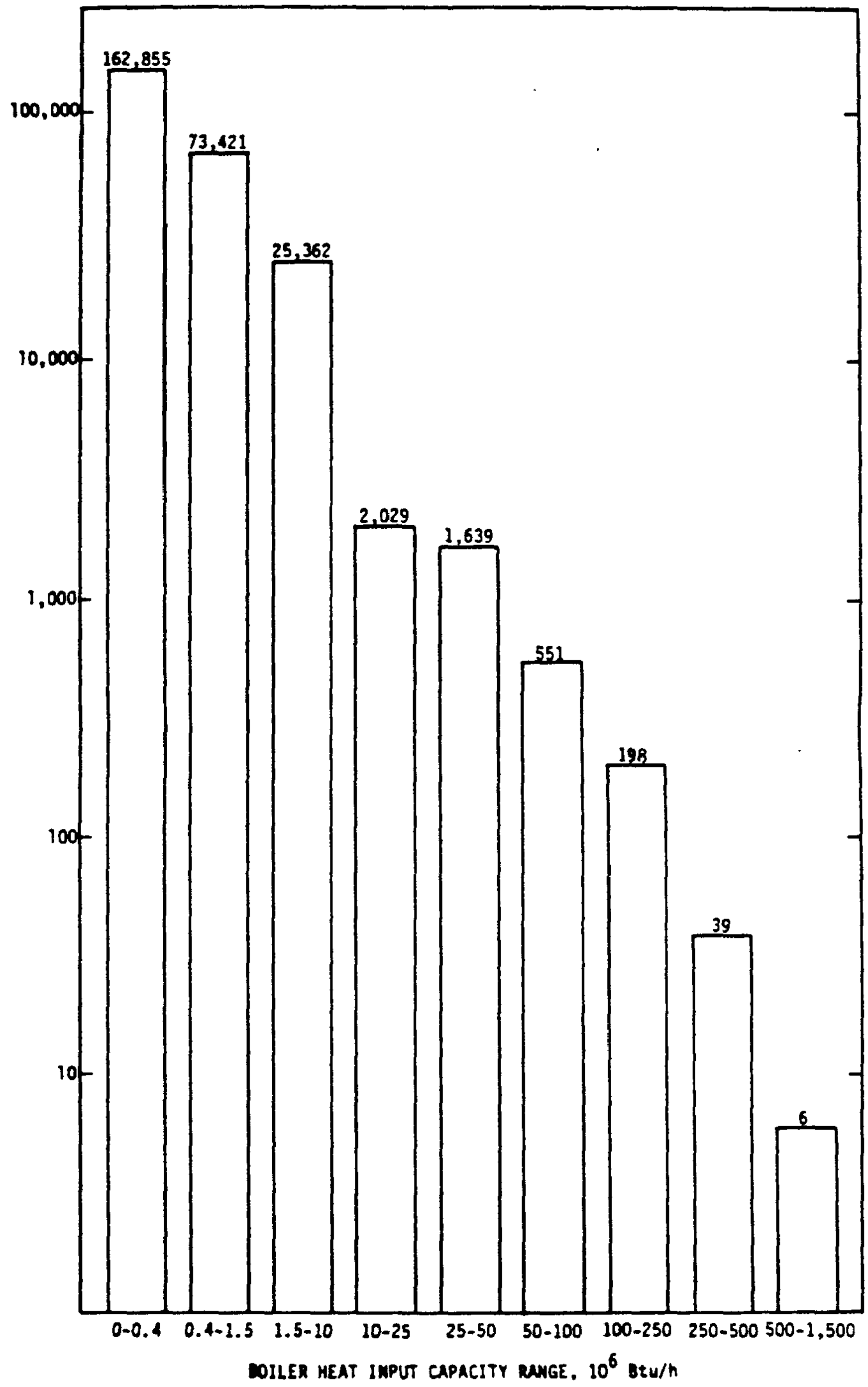


Figure A-3. Number of commercial/institutional, residual-oil-fired boilers.

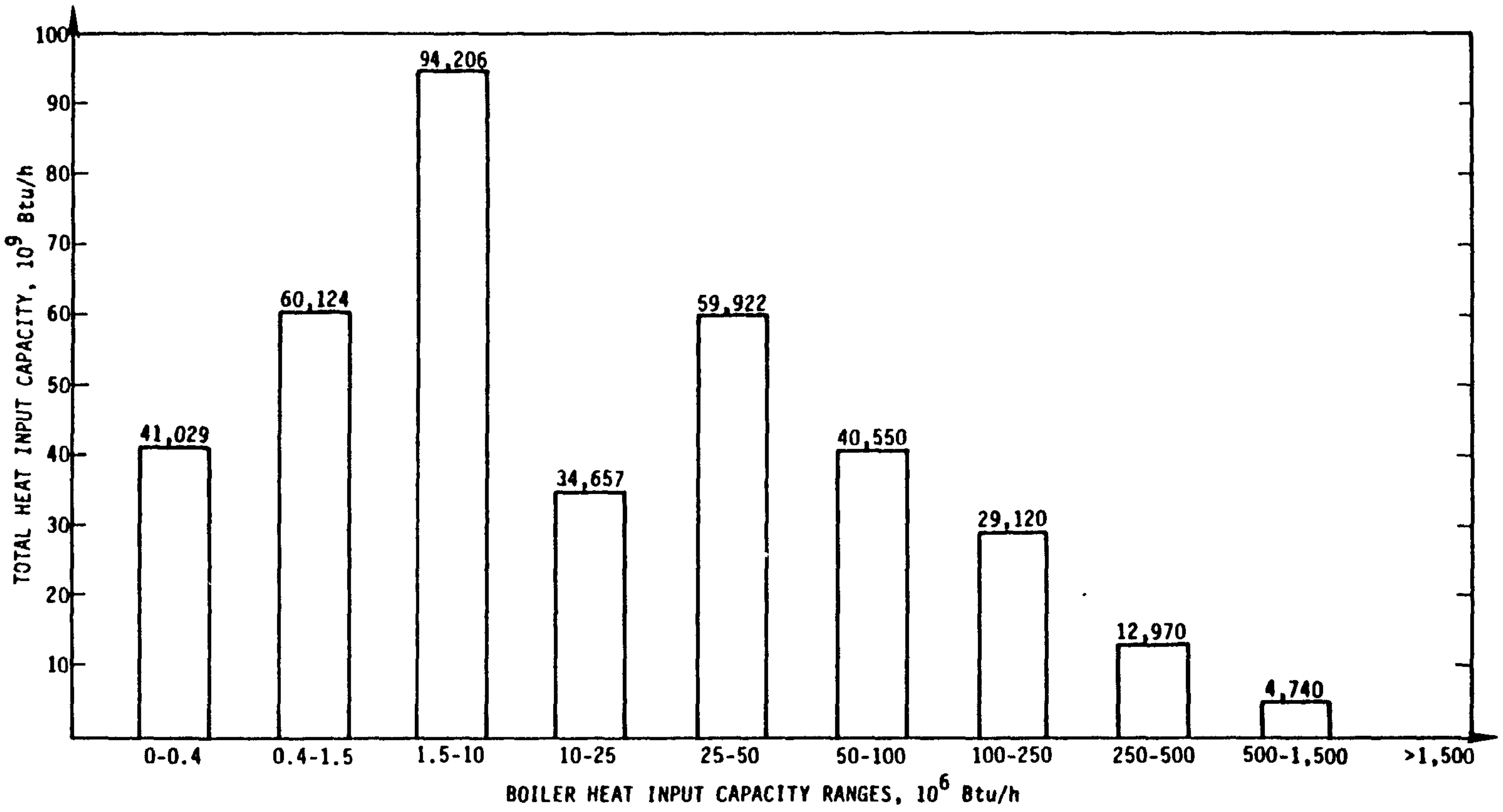


Figure A-4. Heat input capacity of commercial/institutional, residual-oil-fired boilers.

TABLE A-9. THE 1977 POPULATION OF COMMERCIAL WATER-TUBE BOILERS FIRING RESIDUAL OIL

	Number	Capacity, 10^6 Btu/h
Class population	4,081	154,540
Distribution by capacity ranges, 10^6 Btu/h		
0 to 0.4	0	
Over 0.4 to 1.5	399	480
Over 1.5 to 10	772	3,960
Over 10 to 25	710	11,540
Over 25 to 50	1,406	51,180
Over 50 to 100	551	40,550
Over 100 to 250	198	29,120
Over 250 to 500	39	12,970
Over 500 to 1,500	6	4,740
Over 1,500	0	

TABLE A-10. THE 1977 POPULATION OF COMMERCIAL/INSTITUTIONAL SCOTCH FIRE-TUBE BOILERS FIRING RESIDUAL OIL

	Number	Capacity, 10^6 Btu/h
Class population	7,729	30,753
Distribution by capacity ranges, 10^6 Btu/h		
0 to 0.4	0	
Over 0.4 to 1.5	4,866	4,865
Over 1.5 to 10	2,196	11,958
Over 10 to 25	555	9,734
Over 25 to 50	112	4,196
Over 50 to 100	0	
Over 100 to 250	0	
Over 250 to 500	0	
Over 500 to 1,500	0	
Over 1,500	0	

TABLE A-11. THE 1977 POPULATION OF COMMERCIAL/INSTITUTIONAL FIREBOX FIRE-TUBE BOILERS FIRING RESIDUAL OIL

	Number	Capacity, 10^6 Btu/h
Class population	10,589	32,362
Distribution by capacity ranges, 10^6 Btu/h		
0 to 0.4	0	
Over 0.4 to 1.5	8,156	8,156
Over 1.5 to 10	2,110	11,580
Over 10 to 25	481	8,430
Over 25 to 50	112	4,196
Over 50 to 100	0	
Over 100 to 250	0	
Over 250 to 500	0	
Over 500 to 1,500	0	
Over 1,500	0	

TABLE A-12. THE 1977 POPULATION OF COMMERCIAL/INSTITUTIONAL HRT FIRE-TUBE BOILERS FIRING RESIDUAL OIL

	Number	Capacity, 10^6 Btu/h
Class population	2,309	8,871
Distribution by capacity ranges, 10^6 Btu/h		
0 to 0.4	0	
Over 0.4 to 1.5	1,522	1,522
Over 1.5 to 10	546	3,128
Over 10 to 25	241	4,221
Over 25 to 50	0	
Over 50 to 100	0	
Over 100 to 250	0	
Over 250 to 500	0	
Over 500 to 1,500	0	
Over 1,500	0	

TABLE A-13. THE 1977 POPULATION OF OTHER COMMERCIAL/INSTITUTIONAL FIRE-TUBE BOILERS FIRING RESIDUAL OIL

	Number	Capacity, 10^6 Btu/h
Class population	1,548	3,971
Distribution by capacity ranges, 10^6 Btu/h		
0 to 0.4	0	
Over 0.4 to 1.5	1,187	1,187
Over 1.5 to 10	310	1,702
Over 10 to 25	42	732
Over 25 to 50	9	350
Over 50 to 100	0	
Over 100 to 250	0	
Over 250 to 500	0	
Over 500 to 1,500	0	
Over 1,500	0	

TABLE A-14. THE 1977 POPULATION OF COMMERCIAL/INSTITUTIONAL CAST IRON BOILERS FIRING RESIDUAL OIL

	Number	Capacity, 10^6 Btu/h
Class population	239,574	146,821
Distribution by capacity ranges, 10^6 Btu/h		
0 to 0.4	162,855	41,029
Over 0.4 to 1.5	57,291	43,914
Over 1.5 to 10	19,428	61,878
Over 10 to 25	0	
Over 25 to 50	0	
Over 50 to 100	0	
Over 100 to 250	0	
Over 250 to 500	0	
Over 500 to 1,500	0	
Over 1,500	0	

more detailed data on the numbers and capacities of various sizes of commercial/institutional boilers by type of boiler (i.e., water-tube, fire-tube, etc.).

