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ATMOSPHERIC CADMIUM: POPULATION EXPOSURE ANALYSIS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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ATMOSPHERIC CADMIUM: POPULATION EXPOSURE ANALYSIS

by

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ENVIRONMENTAL PROTECTION AGENCY

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The conclusions presented in the study are, of course, solely the responsibility of Energy and Environmental Analysis, Inc.

EXECUTIVE SUMMARY

This report is one of a series of reports which will be used by EPA in responding to the Congressional mandate under the Clean Air Act Amendments of 1977 to determine whether atmospheric emissions of cadmium post any threat to public health. This report identified the population exposed to specified cadmium levels from selected point sources. A companion report[1/] had identified the specific sources of interest.

Although cadmium is a true multi-media pollutant this report focuses only on ambient air concentrations of cadmium. Even though significant exposures of cadmium are caused by all media and atmospheric emissions may contribute to other media through various deposition mechanisms these are not considered here. This report focuses on the exposure caused by specific stationary sources. The sources considered are iron and steel mills, municipal incinerators, primary smelters (zinc, copper, lead, cadmium), and secondary smelters (copper and zinc).

Methodology

The basic methodology used in this report involved the following procedures:

- Determination of the size and location of each source within each source category. In this regard, size data were obtained from trade directories, etc., and locations from United States Geologic Survey (USGS)

- Determination of annual concentration caused by each source within each source category. For this purpose, annual concentration of cadmium caused by each were developed and were determined using general diffusion models and model plants.

- Determination of population exposed by each source. Estimates of annual concentrations due to each source and 1970 Census data were combined to give an estimate of the population exposed by each source.

As would be expected in any analysis of this type, many assumptions were made based on limited data. Analysis was carried out on a very detailed level and errors are possible stemming from: source size and location, the actual emissions of cadmium from each source, the type and efficiency of control technologies employed at each source, and the general nature of the dispersion modelling. In all cases, the best data available were used. The estimates of population exposure should be considered to provide a reasonable accurate estimate of the number of exposed individuals.

Results

Table 1 shows a summary of the results of this analysis. This table shows the population exposed to concentration greater the 0.1 ng/m^3, the the average level to which this population is exposed and the total exposure (expressed as nanagrams-person-year) caused by each source type. As shown in Table 1, municipal

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* This is approximately the current level of detectability for cadmium.

TABLE 1

STUDY RESULTS

Source	Population Exposed (10^3 people)	Average Exposure (ng/m^3)	Exposure (10^6 ng-person-year)
Secondary Copper	9,891	1.54	15.1
Secondary Zinc	37	0.47	0
Municipal Incinerators	49,026	7.16	350.8
Primary Zinc	399	10[a/]	4.5
Primary Lead	80	10[a/]	0.9
Primary Copper	620	10[a/]	6.2
Primary Cadmium	245	10[a/]	2.5
Iron and Steel	19,896	1.9	36.2

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a/ Assumed concentration; see text section VI

incinerators are the chief contribution to the population exposed; have the highest annual average; and cause the greatest exposure. The chief source of cadmium in incinerators is the combustion of plastics containing cadmium stabilizers and the combusion of materials with cadmium containing paint.

Iron and steel production is the second most significant source in each catagory. Cadmium emissions from this source result from the processing of steels coated with zinc or cadmium.

Table 2 shows the population exposed to cadmium levels greater than 0.1 ng/m^3 by region. The regional breakdown shown on Table 2 is based on EPA regions shows in Figure 1.

It is evident from the data on Table 2 that municipal incinerators in the Northeast and Midwest expose the largest number of people and also cause high average exposures. Iron and steel mills rank second in exposure. None of the other sources appear to expose a large number of people.

Table 3 shows a regional breakdown of the exposure (expressed in nanograms per person-year) due to each source type. Again, municipal incinerators dominate the list, with iron and steel mills rankiny second. Also, as before, the Northeastern and Midwest areas show the highest levels.

TABLE 2

POPULATION EXPOSED TO GREATER THAN 0.1 ng/m^3 OF CADMIUM
(10^3 People)

	REGION										
SOURCE TYPE	1	2	3	4	5	6	7	8	9	10	TOTAL
Secondary Copper	0	1434	0	0	1889	1043	313	195	1610	3400	9891
Secondary Zinc	0	0	0	0	18	19	0	0	0	0	37
Municipal Incinerators	6570	15163	8742	2995	12501	1121	1760	173	0	0	49026
Primary Zinc	0	0	258	0	100	0	0	0	0	41	399
Primary Lead	0	0	0	0	0	0	35	28	0	17	80
Primary Copper	0	0	0	19	2.6	16	0	92	29	461	620
Primary Cadmium	0	0	100	0	87	41	0	0	0	17	245
Iron and Steel	93	1649	4543	1611	8710	1575	108	0	774	833	19896