Geographical Distribution of Residual-Oil-Fired Boilers

Although it was not an objective of this study to survey small boilers, it is useful to provide some indication of the relative potential use of waste oil across the Nation. Two approaches were considered for obtaining an estimate of the small boiler distribution. The first approach was to base the distribution on residual fuel oil deliveries to the commercial/institutional sector by state. These data are available from the U.S. Department of Energy. This approach indicated that three states (New York, New Jersey, and Louisiana) accounted for 54 percent of the fuel oil deliveries. This large percentage results from the DOE figures reflecting fuel deliveries rather than fuel use. States with large ports suitable for oil barges would naturally show the largest amounts of fuel delivered. This obvious bias eliminated the use of fuel oil delivery data from further consideration.

A second approach was based on data obtained from a survey of states and waste oil collectors/processors. Franklin Associates Ltd. conducted the survey and used the information obtained to estimate the amount of waste oil generated by each state and the approximate portion of the generated waste oil that is burned as fuel.[5] These numbers are shown in Table A-15. Based on the assumption that about 50,000 small boilers in the country

TABLE A-15. AN ESTIMATE OF THE DISTRIBUTION OF SMALL BOILERS (<15 million Btu/h) WITH THE POTENTIAL FOR BURNING WASTE OIL

State	Waste oil generated, 1000 gallons	Proportion burned per state, %	Amount burned per state, 1000 gallons	Proportion burned, % of total	Number of small boilers
Alabama	14,500	60	8,700	1.46	730
Alaska	1,400	30	400	0.07	35
Arkansas	10,600	80	8,500	1.43	715
Arizona	9,100	70	6,700	1.12	560
California	74,500	60	44,700	7.49	3,745
Colorado	9,600	70	6,700	1.12	560
Connecticut	6,900	30	2,100	0.35	175
Delaware	2,000	90	1,800	0.30	150
Florida	18,800	80	15,000	2.52	1,260
Georgia	18,600	60	11,200	1.88	940
Hawaii	1,600	60	1,000	0.17	85
Idaho	2,800	30	800	0.13	65
Illinois	51,800	70	36,300	6.09	3,045
Indiana	25,500	30	7,600	1.27	635
Iowa	12,600	40	5,000	0.84	420
Kansas	15,600	80	12,500	2.10	1,050
Kentucky	15,400	70	10,800	1.81	905
Louisiana	29,100	80	23,300	3.91	1,955
Maine	3,000	80	2,400	0.40	200
Maryland	10,600	90	9,500	1.59	795
Massachusetts	13,000	90	11,700	1.96	980
Michigan	48,200	80	38,600	6.47	3,235
Minnesota	17,300	70	12,100	2.03	1,015
Mississippi	9,600	70	6,700	1.12	560
Missouri	24,300	80	19,400	3.25	1,625
Montana	3,800	40	1,500	0.25	125
Nebraska	9,100	80	7,300	1.22	610
Nevada	1,700	70	1,200	0.20	100
New Hampshire	1,400	90	1,300	0.22	110
New Jersey	34,500	80	27,600	4.63	2,315
New Mexico	4,900	70	3,400	0.57	285
New York	31,400	80	25,100	4.21	2,105
North Carolina	18,100	60	10,900	1.83	915
North Dakota	2,900	60	1,700	0.29	145
Ohio	54,500	40	21,800	3.66	1,830
Oklahoma	20,500	70	14,400	2.41	1,205
Oregon	11,500	90	10,400	1.74	870
Pennsylania	58,700	80	47,000	7.88	3,940
Rhode Island	2,000	90	1,800	0.22	150
South Carolina	7,800	70	5,500	0.92	460
South Dakota	2,800	70	2,000	0.34	170
Tennessee	18,500	80	14,800	2.48	1,240
Texas	78,200	70	54,700	9.17	4,585
Utah	4,300	50	2,100	0.35	175
Vermont	1,100	80	900	0.15	75
Virginia	14,100	85	12,000	2.01	1,005
Washington	10,800	90	9,700	1.63	815
Washington, D.C.	1,100	90	1,000	0.17	85
West Virginia	9,400	60	5,600	0.94	470
Wisconsin	15,300	50	7,600	1.27	635
Wyoming	3,100	50	1,600	0.27	135
Total	867,900	69 (average)	596,400		~50,000

could be burning waste oil (as estimated in Reference 5), these 50,000 were distributed according to the amount of waste oil estimated to be burned in each state. The resulting distribution is shown in Table A-15. This method indicated that New Jersey, New York, Pennsylvania, Illinois, Michigan, Texas, and California have the largest number of small boilers with the potential for burning waste oil. These seven states account for almost 46 percent of the 50,000 boilers. Illinois, Michigan, Texas, and California alone account for 29 percent of the total. Other states with a significant number of small boilers with the potential for burning waste oil are Ohio, Virginia, Tennessee, Florida, Louisiana, Oklahoma, Kansas, Nebraska, and Minnesota.

The accuracy of this second method is questionable for two reasons: 1) the number of small boilers with the potential for burning waste oil (~50,000) is only an estimate; and 2) the distribution shown in Table A-15 is based on the premise that the amount of waste oil burned correlates directly with the number of small boilers. The actual relationship is probably less direct.

REFERENCES FOR APPENDIX A

1. Utility Data Institute, Inc. Power Directory, 1981 - An Environmental Directory of U.S. Steam Electric Power Plants. Prepared for Edison Electric Institute. 1981.

2. Electrical World Directory of Electric Utilities (1980-1981). 89th ed. McGraw-Hill, Inc., New York. 1980.

3. U.S. Department of Commerce. 1977 Census of Manufacturers. Volume III, Geographic Series. Bureau of Census, Washington, D.C. 1981.

4. U.S. Department of Commerce. County and City Data Book 1977. Bureau of Census, Washington, D.C. 1978.

5. Franklin Associates Limited and PEDCo Environmental, Inc. Survey of the Waste Oil Industry and Waste Oil Composition Draft Report. April 1983.

APPENDIX B

AIR QUALITY MODELING TECHNIQUES
AND
ASSUMPTIONS

APPENDIX B

AIR QUALITY MODELING TECHNIQUES AND ASSUMPTIONS

B.1 INTRODUCTION

Two air dispersion models were selected for the calculation of air quality impact due to emissions from waste oil burning. Modeling was performed at two different spatial scales of analysis to investigate air quality impacts from estimates of concentrations from single sources and areawide sources over a year. The three models selected and used in the Section 4 analysis were:

1) The Industrial Source Complex Model[1] for monthly impacts within 10 km.

2) The Hanna-Gifford Model[2] for monthly and annual impacts within 50 km.

3) The Brookhaven/Pacific Northwest Model[3] for monthly and annual impacts beyond 50 km.

Section 4 focused on the use of these models and the resulting estimates. This appendix describes each model in more detail and presents the modeling assumptions, techniques, and input variables and how they were specified.

B.2 INDUSTRIAL SOURCE COMPLEX (ISC) MODEL

The Industrial Source Complex (ISC) Model[1] is a steady-state Gaussian plume model that can be used to assess pollutant concentrations from a wide variety of sources associated with an industrial source complex. This model can account for settling and dry deposition of particulates, downwash, area, line, and volume sources; plume rise as a function of downwind distance; physical separation of point sources; and limited terrain adjustment. It operates in both long-term (monthly to annual) and short-term (1- to 24-hour) averaging time modes. The ISC concentration model for point sources uses the steady-state Gaussian plume equation for a continuous ground-level or elevated source. For each stack and each hour, the hourly ground-level concentration at downwind distance x and crosswind distance y is given by:

$$\chi = \frac{KQ}{\pi \bar{u} \sigma_y \sigma_z} \exp \left[- \tfrac{1}{2} \left(\frac{y}{\sigma_y} \right)^2 \right] [V] [D]$$

where Q = pollutant emission rate

K = a scaling coefficient for units

σ_y, σ_z = standard deviation of the lateral and vertical concentration

$\bar{u}$ = mean windspeed at stack height

V = accounts for vertical plume spread, reflection from the ground and upper mixing height limits, and gravitational settling

D = accounts for simple pollutant removal by physical or chemical processes

Specifications of variables, model options, and output are summarized in Table B-1.

The long-term version of the ISC Model was applied to calculate monthly average concentrations of contaminants with a

TABLE B-1. ISC MODEL SPECIFICATIONS

Parameter	Description
Input requirements	Emissions data: Location, emission rate, pollutant decay coefficient, elevation of source (MSL), stack height, stack exit velocity, stack inside diameter, stack exit temperature, particle size distribution with corresponding settling velocities, surface reflection coefficient, dimensions of adjacent buildings. Meteorological data: Short-term--hourly surface weather data, including cloud ceiling, wind direction, windspeed, temperature, opaque cloud cover. Daily mixing height is also required. Long-term--stability wind rose (STAR deck), average afternoon mixing height, average morning mixing height, and average air temperature.
Output	Concentration or deposition for any averaging time for any combination of sources. Table of high, second-high values and highest 50.
Model options	Site-specific wind profile exponents, site-specific vertical temperature gradients, dry deposition, terrain effects (limited), variable emission rates, stack and building downwash.
Model limitations	Flat or gently rolling terrain.
Pollutant types	Nonreactive. Particulates with or without significant settling velocities. Reactive pollutants, if they can be accounted for by the exponential decay term.
Source-receptor relationships	Arbitrary location for point, line, area, and volume sources. Arbitrary receptor locations or receptor rings. Receptors at ground level at elevation not exceeding stack height.
Plume behavior	Briggs plume-rise formulas. Building downwash and stack tip downwash. If plume height exceeds mixing height, ground-level concentration set to zero. Does not treat fumigations.
Horizontal wind field	Uses user-supplied hourly windspeeds. Uses user-supplied hourly wind direction (nearest 10 degrees), internally modified by addition of a random integer value between -4 degrees and +5 degrees. Windspeeds corrected for release height based on power law variation, different exponents for different stability classes, reference height = 10 meters. Constant, uniform (steady-state) wind assumed within each hour.
Vertical wind field	Assumed equal to zero.
Dispersion	Semi-empirical/Gaussian plume. Six hourly stability classes. Dispersion coefficient for urban or rural.
Chemistry/reaction mechanism	Exponential decay, user input time constant. Surface deposition.
Physical removal	Settling and dry deposition of particulates.

threshold response resulting from the burning of waste oil in single or multiple point sources. The long-term version of ISC calculates concentrations for specific meteorological categories and then determines the weighted concentration average at each receptor, based on climatological frequency distributions.

All point-source characteristics for medium-size and small boilers and space heaters were specified in Sections 3 and 4. Three options in the ISC Model provide methods for including variations of the Gaussian plume approximation: 1) plume downwash, 2) particle deposition, and 3) physical and chemical removal.

Downwash effects due to building wake were not included because the low plume heights lead to conservative concentration estimates even if downwash effects are not included. A second reason for not including these effects was the ill-defined nature of typical stack-building configurations.

The importance of considering the particulate size distribution of emissions due to waste oil burning was assessed by applying the ISC Model for sources both with and without deposition. The input parameters used in this sensitivity analysis are presented in Table B-2. The methods suggested in the ISC Model were used to calculate the mass mean diameter, the settling velocity, and the reflection coefficient (how much is reflected from the surface versus how much is retained) for each particle size category. The particle size distribution was derived from previous emissions testing[4] and represents a particle size distribution of lead particulate emissions due to waste oil burning. Results of this analysis for the whole range of small boiler sizes (capacities of 19 to 246 liters/h) indicate a maximum difference of less than about 2 percent in a comparison of the highest downwind concentrations with and without deposition.