FIGURE 1

REGIONAL BREAKDOWN

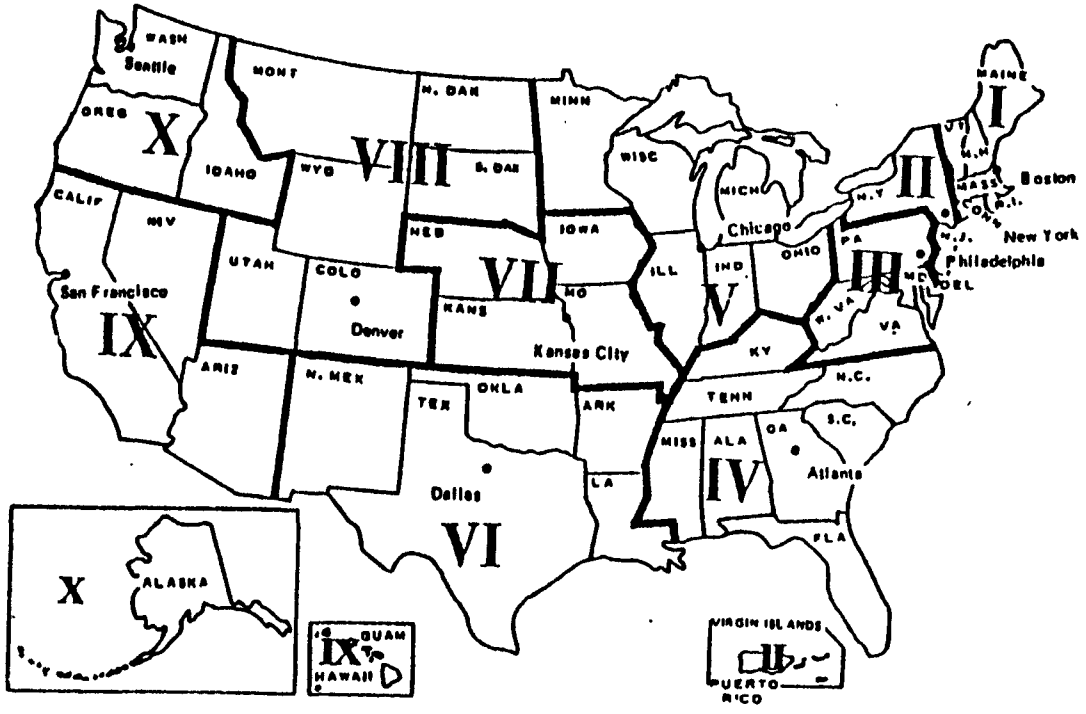

TABLE 3

COMPARISON OF CADMIUM EXPOSURES AMONG SOURCES (10^6 Nanograms-Person-Year)[2/]

Source Type	1	2	3	4	5	6	7	8	9	10	TOTAL
Secondary Copper	0	2.9	0	0	3.6	2.5	0.8	0.3	4.9	0	15.1
Secondary Zinc	0	0	0	0	0	0	0	0	0	0	0
Municipal Incinerators	40.3	172.6	40.1	11.8	67.4	11.6	5.8	0.6	0	0	350.8
Primary Zinc	0	0	3.6	0	0	0.7	0	.1	0	0.1	4.5
Primary Lead	0	0	0	0	0	0	0.4	0.3	0	0.2	0.9
Primary Copper	0	0	0	0.2	0	0.2	0	0.9	0.4	4.6	6.2
Primary Cadmium	0	0	1.0	0	0.9	0.4	0	0	0	0.2	2.5
Iron and Steel	0	2.3	11.3	4.5	13.1	2.3	0.1	0.3	0.9	0.6	36.2
TOTAL[1/]	40.3	177.8	56.5	16.5	85.0	17.7	7.1	2.5	6.2	5.7	415.1

1/ May not sum due to independent rounding.

2/ Computed by multiplying the population exposed to each source by the concentrations resulting from that source.

SECTION I

INTRODUCTION

This report is one in a series of reports which will assist EPA in responding to the Congressional mandate in Section 122 of the Clean Air Act Amendments of 1977. Under this Section of the act, EPA is required to review the current data on the health and welfare effects of cadmium (as well as other substances) and determine "whether or not emissions of...cadmium...into the ambient air will cause, or contribute to, air pollution which may reasonably be anticipate to endanger public health."