TABLE B-2. PARTICLE DISTRIBUTION AND CALCULATED CHARACTERISTICS

Particle size category, μm	Percentage by weight in each category, %	Mass mean diameter, μm	Settling velocity, cm/s	Reflection coefficient (unitless)
<1	76	0.63	0.002437	1.0
1-10	16	6.52	0.25295	0.88
10-50	8	33.9	6.838	0.57

The sensitivity of the ISC Model calculations to physical and chemical reactivity was also tested by using the first-order decay coefficient algorithm included in the ISC Model. The equation, which adjusts for pollutant reactivity, decreases the emissions term as a function of downwind distance and pollutant half-life and takes the form:

$$D = \exp\left[-\psi\, x/\bar{u}\right]$$

where D = decay term in Gaussian equation

x = downwind distance, m

$\bar{u}$ = the average wind speed, m/s

ψ = decay coefficient, liters/s = $0.693/T_{\frac{1}{2}}$

$T_{\frac{1}{2}}$ = pollutant half-life, s

A contaminant half-life of 5 hours yielded concentration estimates less than 1 percent different from those concentrations without reactivity. Because most of the organic contaminants of interest had half-lives greater than 5 hours (indicating even less model sensitivity), all subsequent ISC calculations neglected contaminant reactivity.

Meteorological data used in the ISC Model analysis of waste oil burning included windspeed, wind direction, atmospheric stability, monthly averaged mixing heights, and monthly averaged ambient temperatures. The primary meteorological input for the long-term ISC Model is the STability ARray (STAR), a joint frequency distribution of windspeed, wind direction, and atmospheric stability class. For this analysis, meteorological data characteristic of an urban location were selected, i.e. from the John F. Kennedy International Airport (National Weather Service, Station No. 94789) for the years 1974-1978. For this 5-year period, 3720 observations were tabulated for the month of January. Figure B-1 presents a wind rose combining all stability classes for January at the JFK Airport. Of considerable prominence are winds from the west and northwest at all atmospheric stabilities.

The mixing heights and temperatures for the study area were estimated by use of available mixing height climatologies[5] and Local Climatological Data summaries.[6] All meteorological inputs were determined as specified by the ISC Model. Values used in the analysis are presented in Table B-3.

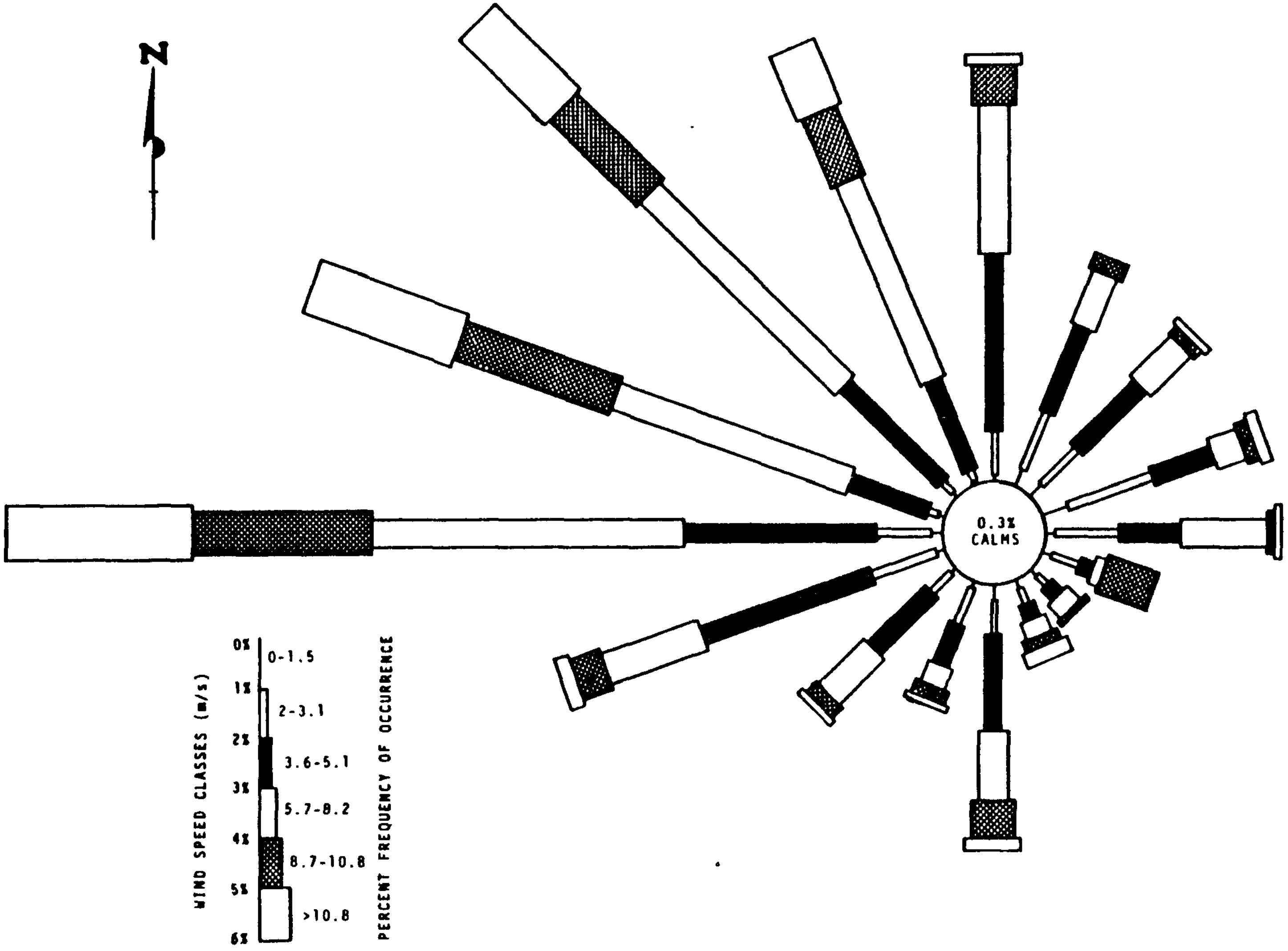


Figure B-1. Wind rose for JFK International Airport, 1974-1978.

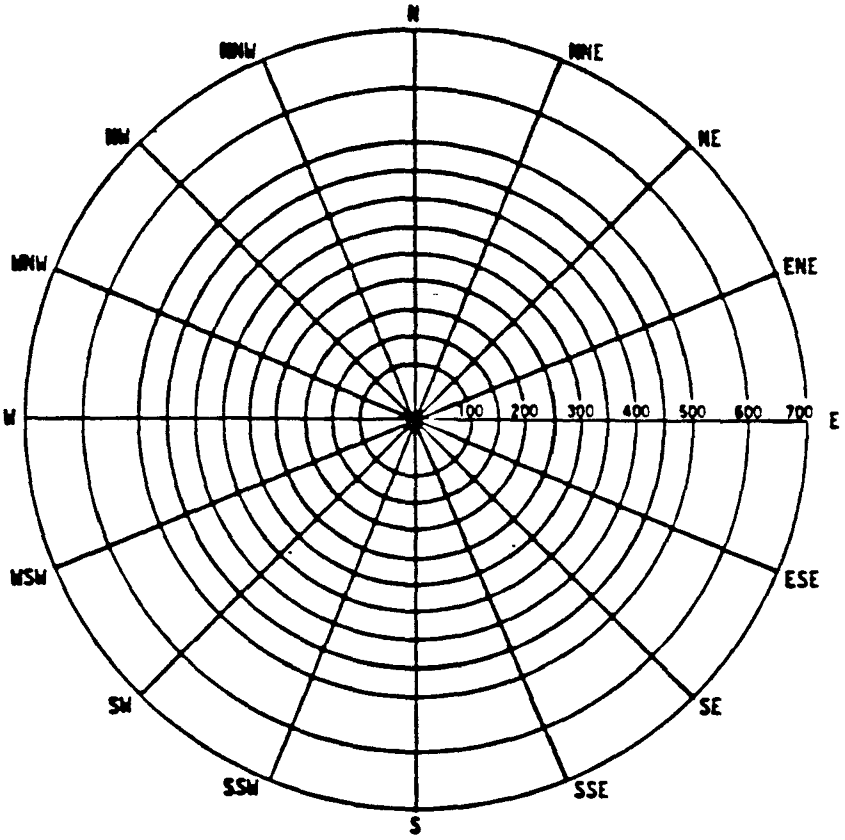
TABLE B-3. AVERAGE JANUARY TEMPERATURES AND MIXING HEIGHTS FOR NEW YORK USED IN ISC ANALYSIS

	Stability class					
	A	B	C	D	E	F
Average January temperature, K	276	276	276	273	269	269
Average January mixing heights, m	1350	900	900	925	950	950

Preliminary analysis of the characteristics of stacks of small and medium-size boilers and space heaters indicated maximum concentrations within the first 1000 meters of the lower-stack sources and within 1500 for the taller-stack sources. An array of 320 receptor locations was selected to ensure that the maximum monthly concentrations were located for each individual source analysis. These receptors were arranged in concentric circles at 20 specified distances every 22.5 degrees (16 directions in all) around the source. The receptors were located at distances of 100, 150, 200, 250, 300, 350, 400, 450, 500, 600, 700, 800, 900, 1000, 1500, 2000, 2500, 3000, 4000, and 5000 meters distant from the source. The receptor grid used in each analysis is shown in Figure B-2.

B.3 HANNA-GIFFORD MODEL

The Hanna-Gifford Model[2] was developed by the Air Resources Atmospheric Turbulence and Diffusion Laboratory at Oak Ridge, Tennessee, and has been used by the EPA for previous hazardous pollutant analyses.[7] The model is a simple but realistic dispersion model that has proved to be adequate for estimating



NOT SHOWN: 800, 900, 1000, 1500, 2000, 2500, 3000, 4000, 5000m.

RECEPTORS ARE LOCATED AT INTERSECTION OF RAYS AND CONCENTRIC CIRCLES.

Figure B-2. Receptor grid used in ISC Model analysis of single and multiple sources.

pollutant concentrations due to widely distributed low-level and area source emissions in urban areas.[8,9,10] The surface concentration of each pollutant was directly proportional to the local area (or grid) source strength and inversely proportional to average windspeed as indicated by the following equation:

$$\chi = CQ_i/u$$

where χ = the average surface concentrations over the analysis grid

Q_i = the total distributed emissions of a given pollutant over a specified area (i)

u = the average windspeed (averaged over the period of interest)

C = a constant that relates the ambient concentrations to source contributions within the grid of the analysis and those upwind

The constant C may be defined in terms of the grid size, the average number of upwind grids, and two stability-dependent empirical coefficients. The constant C is expressed by:

$$C = \left(\frac{2}{\pi}\right)^{\frac{1}{2}} \left(\frac{1}{a(1-b)}\right) \left(\frac{\Delta x}{2}\right)^{1-b} \left[1+ \sum_{i=1}^{N} \left((2i+1)^{1-b}-(2i-1)^{1-b}\right)\right]$$

where Δx = grid size in meters

a,b = stability dependent coefficients for D-stability;

$a = 0.15(m)^{1-b}$, $b = 0.75$

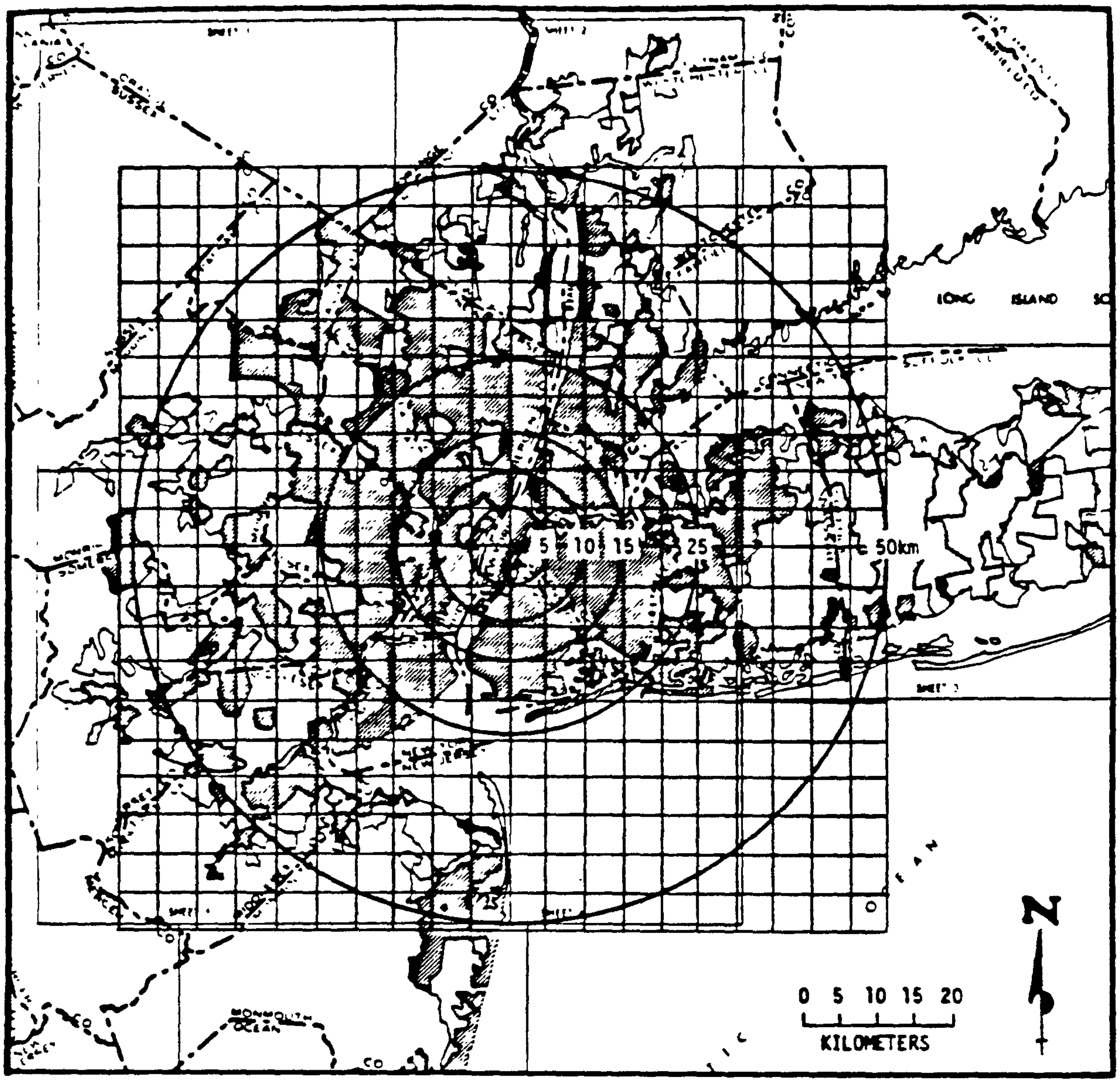
The study area selected for this analysis was a highly urban portion of AQCR 43. The area was characterized by a large number of small boilers and space heaters and high population densities. Figure B-3 presents the study area and shows the five subareas that were used in this analysis and the 5 km x 5 km grids in each subarea. The major divisions between subareas are the concentric circles at intervals of 5, 10, 15, 25, and 50 km, as indicated.

For calculation of the factor C, the constants a and b as specified, the average number of upwind grids (N = 9), and the grid size (5 km) were used. The resulting constant C was 314. As a test of the sensitivity of the Hanna-Gifford Model to particle deposition and contaminant reactivity, the factor C was modified and tested for each effect. Testing the factor C was most appropriate because of its dependence on upwind emission grids, which can be adjusted for deposition and reactivity effects.

For the case of particle depositon, the factor C was modified by incorporating a plume depletion technique (as summarized in Slade).[11] The factor C (including the effects of deposition) took the form:

$$C = \left(\frac{2}{\pi}\right)^{\frac{1}{2}} \left(\frac{1}{a(1-b)}\right) \left(\frac{\Delta x}{2}\right)^{1-b} \left[\sum_{j=1}^{M} f_j (F_j)_{\Delta x/4} + \sum_{i=1}^{N} \sum_{j=1}^{M} \left[\left((2i+1)^{1-b} - (2i-1)^{1-b} \right) \left(f_j (F_j)_{i\Delta x} \right) \right] \right]$$

where $(F_j)_{\Delta x/4}$ = the depletion factor for each particle category j taken in the grid wherein the receptor lies at half the distance from the center of the grid to its edge ($\Delta x/4$)



* Only grids within 50-km ring are considered in analysis.

Figure B-3. Urban study area with subareas and 5 km x 5 km grids.*

$(F_j)_{i\Delta x}$ = the plume depletion factor for each particle size category j in each grid at a distance $i\Delta x$ from the receptor

f_j = percent of particles in particle size category j

Based on a particle distribution similar to that in Section A.2 (90 percent are less than or equal to 10 μm and 10 percent are greater than 10 μm), a factor of C equal to 310 was calculated. This, and the effects of deposition made only a 1 percent difference over the entire urban study area and was considered insignificant in terms of calculating subarea contaminant concentration estimates.

Factors to adjust upwind concentrations for reactive physical and chemical processes also may be estimated by using the first-order rate decay term suggested in the ISC Model. The suggested expression (with symbols modified for consistency with the previous equation) was:

$$D_{i\Delta x} = \exp\left(-\frac{0.693\ i\Delta x}{T_{\frac{1}{2}}\ \bar{u}}\right)$$

where $D_{i\Delta x}$ = the decay factor for grid i at distance $i\Delta x$

Δx = grid spacing in m

$\bar{u}$ = monthly, seasonal, or annual average windspeed in m/s

$T_{\frac{1}{2}}$ = half-life of the given pollutant in seconds

The resulting expression for C was:

$$C = \left(\frac{2}{\pi}\right)^{\frac{1}{2}} \left(\frac{1}{a(1-b)}\right) \left(\frac{\Delta x}{2}\right)^{1-b} \left[D_{\Delta x/4} + \sum_{i=1}^{N} \left((2i+1)^{1-b} - (2i-1)^{1-b}\right) (D_{i\Delta x})\right]$$

where $D_{\Delta x/4}$ = depletion factor for grid where receptor is located

A half-life of 8 hours was used with a windspeed of about 6 m/s (an average value from climatological records) to calculate a C factor of 302. Using the value of C (302) rather than the original 314 results in a concentration decrease of about 4 percent at 50 km. Because most of the organic contaminants had characteristic half-lives in ambient air that were longer than 8 hours, and because concentration differences were less than 4 percent, effects of reactivity were considered insignificant and therefore received no further consideration.

The Hanna-Gifford Model was applied in an iterative fashion by using the calculated value of the parameter C, estimating the appropriate monthly or annual windspeeds, and estimating the subarea emissions due to waste oil burning. Because upwind grids of emissions are considered to be the same as the grid under consideration (with the uniform emissions assumption), wind direction was of little consequence. The contaminant concentration estimate for air that was made in each ring was assumed to be applicable over the whole subarea.

The area (in square meters) of each subarea in Figure B-3 was calculated to determine the extent over which subarea-specific emissions were distributed. The areas of each subarea bounded by the distances specified in Figure B-3 are as shown in Table B-4.

TABLE B-4. AREAS OF EACH STUDY SUBAREA

Distance from study area centroid, km	Area of subarea, 10^7 m²
0-5	7.85
5-10	23.6
10-15	39.3
15-25	134.
25-50	589.

Based on the estimates of emissions of waste oil contaminants, emissions per liter of waste oil burned were calculated for the contaminant levels assumed at the 90th percentile values. These emissions estimates were used with the estimates of waste oil burned in each subarea to calculate the rates of emissions. Expressed in equation form:

$$Q_i = \frac{WOG_i * EF * CF * HDDF_i}{AREA_i * ATF}$$

where Q_i = the emission rate in which each subarea i, g/s-m²

WOG_i = the waste oil generated in each subarea i, liters/yr

EF = the contaminant emission factor, g/liter

CF = the combustion factor, i.e., the portion of waste oil generated that is burned

$HDDF_i$ = the monthly or annual use factor based on heating degree-days in each subarea i

ATF = the averaging time factor to convert time units to seconds

$AREA_i$ = the area of each subarea, m²

The emission factors for each contaminant are specified in Table 4-24. Distribution of waste oil generated within the urban area is described in Appendix C. The state's available waste oil per year was apportioned to the individual urban study subareas by distribution of multiple-dwelling units. The use of multiple dwellings is thought to provide the best distribution of waste oil consumption because these are the most likely locations for small boilers and space heaters.

The combustion factors (CF) were based on state and local estimates of waste oil burning as described in Appendix A (see Table A-15) and set equal to 70 percent for AQCR 43. The use factors ($HDDF_i$) were calculated on the basis of heating degree-days. This is a reasonable basis for calculation because the waste oil burned was proportional to the demand for space heating. On an annual basis, $HDDF_i$ equaled 1.0 because all the waste oil that was available for burning was burned sometime during the year. For the monthly analysis, $HDDF_i$ was estimated as a function of the ratio of heating degree-days for January and the annual heating degree-days. This ratio was assumed to reflect the use of waste oil for burning in January as a percent of the total available in a year. Table B-5 describes the National Weather Service (NWS)[12,6] locations and the associated heating degree-day totals for each subarea of the urban analysis. At least 10 or more years of observations were used in the climatological summaries of heating degree-days. All emissions for January totals of threshold contaminants and annual totals of nonthreshold contaminants were presented in Section 4.4.2.

TABLE B-5. HEATING DEGREE-DAY TOTALS IN EACH URBAN SUBAREA AND ASSOCIATED USE FACTOR ($HDDF_i$)

Distance from study area centroid, km	NWS sites	Heating degree-day totals		$HDDF_i$[a]
		January	Annual	
0-5	Central Park	1017	4848	0.21
5-10	La Guardia	1020	4909	0.21
10-15	Newark	1042	5034	0.21
15-25	JFK International	1042	5184	0.20
25-50	Bridgeport	1079	5461	0.20

[a] $HDDF_i$, the ratio of January to annual heating degree-days for subarea (i).

One other critical element in the application of the Hanna-Gifford Model to the urban study area was the specification of windspeed averaged over the two averaging times of interest (i.e., January and annual). The five NWS stations used to derive the heating degree-day totals were examined to determine monthly and annual average windspeeds. Outside of the 0-5 km subarea, windspeeds were nearly identical with the reduced windspeeds evident within the 0-5 km subarea. Table B-6 describes the derived windspeeds used in all subsequent calculations with the Hanna-Gifford Model for urban-scale modeling.