This report addresses one area of information needed to make this determination--the estimation of the population exposed to atmospheric levels of cadmium from "significant cadmium sources" (those source types for which individual plants can produce an ambient concentration of 0.1 ng/m^3 on an annual basis.) This report draws no conclusions as to the health consequences of atmospheric cadmium levels, nor does it provide a total estimate of the population exposed to specified cadmium levels. Rather, the purpose of the report is to provide a relative ranking of sources by magnitude of population exposed and to present this information in such a way that EPA can make estimates of the health implications of the reported exposures.

The report is organized into several sections summarized below:

- SECTION II provides an overview of the physical and chemical properties of cadmium as well as the routes through which human exposures to cadmium could occur.

- SECTION III provides an overview of the methodology used in the report.

- SECTIONS IV through VII provide estimates of the population exposed to cadmium emissions from selected sources. The sources considered are:

  Section IV--Iron and Steel Mills
  Section V--Municipal Incinerators
  Section VI--Primary Smelters (copper, lead, zinc, and cadmium)
  Section VII--Secondary Smelters (cooper and zinc)

The background data for this report is based primarily on information presented in a companion report[1/] which focused on:

- the development of cadmium emission factors;

- the estimation of total atmospheric emissions of cadmium from all sources; and

- the screening of sources to determine if individual sources within a source category can cause measurable ambient levels of cadmium (based on the annual average).

Many of the assumptions and information used in this report are documented in the companion report.

SECTION II

CADMIUM IN THE ENVIRONMENT

A. Introduction

This section discusses the physical and chemical properties of cadmium and the multi-media nature of cadmium exposures. Although this report focuses only on atmospheric exposures to cadmium, it is important to keep in mind that there are many other types of human exposure to cadmium including food, water, and tobacco smoke.

B. Physical and Chemical Characteristics of Cadmium

Cadmium is a relatively rare element in the earth's crust. It occurs at a concentration of 0.1 to 0.5 ppm. It is of low abundance, ranking between mercury and silver, and thus, not in sufficient quantities to be mined as an ore.[2/] Table II-1 shows the physical properties of cadmium. Cadmium is always associated with zinc and is usally present as sulfide.[3/]

The most important characteristic of cadmium, from an air pollution viewpoint, it its high volatility. This is evidenced by its low melting (312^{o} C) and boiling (765^{o} C) points. Thus, any high temperature process, such as metallurgical processes (e.g., steel-making, sintering) or incineration, are likely to release whatever cadmium is present in the feed.

TABLE II-1

PHYSICAL PROPERTIES OF CADMIUM[a,b/]

Atomic Number	48
Atomic Weight	112.41
Color	silver-white
Crystal Structure	hexagonal pyramids
Hardness	2.0 Mohs
Ductility	Considerable
Density	
20°C (68°F) (solid)	8.65 g/cc
330°C (626°F) (liquid)	8.01 g/cc
Melting point	321°C (609.8°F)
Boiling point	767°C (1412.6°F)
Specific heat	
25°C (77°F) (solid)	0.055 g-cal/g
Electrochemical equivalent	
Cd^{++} ion	0.582 mg/coulomb
Electrode potential	
Cd^{++} ion	-0.40 volt[a/]

a/ From Reference 4

b/ National Bureau of Standards nomenclature, H_2.

Vaporized cadmium metal is quite reactive and should react very quickly to form an oxide, sulfate, or other compound. In these forms, cadmium is quite stable and of very low solubility in water.

Cadmium metal is very ductile, easily soldered, can be readily electroplated, and maintains a lustrous finish in air.[4/] These properties lead to the use of cadmium as a protective coating on iron and steel products.

C. Multi-Media Nature of Cadmium Exposures

While this report is focused on atmospheric emissions of cadmium, it is important to recognize the overall cycle of cadmium in the environment. Measurable levels of cadmium occur in all phases of environmental concern (air, water, food, solid waste), and in almost all areas. One author[5/] refers to cadmium as the "dissipated element." EPA in 1975[6/] estimated that about 1,800 Mg/year of cadmium was lost to the environment. Of this, about 18 percent was in atmospheric emissions, 75 percent in solid waste, and the remainder in water-borne emissions.

Measurable cadmium levels have been found in air, water, soil, and food. Atmospheric concentrations generally have been measured in the center of urban areas and generally range from ten ng/m^3 down to below the detectable limit. Typical urban concentrations are in the range of three ng/m^3. Due to the low solubility of cadmium compounds, levels of cadmium in water supplies are generally low. Main sources of cadmium are discharges from mining operations, leaching from soil disposal of wastes, and fall-out from atmospheric emissions.