TABLE B-6. JANUARY AND ANNUAL AVERAGE WINDSPEEDS FOR THE URBAN-SCALE MODELING

Distance from study area centroid, km	Average windspeeds, m/s	
	January	Annual
0-5	4.8	4.2
5-10	5.8	5.4
10-15	5.8	5.4
15-25	5.8	5.4
25-50	5.8	5.4

Because all grids within a given subarea had uniform emissions, only five receptor points were needed to describe the concentrations in the urban study area, i.e., one in each subarea. In the Hanna-Gifford Model, a receptor is usually placed in each grid; in this case, however, the uniformity of emissions (i.e., adjacent grids had the same concentrations) was unnecessary. The assumption of uniform emissions in each subarea was reasonable because of the ill-defined nature of the sources and emissions.

REFERENCES FOR APPENDIX B

1. Bowers, J. F., J. R. Bjorkland, and C. S. Cheney. Industrial Source Complex (ISC) Dispersion Model User's Guide, Volumes 1 and 2. EPA-450/4-79-030 and EPA-450/4-79-031, December 1979.

2. Gifford, F. A., and S. R. Hanna. Modeling Urban Air Pollution. Atmos. Environment, 7:131-136, 1973.

3. Rowe, M. D. Human Exposure to Particulate Emissions From Power Plants. Brookhaven National Laboratory. Upton, Long Island, New York. BNL 51305, May 1981.

4. U.S. Environmental Protection Agency. Report to Congress; Waste Oil Study. Accession No. PB-257693, April 1974.

5. Holzworth, G. C. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. Environmental Protection Agency, Research Triangle Park, North Carolina. AP-101, January 1972.

6. National Oceanic and Atmospheric Administration. Local Climatological Data for J. F. Kennedy International Airport. National Climatic Center, Asheville, North Carolina. 1979.

7. Anderson, G. E., et al. Human Exposure to Atmospheric Concentrations of Selected Chemicals. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. March 1980.

8. Hanna, S. R. A Simple Method of Calculating Dispersion from Urban Area Sources. JAPCA, 21(8), December 1971.

9. Miller, C. W. An Application of the ATDL Simple Dispersion Model. JAPCA, 28(8), August 1978.

10. Hanna, S. R. Urban Diffusion Problems. Presented at the AMS Workshop of Meteorology and Environmental Assessment, Boston, Massachusetts, October 1975.

11. Atomic Energy Commission. Meteorology and Atomic Energy 1968. Slade, D. H., ed. Oak Ridge, Tennessee. July 1971.

12. National Oceanic and Atmospheric Administration. Local Climatological Data. Central Park, New York, New York, 1979; La Guardia Airport, New York, New York, 1979; Newark, New Jersey, 1979; Bridgeport, Connecticut, 1975. National Climatic Center, Asheville, North Carolina.

APPENDIX C

ESTIMATES OF WASTE OIL BURNED IN URBAN STUDY AREA

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The Hanna-Gifford model[1] was chosen to estimate airborne emissions and their dispersion over a medium-range area (0 to 50 km in diameter). The exposures from the ground-level concentrations of waste oil contaminants (as calculated by the modeling) were subsequently used to estimate risk to human populations.

The amount of waste oil available for use as a fuel source was taken from a recent report that gave a breakdown of total waste oil generation by state.[2] These numbers were adjusted by deducting the amount of oil that is not recycled back into the collection system[3] (i.e., waste oil that is unavailable to collectors and processors), and the remaining volume of waste oil was then distributed among all Air Quality Control Regions (AQCR's) in the contiguous United States according to the population figures given in the 1980 Census.[4] This approach was used for both the Hanna-Gifford and the Brookhaven Long Range Transport models.[5]

Because the intent of the study was to determine whether uncontrolled burning of waste oil presents an environmental problem requiring regulation, an exposure scenario was developed that is believed to represent maximum concentrations of waste oil contaminants to which high-density population areas typical of populated northeastern cities are exposed. A hypothetical study area was constructed by using a pattern of five concentric rings with increasing radial distances (5, 10, 15, 25 and 50 kilometers) from the study area center. The amount of waste oil generated, the portion of that waste oil burned, and the population densities were then calculated for each ring, based on statistics from the northeastern United States.

The distribution of waste oil among the five rings was based on the estimated demand for fuel oil from multiple-family dwelling units.

The estimation of demand was calculated by modifying the "heating degree-day formula" outlined in the EPA's Guide for Compiling a Comprehensive Emission Inventory.[6] The modified formula is as follows:

$$\text{Demand for heating oil (gallons)} = 0.18\ a\left(\frac{b}{5}\right)c$$

where 0.18 = gallons burned per dwelling unit per heating degree-day

a = heating degree-days per year

b = rooms per dwelling unit

c = number of dwelling units in study area

The demand for waste oil as a heating fuel was estimated by considering only multiple-family dwelling units equipped to burn oil because waste oil is generally not burned in the type of small heating furnaces used in single-family homes. The rooms per dwelling unit (b) and the number of dwelling units in the study area (c) were adjusted to reflect only multiple-family dwellings. Table C-1 presents the results. It is assumed that the percent demand for heating fuel oil by multiple-family dwelling in each ring reflects the same level of demand for waste oil resources. An estimated total amount of waste oil available for heating and the percent demand for oil from multiple-family housing were used to calculate annual estimates of waste oil burned in the study area (Table C-2). This table also presents monthly and seasonal estimates of waste oil. These estimates are based on portional reductions in the heating degree-days for the highest-demand month (January) and the highest-demand season (winter: December, January, and February).

TABLE C-1. CALCULATION OF DEMAND FOR HEATING OIL BY MULTI-FAMILY DWELLING UNITS IN THE STUDY AREA

Study area ring	Distance from center, km	Average heating degree days/year[a]	Average rooms/multi-family dwelling unit[b]	Number of multi-family dwelling units[b]	Percent of dwelling units equipped to burn heating oil	Estimated annual need for heating oil for multi-family buildings	
						10^3 gal	percentage
1	0-5	4848	3.2	535,126	63	188,300	14
2	5-10	4909	3.5	679,251	58	243,700	17
3	10-15	5075	3.6	885,990	56	326,300	24
4	15-25	5241	3.7	1,116,475	55	428,700	31
5	25-50	5696	3.8	449,528	54	189,200	14
Total				3,666,370		1,376,200	100

[a] Annual heating degree-days (these are averages of heating degree-day data from weather stations located in each ring).[6]

[b] Reference 4.

TABLE C-2. CALCULATION OF WASTE OIL USAGE IN THE STUDY AREA

Study area ring	Distance from center, km	Waste oil generated,[a] 1000 gal/yr	Waste oil available for burning (70%),[b] 1000 gal/yr	Percentage demand for heating oil from multi-family dwelling units[c]	Annual estimate of waste oil burned, 1000 gal/yr	Monthly and seasonal estimates of waste oil			
						January		Winter	
						%[d]	1000 gal/mo.	%[d]	1000 gal/ Dec.-Feb.
1	0-5			14	3,584	0.21	753	0.58	2,079
2	5-10			17	4,352	0.21	914	0.58	2,524
3	10-15			24	6,144	0.21	1,290	0.58	3,564
4	15-25			31	7,936	0.20	1,587	0.56	4,444
5	25-50			14	3,584	0.20	717	0.55	1,971
Total		36,572	25,600	100	25,600		5,261		14,582

[a] Reference 2.

[b] Estimate obtained from Franklin Associates Limited. Personal communication, C. Jarvis, PEDCo Environmental with R. Hunt, February 1983.

[c] See Table A-1.

[d] January percentage values represent the number of heating degree-days in January divided by the annual number of heating degree-days. Seasonal percentage values represent the number of heating degree-days for the winter months of December, January, and February divided by the annual number of heating-degree-days.[6]

REFERENCES FOR APPENDIX C

1. Hanna, S. R. A Simple Method of Calculating Dispersion from Urban Area Sources. JAPCA, 21(12), December 1971.

2. Franklin Associates Limited. Evaluation of the Use of Waste Oil as a Dust Suppressant. Draft Report. January 1983.

3. Franklin Associates Limited. Waste Oil Management and Composition. Draft Report. February 1983.

4. U.S. Department of Commerce. 1980 Census Summary Tape File (STF3). Bureau of Census, Washington, D.C. January 1983.

5. Eadie, W. J., and W. E. Davis. The Development of a National Inter-Regional Transport Matrix for Respirable Particulates. Pacific Northwest Laboratories, Richland, Washington. PNL-RAP-37, 1979.

6. U.S. Environmental Protection Agency. Guide for Compiling a Comprehensive Emission Inventory. Washington, D.C. APTD-1135, 1976.

APPENDIX D

COMPARISON OF CONTAMINANT EMISSION RATES FROM THE COMBUSTION OF WASTE OIL WITH THOSE FROM OTHER COMBUSTION SOURCES

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COMPARISON OF CONTAMINANT EMISSION RATES FROM THE COMBUSTION OF WASTE OIL WITH THOSE FROM OTHER COMBUSTION SOURCES

Atmospheric emissions of contaminants from the burning of waste oil may have some adverse environmental impact. The potential contaminant emissions discussed here are:

- Lead
- Arsenic
- Polynuclear aromatic hydrocarbons
- Benzene
- Naphthalene

Emission rates of these contaminants from waste oil combustion are compared with their emission rates from other combustion sources.

LEAD EMISSIONS

Lead emissions from the following sources are compared: 1) a space heater burning waste oil, 2) an idling car burning leaded fuel, 3) an idling car burning unleaded fuel, 4) a small boiler (9×10^6 Btu/h) burning waste oil, and 5) a small boiler (9×10^6 Btu/h) burning residual fuel oil.

Lead contamination in waste oil is estimated to be 220 µg/g,[1] and in automotive waste oil, it can be as high as 1000 µg/g.[2] Lead concentrations can be as high as 2.65 g/gal in leaded gasoline[3] and 0.5 g/gal in unleaded gasoline.[2] Since July 1983, the lead in leaded gasoline has been limited to 1.1 g/gal.[3]

Both this value and the higher estimated value (2.65 g/gal) were used in this comparison because currently available waste oil could have been contaminated prior to the effective date of this limitation. Assuming a density of 3.3 kg/gal for gasoline, the lead concentration converts to 800 µg/g and 150 µg/g for leaded and unleaded gasoline, respectively. The concentration of lead in residual or No. 6 fuel oil ranges from 0.4 to 2.0 µg/g.[1] For all combustion processes except space heaters, it is assumed that 75 percent of the lead is emitted through the exhaust to the atmosphere. An atomizing space heater is estimated to emit 50 percent of the lead in the fuel.[3] A vaporizing space heater retains more of the lead in the pot residue, and 4 to 30 percent of the lead is estimated to be emitted.[3] In this comparison, a conservative number of 25 percent will be used for this source.

Another critical assumption for this comparison is that an idling car will burn 2 gallons of gasoline per hour. This estimate may be high; however, because of the wide range of fuel economy (1 to 3 gallons per hour) in automobile engines, 2 gallons was arbitrarily selected and is probably a conservative value. This theoretical approach was taken to estimate lead emissions from automobiles because no specific data are available on the amount of lead emitted by an "average" automobile in the course of an hour's operation.

Based on these assumptions, lead emission rates were calculated and are presented in Table D-1. The emission rate at the source does not directly relate to risk because dispersion modeling parameters were not considered. These data only indicate the

TABLE D-1. ESTIMATE OF LEAD EMISSION RATES

	Fuel feed rate, g/h	Lead concentration, μg/g	Percent lead emitted	Lead emission rate, μg/s
Atomizing space heater, 100% waste oil	3,580	220-1000	50	110-500
Vaporizing space heater, 100% waste oil	3,500	220-1000	25	55-250
Idling car, leaded fuel	6,700	330[a]-800	75	460-1,100
Idling car, unleaded fuel	6,700	150	75	210
Small boiler, 100% waste oil	220,000	220-1,000	75	10,000-46,000
Small boiler, residual fuel oil	220,000	0.4-2	75	18-92

[a] As of July 1983, refineries will be limited to 1.1 g/gal of lead.[3]

potential rate of lead emissions from one particular isolated source.

ARSENIC EMISSIONS

Arsenic contamination in waste oil is 11 µg/g (median) and 16 µg/g (90th percentile).[1] The concentration in residual fuel oil ranges from 0.2 to 0.8 µg/g.[1,4] It is estimated that 75 percent of the arsenic in the waste oil or fuel is emitted to the atmosphere from combustion in boilers. In space heaters, 50 percent of the arsenic is emitted from atomizing burners and 25 percent from vaporizing burners. Based on these assumptions, the arsenic emission rates were calculated and reported in Table D-2. The arsenic emission rate from space heaters is 3 to 8 µg/s. The arsenic emission rate from small boilers burning 100 percent waste oil is 504 µg/s (median) and 733 µg/s (90th percentile), and the emission rate from the same source while burning residual oil is 9 to 37 µg/s.

POLYNUCLEAR AROMATIC HYDROCARBONS

Polynuclear aromatic hydrocarbons (PNA's) have been reported to be contaminants in waste oil.[5] This group of compounds is also a product of incomplete combustion.[6] Typical combustion process temperatures up to 800°C (1500°F) provide the environment for the formation of PNA's.[7] Thus, the burning of waste oil may cause the emission of PNA's to the atmosphere. These emissions are of concern because several members of this class of organics compounds are considered to be nonthreshold contaminants.

TABLE D-2. ESTIMATE OF ARSENIC EMISSION RATES

	Fuel feed rate, g/h	Arsenic concentration, µg/g	Percent arsenic emitted	Arsenic emission rate, µg/s
Atomizing space heater, 100% waste oil	3,580	11-16	50	5-8
Vaporizing space heater, 100% waste oil	3,580	11-16	25	3-4
Small boiler, 100% waste oil	220,000	11-16	75	504-733
Small boiler, residual fuel oil	220,000	0.2-0.8	75	9-37

Sources of PNA emissions under consideration for this discussion are waste oil space heaters (atomizing and vaporizing pot), small boilers burning waste oil, and small boilers burning residual fuel oil.

Based on the literature estimates, emissions from vaporizing pot space heaters are higher in PNA's than those from atomizing space heaters.[8] Table D-3 presents emission test data for several PNA compounds for these two combustion sources. The average total PNA emission rate from vaporizing pot space heaters is 75 $\mu g/m^3$, and the average from atomizing space heaters is 15 $\mu g/m^3$. Benzo(a)pyrene (BaP) emissions average 7 $\mu g/m^3$ from vaporizing pot space heaters and 1 $\mu g/m^3$ from atomizing space heaters. Assuming a volumetric flow rate* of 0.12 m^3/s for the vaporizing pot heater and 0.044 m^3/s for the atomizing heater, the emission rates are as follows:

Space heater type	Emission rates ($\mu g/s$)	
	PNA	BaP
Atomizing	0.7	0.04
Vaporizing pot	9	0.8

Emission factors reported in the literature for residual-oil-fired boilers with capacities of less than 250 x 10^6 Btu/h are 46 ng/Btu for PNA's and 0.4 to 1.0 ng/Btu for BaP.[9,10] Benzo(a)pyrene is also included because specific data are available for this particular PNA compound. Based on these emission factors, it is

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* The assumed volumetric flow rates are based on velocities measured during tests reported in Reference 8; a stack diameter of 20 cm is assumed.

TABLE D-3. TEST RESULTS OF PNA EMISSIONS FROM SPACE HEATERS BURNING WASTE OIL[a]

Compound	Amount detected, $\mu g/m^3$ dry			
	Vaporizing pot		Atomizing	
	Run 1	Run 2	Run 1	Run 2
Naphthalene	12	6	5	4
Acenaphthene	--	--	0.3	0.2
Acenaphthylene	2	--	--	--
Fluorene	6	0.6	0.8	0.7
Phenanthrene	70[b]	5	6	4
Anthracene	--	2	0.2	0.2
Fluoranthene	--	--	0.4	0.5
Pyrene	3	2	0.5	0.5
Benzo(_a_)anthracene	--	4	0.2	0.4
Chrysene	--	--	0.2	0.4
Benzo(_k_/_b_)fluoranthene	--	6	--	--
Benzo(_e_)pyrene	5	6	--	0.05
Benzo(_a_)pyrene	6	8	--	1
Perylene	--	6	--	0.6
Indeno(1,2,3-_c_,_d_)pyrene	--	--	--	0.8
Benzo(_g_,_h_,_i_)perylene	--	--	0.1	0.6
Anthanthrene	--	--	0.1	1.1
Coronene	--	--	--	0.1
Total	104	46	14	15

[a] Reference 8.

[b] This seemingly high result was verified by fragment ion patterns and appears to be an outlier.

estimated that PNA emissions from a boiler burning residual oil at 9×10^6 Btu/h would be approximately 110 μg/s and BaP emissions would be 1 to 2.5 μg/s.

Data are insufficient to indicate that PNA emissions from the combustion of waste oil differ from those from combustion of virgin oil. Concentrations of BaP in waste oil are similar to those in regular fuel oils. Table D-4 presents the BaP concentrations in various oils. Concentrations of BaP have been found in residual fuel oil at levels from 10 to 320 ppm and at levels up to 400 ppm in waste oil. Typical values in residual and waste oil are 10 to 15 ppm.[4] Other PNA compounds that the literature indicates are found in waste oil are presented in Table D-5.

The uncontrolled emission factor for PNA from the combustion of waste oil is reported as 0.0075 lb/10^3 gal (0.9 mg/liter).[11] Assuming a waste oil feed rate of 220,000 g/h (246 liters/h), the PNA emission rate would be 60 μg/s based on this emission factor. The two estimated emission rates (60 μg/s and 110 μg/s) for small boilers burning waste oil and residual oil, respectively, are generally equivalent. Table D-6 summarizes the estimated emission rates for the PNA compounds and BaP just discussed.

BENZENE AND NAPHTHALENE

Estimates of benzene and naphthalene emissions are based on theoretical calculations and available test data. The three sources evaluated are 1) space heaters burning waste oil, 2) small boilers burning waste oil, and 3) small boilers burning residual fuel oil.

TABLE D-4. BENZO(a)PYRENE CONCENTRATIONS IN VARIOUS OILS[a]
(μg/g)

Oil type	Concentrations
Virgin No. 2 oils	0.03-0.6
Virgin No. 4 oil	2.1
Virgin No. 5 oils	2.8-3.3
Virgin No. 6 oils (residual oils)	2.9-44
Unused motor oil basestocks	0.03-0.28
Used motor oils and waste oils	3.2-28
Used diesel motor oil	<0.15
Used synthetic motor oil	16
Used oil (new car dealer)	0.7
Unused re-refined motor oil basestock	2.1
Used industrial oil	5.9
Reprocessed used oil	10.5
Used oil/fuel oil blends	1.6-3.0

[a] Reference 11.

TABLE D-5. TEST RESULTS OF ANALYSIS OF WASTE OIL SAMPLES FOR PNA COMPOUNDS[a] (μg/g)

Compound	Average concentration[b]
Naphthalene	390
Phenanthrene/Anthracene	190
Pyrene	32
Benz(a)anthracene/Benz(a)phenanthrene	18
Benzo(a)pyrene	12
Total	640

[a] Reference 12.

[b] Average of analysis results on 14 waste oil samples.

TABLE D-6. ESTIMATE OF PNA EMISSION RATES (μg/s)

	PNA compounds	BaP
Atomizing space heater, 100% waste oil	0.7	0.04
Vaporizing pot space heater, 100% waste oil	9	0.8
Small boiler, 100% waste oil	60	
Small boiler, residual fuel oil	110	1-2.5

TABLE D-7. CONCENTRATIONS OF BENZENE AND NAPHTHALENE IN RESIDUAL AND WASTE OIL SAMPLES (ppm)

	Residual oil	Waste oil
Benzene	<2-37[a] 20 (avg)	18-890[b] 70 (avg)
Naphthalene		110-1400[b] 460 (avg)

[a] Reference 11.

[b] Reference 5.

An analysis of residual oil and waste oil samples is presented in Table D-7 for the two compounds of interest. These data are from the available literature sources. Based on these data, a direct correlation is made to compare benzene and naphthalene emissions from small boilers of the same type and feed rate, with one burning 100 percent waste oil and the other burning residual fuel oil. Assuming the two combustion processes have the same destruction efficiency, emissions would be directly proportional to the pollutant concentration in the oil.

The assumed destruction removal efficiency for vaporizing pot space heaters was 40 percent, and that for the atomizing space heaters was 53 percent.[3] Destruction removal efficiency was assumed to be 97 percent for small boilers.[1] Based on these assumptions and the concentrations presented in Table D-7, the estimated emission rates for benzene and naphthalene were calculated and are presented in Table D-8.

A summary of all emissions discussed in this report is presented in Table D-9.

TABLE D-8. CALCULATED BENZENE AND NAPHTHALENE EMISSION RATES

Source	Fuel feed rate, g/h	Destruction efficiency, %	Emission rate, µg/s	
			Benzene	Naphthalene
Vaporizing pot space heater, 100% waste oil	3,580	40	42	270
Atomizing space heater, 100% waste oil	3,580	53	33	215
Small boiler, 100% waste oil	220,000	97	290	1,060
Small boiler, residual oil	220,000	97	37	

TABLE D-9. SUMMARY OF ESTIMATED EMISSION RATES[a]
(μg/s)

Source	Pollutant					
	Lead	Arsenic	PNA	BaP	Benzene	Naphthalene
Atomizing space heater, 100% waste oil	110	5	0.7	0.04	33	215
Vaporizing pot space heater, 100% waste oil	55	3	9	0.8	42	270
Idling car, leaded fuel	460	-	-	-	-	-
Idling car, unleaded fuel	210	-	-	-	-	-
Small boiler, 100% waste oil	10,000	504	60		290	1,060
Small boiler, residual oil	55	23	110	1.8	37	

[a] Only average or median values reported on this table. Maximum or 90th percentile values were reported in text and on previous tables.

REFERENCES FOR APPENDIX D

1. PEDCo Environmental, Inc. A Risk Assessment of Waste Oil Burning in Boilers and Space Heaters. (Preliminary draft) U.S. Environmental Protection Agency Office of Solid Waste. May 1983.

2. Letter to Docket Clerk from Timothy A. Vanderver, Jr., Counsel for Walter Kroll GmbH and Heating Alternatives, Inc. August 14, 1980.

3. Robertson, W. Implications of the Report "Chemical Analysis of Waste Crankcase Oil Combustion Samples" and Other Studies on the Burning of Used Oil. Robertson Company. May 12, 1983.

4. U.S. Environmental Protection Agency. Memo to Stephen A. Lingle from Michael Petruska. Subject: Comparison of Fuel Oils and Waste Oils. June 8, 1983.

5. GCA Corporation. The Fate of Hazardous and Nonhazardous Wastes in Used Oil Recycling. (Draft final report) Prepared for U.S. Department of Energy. April 15, 1983.

6. Davies, I. W., et al. Municipal Incinerator as Source of Polynuclear Aromatic Hydrocarbons in Environment. Environmental Science and Technology, 10(5):May 1976.

7. National Academy of Sciences. Particulate Polycyclic Organic Matter. 1972.

8. Cooke, M., et al. Emissions From Waste-Oil-Fired Heaters. Prepared by Battelle-Columbus Laboratories for U.S. Environmental Protection Agency. May 1983.

9. Krishnan, E. R., and G. V. Hellwig. Trace Emissions from Coal and Oil Combustion. Environmental Progress, 1(4):November 1982.

10. Surprenant, N. F., et al. Emissions Assessment of Conventional Stationary Combustion Systems: Vol. IV. Commercial/-Institutional Combustion Sources. EPA-600/7-81-003b, 1981.

REFERENCES (continued)

11. Recon Systems, Inc., and ETA Engineering, Inc. Used Oil Burned as a Fuel. 1980.

12. Brinkman, D. W., P. Fennelly, and N. Surprenant. The Fate of Hazardous Wastes in Used Oil Recycling (Abstract) U.S. Department of Energy and GCA Corporation. April 1983.

13. Hall, R. R. Comparative Analysis of Contaminated Heating Oils. (Draft Final Report) Prepared for U.S. Environmental Protection Agency by the GCA Corporation. May 1983.

APPENDIX E

HEALTH EFFECTS ASSESSMENT METHOD

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HEALTH EFFECTS ASSESSMENT METHOD

INTRODUCTION

Assessing the effects of waste oil burning on human health requires an individual analysis of the impact of each waste oil contaminant. Analysis of waste oil emissions as a single waste stream is not practical because of the wide range of health effects produced by the various individual emission components. When the impact on human health is examined, two general classes of effects can be distinguished: threshold and nonthreshold.

The traditional approach to the establishment of acceptable exposure levels to chemical substances is to identify concentrations that will have no adverse effects in target populations.[1-3] This approach assumes the existence of a threshold dose below which no deleterious effects will occur. Indeed, many chemical substances have been characterized as eliciting a threshold-type response, e.g., irritants and simple poisons.[4] In this report, concentration limits believed to protect public health from acute adverse reactions resulting from chronic exposure to toxic emissions eliciting a threshold effect are referred to as Environmental Exposure Limits (EEL's).

Safe exposure levels are not easily identified for some chemical substances. Any exposure to these chemicals elicits a response, no matter how small the concentration. Such substances are said to produce nonthreshold responses in their target populations. Several substances that appear to elicit a nonthreshold response have been identified. A pathological end-point of great public concern that results from a nonthreshold response is cancer. In the case of carcinogens, evidence indicates that these substances have the potential to produce deleterious effects regardless of the quantity of the chemical present in the body; i.e., one molecule can initiate the process of carcinogenesis (one-hit theory). Although a debate still goes on within the regulatory community on how best to regulate cancer-producing chemicals, it is generally accepted that the weight of scientific data clearly supports the existence of the nonthreshold phenomenon.[5]

Because threshold doses have not been established for carcinogens, the practice of "risk estimation" has gained wide acceptance.[5,6] Estimates of cancer risk involve the use of animal toxicological data, human epidemiological data, and mathematical models to estimate the cancer incidence rates associated with exposures to suspected carcinogens. This risk estimation method entails the use of a carcinogen's exposure-response relationship to estimate the health impact of the substances. These estimates are generally expressed as the number of excess cancers per unit of population (e.g., one excess cancer per 100,000 people, referred to as a risk of 10^{-5}) or the lifetime risk to the highest exposed individual. For the purposes of this report it was convenient to express the exposure-response relationship as specific reference concentrations (i.e., at what concentration could a risk of cancer of 10^{-4}, 10^{-5}, 10^{-6}, etc., be expected). This appendix describes the data and assumptions used to determine both the EEL's and the reference concentrations.

MODEL FOR ESTIMATING ENVIRONMENTAL EXPOSURE LEVELS

The structure of the model chosen to estimate EEL's for use in the waste oil risk assessment study is similar to that of several models currently used in the health risk assessment community.[7-11] The major premise behind all of these models (a premise that is not universally accepted) is that workplace threshold limit values (TLV's) published by the American Conference of Governmental Industrial Hygienists (ACGIH) can be adjusted mathematically for use in assessing nontraditional workplace or environmental exposures.[4] These mathematical adjustments have ranged from simple time adjustments[9] to a few sophisticated models that incorporate uptake and excretion coefficients.[7,8] The success of each attempt depends on how well the authors have accounted for the limitations inherently associated with the use of TLV's. The preface to the ACGIH publication clearly states the limitations associated with the TLV's as identified by the committee:[3]

> "Threshold limit values refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect. Because of wide variation in individual susceptibility, however, a small percentage of workers may experience discomfort from some substances at concentrations at or below the threshold limit; a smaller percentage may be affected more seriously by aggravation of a pre-existing condition or by development of an occupational illness.
>
> "Threshold limits are based on the best available information from industrial experience, from experimental human and animal studies, and when possible, from a combination of the three. The basis on which the values are established may differ from substance to substance; protection against impairment of health may be a guiding factor for some, whereas reasonable freedom from irritation, narcosis, nuisance, or other forms of stress may form the basis for others.
>
> "The amount and nature of the information available for establishing a TLV varies from substance to substance; consequently, the precision of the estimated TLV is also subject to variation, and the latest documentation should be consulted in order to assess the extent of the data available for a given substance."

This preface identifies five important caveats that should be addressed when TLV's are adjusted to account for environmental exposures: 1) the exposure duration, 2) the population at greatest risk (susceptibility), 3) pre-existing conditions or illnesses in the exposed population, 4) the basis for determining the original TLV, and 5) the type of protection intended.

All models developed to date (including the model presented herein) are only partially successful in addressing each of these caveats or limitations. Mathematical models are usually developed for specific purposes (e.g., to establish exposure limits for 10- or 12-hour workdays, overtime, the additive effects of a second job, avocational exposures to toxic agents, or chronic environmental exposures). These needs have limited the past application to the most applicable or important caveats (e.g., accounting for the duration of exposure when the 8-hour TLV is used to derive a 12-hour workplace exposure limit). Also, models usually were designed to address only those limitations for which corrective information was readily available. Despite these deficiencies, outputs from these modified models are of greater utility than the original TLV's simply because the adjusted value accounts for one or more of the limitations. The greater the number of limitations addressed, the more confidence one can place in the model.

The model used to calculate TLV-derived EEL's for use during this waste oil risk assessment is presented in Equation 1.

$$EEL = \frac{TLV\ (D_{af})\ \ (M_{af})}{S_f} \times 10^3 \qquad \text{(Eq. 1)}$$

where EEL = environmental exposure limit, $\mu g/m^3$

TLV = 8-hour time-weighted average threshold limit value, mg/m^3

D_{af} = duration of exposure adjustment factor (0.12), nondimensional

M_{af} = magnitude of exposure adjustment factor (0.72), nondimensional

S_f = safety factor (10-1000), nondimensional

This model adjusts for differences in duration and magnitude of exposure. Also, through the selection of a safety factor, it accounts for differences in the documentation used to develop each TLV and the type of protection the TLV is intended to provide.

Duration of Exposure Adjustment Factor (D_{af})

The ACGIH TLV's were developed to provide protection "...for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect." This excerpt defines the length of a "normal" weekly work schedule and also implies a normal working lifetime.

Because environmental exposures are not limited to an 8-hour day, a 40-hour workweek, or a working lifetime, an adjustment in exposure was made by estimating the ratio of a "normal" work exposure duration to a public lifetime exposure. The normal working lifetime of an adult male worker* was calculated to be 8.0×10^4 hours.** This value represents the likely duration of an occupational exposure.

Environmental exposures have the potential of occurring over an entire lifetime. The value used to define the duration of a biological lifetime must account for variations in longevity within the general population. Consideration of this variation is important because a person with a long life span will experience a greater total exposure and ultimately more stress than a person with a shorter life span. Within the United States average life expectancy varies greatly with gender. An American

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[*] The term "adult male workers" is sometimes used when referring to TLV's. This distinction is made because the vast majority of industrial experience and human exposure data cited in the ACGIH documentation is based on adult male subjects.

[**] Value is based on 8 hours/day, 5 days/week, 50 weeks/year, and a working lifetime of 40 years. The selection of 40 years assumes a starting age of 25 years and a retirement age of 65. This work period provides some allowance for job changes, college, and early retirement, which are not considered in a 47-year working lifetime (18 to 65 years old).

female born in 1979 has a longer average life expectancy than an American male born at the same time (77.8 years for females versus 69.9 years for males).[12] This difference results in a longer lifetime exposure duration for females (6.8×10^5 hours versus 6.1×10^5 hours).* If the gender difference is taken into account, the resulting adjustment factor for the change in the duration of exposure is 8.0×10^4 hours/6.8×10^5 hours, or approximately 0.12. This adjustment factor addresses, in part, the first caveat and accounts for the cohort in the general population with the longest life expectancy.

Magnitude of Exposure Adjustment Factor (M_{af})

Identifying population groups at greatest risk is difficult. The ACGIH noted this difficulty in describing the limitation of the TLV's: "...Because of wide variation in individual susceptibility... a small percentage of workers may experience discomfort from some substances at concentrations at or below the threshold limit..." The reasons for this discomfort may be differences in morphology, physiology, behavior, or genetics among certain members of an exposed population. It is not possible to lower threshold limits to levels that presumably would protect all workers at all times; nor is it possible to reduce EEL's to levels that presumably would protect every portion of the population, regardless of size. The data needed to make such decisions are not available.

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* Female value is based on 24 hours/day, 7 days/week, and 50 weeks/year over a lifetime of 77.8 years. Male value is based on the same hours/day, days/week, and weeks per year but over a lifetime of 69.9 years.

Nevertheless, because environmental exposures, unlike workplace exposures, affect a larger and more heterogenous population, EEL's derived from workplace TLV's must strive to account for and protect those portions of the population that are at risk.

Based on a comparison of daily volumes of air breathed with the body weights of four cohorts of the general population (i.e., adult males, adult females, children, and infants), airborne contaminants present the greatest risk to a 10-year-old child (Table E-1). A magnitude-of-exposure adjustment factor was developed to account for this increased risk to a 10-year-old child. Workplace TLV's are determined from data on adult males (70-kg reference/man) with a daily air volume of 2.3×10^4 liters, which results in a ratio of 3.28×10^2 liters of air/kg of body weight. The daily volume of air breathed by a child (33-kg reference/10-year-old) is 1.5×10^4 liters, which results in a ratio of 4.54×10^2 liters of air/kg body weight.

An adjustment factor of 0.72 ($3.28 \times 10^2/4.54 \times 10^2$) accounts for the greater ventilation rate per unit body weight of a 10-year-old child compared with that of an adult male.

Safety Factor (S_f)

Despite attempts to adjust for differences in exposure duration and to account for large population cohorts known to be at the greatest risk, much uncertainty is still associated with the estimated EEL's. The uncertainty associated with each EEL is directly related to the paucity and quality of information used

TABLE E-1. DAILY AIR VOLUMES, REFERENCE BODY WEIGHTS, AND ESTIMATED ADJUSTMENT FACTORS FOR VARIATIONS IN THE LEVEL OF EXPOSURE EXPERIENCED BY VARIOUS POPULATION COHORTS

Reference individual (cohort)	Daily air volume breathed,[a] liters	Reference body weight,[b] kg	Exposure per unit body weight, liters/kg	Ratio of adult male value to value for reference individual (nondimensional)
Adult male	2.3×10^{4}	70	328	1.00
Adult female	2.1×10^{4}	58	362	0.91
Child (10 years)	1.5×10^{4}	~33[c]	454	0.72
Infant (1 year)	0.38×10^{4}	~10[c]	380	0.86

[a] Reference 13, p. 346. Daily air volumes breathed by adult men and women and the 10-year-old child are based on 8 hours of working ("light activity"), 8 hours of nonoccupational activity, and 8 hours of resting. The value for an infant is based on 8 hours of "light activity" and 16 hours of resting.

[b] Reference 13, p. 13.

[c] Reference 13, p. 11. Reference body weights for a 10-year-old child and a one-year-old infant were taken as an average of both sexes for each age group. In both age groups the actual sex-specific mean body weights vary less than 0.5 kg from the values given above.

in the definition of the original TLV's. An attempt has been made to account for this source of uncertainty by including safety factors in the estimation procedure. Table E-2 presents the safety factors used to define the uncertainty associated with specific conditions of information or experimental data. These factors, which were developed for the determination of water quality criteria,[14] are also applicable to the estimating of environmental exposure limits.

In the use of these safety factors it is recognized that the amount and nature of the information available for establishing a TLV varies from substance to substance. Within these limitations, the information that forms the basis of the ACGIH documentation and the nature of the illness or disease the TLV is designed to protect against are presented in Table E-3. This table also presents the safety factors that best describe the uncertainty associated with each TLV.

Results

Table E-4 presents the estimated airborne EEL's (based on Equation 1) for ten substances found in waste oil. Specific adjustments were made for expected duration differences between workplace and environmental exposures and exposures of a population cohort at great risk. A safety factor was used to account for the condition and quality of information used to develop the workplace TLV's and for the type of protection they are meant to provide.

TABLE E-2. UNCERTAINTY FACTORS ASSOCIATED WITH SPECIFIC CONDITIONS OF THE EXPERIMENTAL DATA

Nature and conditions of experimental data[a]	Uncertainty (safety) factor[b]
Valid experimental results of chronic exposure studies on man	10
Valid results of chronic exposure studies on experimental animals; human exposure data limited to acute studies	100
Acute exposure studies on experimental animals; no human data available	1000

[a] Data that present no indication of carcinogenicity.

[b] Reference 14. Uncertainty factors developed by the National Academy of Sciences during a study of Drinking Water and Health.

TABLE E-3. SUMMARY OF ACGIH DOCUMENTATION FOR SPECIFIC TLV's AND SELECTED UNCERTAINTY (SAFETY) FACTORS[14,15]

Substance	ACGIH TLV 8-h TWA, mg/m^3	Type of information forming basis of ACGIH documentation	Targeted prevention	Selected uncertainty (safety) factor
Barium	0.5	Industrial experience related to barium nitrate exposures	Excitability	100
Cadmium compounds	0.05	Epidemiological and occupational exposure studies	Proteinuria, pulmonary edema, and emphysema	10
Chromium (II and III)	0.5	Clinical studies of exposed workers	Pulmonary edema and irritation	10
Hydrogen chloride	~7.0 (5 ppm)	Occupational exposure studies, and animal studies	Irritation	10
Lead	0.15	Occupational exposure studies, clinical studies of exposed workers, and animal studies	Encephalopathy and renal damage	10
Naphthalene	50.0	Industrial experience, occupational exposure studies, and animal studies	Irritation	10[a]
Xylene	~435 (100 ppm)	Industrial experience, occupational exposure studies, clinical studies of exposed workers, and animal studies	Narcosis, chronic	10
Zinc (as zinc oxide)	5.0	Occupational exposure studies and animal studies	Reduced incidence of metal fume fever	10

(Continued)

TABLE E-3 (Continued)

Substance	ACGIH TLV 8-h TWA, mg/m^3	Type of information forming basis of ACGIH documentation	Targeted prevention	Selected uncertainty (safety) factor
Toluene	~375 (10 ppm)	Occupational exposure studies, clincial studies of exposed workers, and animal studies	Loss of muscle coordination and cardiomuscular changes	10
Trichloroethane (1,1,1-)	~1900 (350 ppm)	Occupational exposure studies, clincial studies of exposed workers, and animal studies	Anesthetic effects and objectionable odor	10

[a] There is some support within the scientific health effects community for applying a safety factor of 1 to those substances identified as irritants. This practice appears to be reasonable for those substances for which no other health effects have been observed. The ACGIH TLV for naphthalene was established to protect against ocular irritation.[4] Although this end-opint is still a major concern, acute exposures to airborne naphthalene are recognized to produce direct hemolytic effects in vivo, and oral exposure may result in the development of cataracts.[6] Because naphthalene exposures may result in toxic end-points other than irritation, an uncertainty factor of 10 has been selected for use in determining a TLV-derived EEL.

TABLE E-4. ESTIMATED AIRBORNE ENVIRONMENTAL EXPOSURE LIMITS

Substance	Environmental exposure level, µg/m^3
Barium	0.43
Cadmium	0.34
Chromium (II and III)	4.32
Hydrogen chloride	59.7
Lead	1.30[a]
Zinc	43.2
Naphthalene	432
Toluene	3,240
1,1,1-Trichloroethane	16,416
Xylene	3,758

[a] The ambient air quality standard of 1.5 µg/m^3 was used instead of the estimated environmental exposure limit of 1.3 µg/m^3.

APPROACH USED TO DETERMINE REFERENCE CONCENTRATIONS FROM CARCINOGENIC POTENCY FACTORS

The reference concentrations provide reference points against which to assess the relative impact of air quality on health and to calculate the cancer risks attributable to that exposure; they are neither estimates of safety nor statements of acceptable levels of risk. The EPA procedures used to evaluate the toxicological data were consistent with the Agency's objective of estimating a risk so as to err on the side of safety.[2] The carcinogenic risk factors were developed from data sets that gave the highest estimate of a lifetime cancer risk. This estimated risk probably errs on the side of safety. The reference concentrations were determined from the carcinogenic potency factors developed for the EPA Water Quality Criteria Documents and updated in the Health Effects Assessment Summary for 300 Hazardous Organic Constituents.[10]

Chemicals eliciting a carcinogenic response are assessed by use of a linear nonthreshold dose-response model. Use of this model is based on the following assumptions: 1) a nonthreshold relationship exists for carcinogens, 2) the dose-response relationship developed from animal and human studies at relatively high exposure levels can be extrapolated to low exposure levels likely to be experienced by the general public over an entire lifetime, and 3) the dose-response relationship is linear. These linear nonthreshold models are used by the Interagency Regulating Liaison Group (IRLG)[5] and the EPA Carcinogen Assessment Group (CAG)[16,17] to evaluate risks posed by potentially carcinogenic substances.

In this study, reference concentrations have been developed by the use of the carcinogenic potency factor q_1* and equivalent dosage estimates.

The EPA developed the q_1* factors from lifetime animal experiments or human epidemiological studies.[16,17] Because of the variety of studies accessed for data, EPA had to correct for differences in metabolism between species and for variable absorption rates via different routes of administration. The resulting q_1* factors are therefore based on exposures likely to produce a given cancer incidence rate.

Table E-5 presents potency factors for carcinogenic substances found in waste oil. Equation 2 presents the method used to derive airborne reference concentrations from the established carcinogenic potency factors.

$$C_a = \frac{K\ (70\ \text{kg})}{q_1*\ \ (20\ \text{m}^3)} \times 10^3 \qquad \text{(Eq. 2)}$$

where C_a = reference concentration in air for a lifetime risk to cancer of 10^{-5}, $\mu g/m^3$

K = risk level, 10^{-5}

q_1* = carcinogenic potency factor, risk per mg/kg per day (Table B-6)

Again, the value of 70 kg represents the weight of a reference adult male.[13] The value of 20 m^3 is an estimate of the total daily volume of air ventilated by an adult male. The derived values for the airborne reference concentrations are presented in Table E-6.

TABLE E-5. CARCINOGENIC POTENCY FACTORS

Substance	Risk, mg/kg per day^{-1}
Arsenic	14.0[a]
Benzene	0.52[b]
Cadmium	6.65[b]
Chromium (VI)	41.0[b]
Carbon tetrachloride	0.13[b]
Polychlorinated biphenols (PCB's)	4.34[a]
Tetrachloroethylene	0.0531[b]
1,1,2-Trichloroethane	0.0573[a]
Trichloroethylene	0.0126[a]

[a] Reference 10, p. 3.

[b] Reference 17.

TABLE E-6. REFERENCE CONCENTRATIONS FOR A 10^{-5} RISK LEVEL

Substance	Air,[a] µg/m³
Arsenic	0.0025[a]
Benzene	0.6731
Cadmium	0.0053
Chromium (VI)	0.0008
Carbon tetrachloride	0.2692
Polychlorinated biphenols (PCBs)	0.0081
Tetrachloroethylene	0.6591
1,1,2-Trichloroethane	0.61
Trichloroethylene	2.78

[a] Airborne reference concentration was determined by use of published carcinogenic potency factors (Table E-5) and a conversion methodology (Equation 2).

REFERENCES FOR APPENDIX E

1. Stokinger, H. E., and R. L. Woodward. Toxicologic Methods for Establishing Drinking Water Standards. J. American Water Works Association, 50:515-529, 1958.

2. U.S. Environmental Protection Agency. Water Quality Criteria Documents: Availability. Federal Register, 45(231):79318-79379.

3. American Conference of Governmental Industrial Hygienists. TLV's Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment With Intended Changes for 1982. Cincinnati, Ohio. 1982.

4. American Conference of Governmental Industrial Hygienists. Documentation of the Threshold Limit Values. 4th Ed. Cincinnati, Ohio. 1982.

5. Report of the Interagency Regulatory Liaison Group, Work Group for Risk Assessment. Federal Register, 44(131), July 6, 1979.

6. Casarett and Doull's Toxicology. The Basic Science of Poisons, 2d Ed. MacMillian Publishing Co., Inc., New York, New York. 1980. pp. 26-27.

7. Hickey, J. L. S., and P. C. Reist. Application of Occupational Exposure Limits to Unusual Work Schedules. American Industrial Hygiene Association Journal 38:613-621, November 1977.

8. Hickey, J. L. S., and P. C. Reist. Adjusting Occupational Exposure Limits for Moonlighting, Overtime, and Environmental Exposures. American Industrial Hygiene Association Journal, 40:727-733, August 1979.

9. Iuliucci, R. L. 12-Hour TLV's. Pollution Engineering, November 1982. pp. 25-27.

10. U.S. Environmental Protection Agency. Health Effects Assessment Summary for 300 Hazardous Organic Constituents. Environmental Criteria and Assessment Office, Cincinnati, Ohio. August 18, 1982.

11. U.S. Environmental Protection Agency. Multimedia Environmental Goals for Environmental Assessment. Vol. 1. EPA-600/7-77-136a, November 1977.

12. U.S. Department of Commerce, Statistical Abstract of the United States: 1981. 102d Ed. Bureau of the Census, Washington, D.C. 1981. p. 69.

13. International Commission on Radiological Protection No. 23. Report of the Task Group on Reference Man. Pergamon Press, New York. 1975. pp. 11, 13, 346.

14. U.S. Environmental Protection Agency. Water Quality Criteria Documents: Availability. Federal Register, 45(231):79353-79355.

15. American Conference of Governmental Industrial Hygienists. Documentation of the Threshold Limit Values. 4th Ed. Cincinnati, Ohio. 1982.

16. U.S. Environmental Protection Agency. Interim Procedures and Guidelines for Health Risk and Economic Impact Assessments of Suspected Carcinogens. Federal Register, Vol. 41. May 25, 1976.

17. Personal communication with Marie Pfaff, Carcinogen Assessment Group, Office of Health and Environmental Assessment. Assistant Administrator for Research and Development, U.S. Environmental Protection Agency, Washington, D.C., July 7, 1983.