Cadmium in food results from a wide variety of sources. Listed in order of importance from a recent Battelle Report,[7/] they are:

1. Direct contact by plants or uptake from soils by plant roots.

    a. Naturally as a normal constituent of soils, particularly of marine origin.

    b. As an impurity (cadmium oxide) in phosphate-treated soils, especially in those treated with "superphosphate."

    c. By fertilization with sludge containing cadmium.

    d. By desposition of cadmium-containing pesticides or as a contaminant of zinc-containing pesticides.

    e. From run-off of mine tailings or from electroplating washing process.

2. Accumulation in animal tissues due to:

    a. Feeding on crops which have absorbed cadmium (the organs of such animals may have very high cadmium concentrations).

    b. Treatment with cadmium-containing helminth killers, used especially in swine.

3. Concentrations of cadmium by molluscs, crustaceans and most other aquatic organisms from ambient waters.

4. Use of zinc-galvanized containers, cans, cooking implements or vessels, or utensils used in food preparation, particularly grinders, pressing machines, or galvanized netting used to dry fish and gelatin.

5. Absorption of cadmium contained in wrapping and packaging materials such as paper, plastic bags, and tin cans.

6. Use of cadmium-contaminated water in cooking or processing operations.

Table II-2 lists the average cadmium concentration of selected adult foods.

Cigarette smoking also provides a large contribution to total cadmium exposure. The estimated intake from two packs per day ranges from four to six micrograms. This can amount to about 20 times the exposure due to atmospheric levels in large urban areas.

Even for smokers, food provides the greatest overall exposure to cadmium, and based on a 6.4 percent retention rate, the greatest daily input (except for three packs-per-day-smokers). Table II-3 summarizes the sources of cadmium exposure.

TABLE II-2

CADMIUM CONTENT OF SELECTED ADULT FOODS [a/]

Commodity	No. of Samples	Average ppm	Standard Deviation, ppm
Carrots, roots fresh	69	0.051	0.077
Lettuce, raw crisp head	69	0.062	0.124
Potatoes, raw white	71	0.057	0.139
Butter	71	0.032	0.071
Margarine	71	0.027	0.048
Eggs, whole fresh	71	0.067	0.072
Chicken fryer, raw whole or whole cut up	71	0.039	0.088
Bacon, cured raw, sliced	71	0.040	0.160
Frankfurters	69	0.042	0.111
Liver, raw beef	71	0.183	0.228
Hamburger, raw ground beef	71	0.075	0.122
Roast, chick beef	71	0.035	0.034
Wheat flour, white	71	0.064	0.150
Sugar refined, beet or cane	71	0.100	0.709
Bread, white	70	0.036	0.063
Orange juice, canned frozen concentrate	71	0.029	0.095
Green beans, canned	71	0.018	0.072
Beans, canned with pork and tomato sauce	71	0.009	0.000
Peas, canned	71	0.042	0.113
Tomatoes, canned	71	0.042	0.113
Diluted fruit drinks, canned	71	0.017	0.052
Peaches, canned	71	0.036	0.061
Pineapple, canned	71	0.059	0.153
Applesauce, canned	71	0.020	0.027

[a/] Source: Reference 8

TABLE II-3

MEDIA CONTRIBUTIONS TO NORMAL RETENTION

OF CADMIUM[a/]

Medium	Exposure Level	Daily Retention (μg)
Ambient air	0.03 $\mu g/m^3$	0.15
Water	1 ppb	0.09
Cigaretts:		
Packs/Day	μg/day[b/]	
1/2	1.1	0.70[c/]
1	2.2	1.41[c/]
2	4.4	2.82[c/]
3	6.6	4.22[c/]
Food	50 μg/day	3.0

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a/ Source: Reference 8.

b/ Based on 0.11 μg per cigarette.

c/ Assumes a 6.4 percent retention rate.

SECTION III

METHODOLOGY

A. Introduction

This section describes the general methodology used in determining the population exposed to specified levels of cadmium. In simplest terms, the methodology can be view as having four components:

- Selection and location of significant sources of cadmium and estimation of emissions from those sources;
- Determination of ambient concentrations of cadmium caused by these sources;
- Development of a population data base; and
- Integration of estimated cadmium concentrations with the estimates of population residing in that area.

B. Source Selection and Location

Based on the results of the companion study, noted previously, which screened all potential cadmium sources on the basis of measurable contribution to annual average ambient levels levels of cadmium,* four source categories were selected for exposure analysis:

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* Cadmium annual averages as low as 0.1 ng/m^3 are assumed measurable.

(1) Iron and Steel Mills
(2) Municipal Incinerators
(3) Primary Smelters (copper, lead, zinc, and cadmium)
(4) Secondary Smelters (copper and zinc

Information on the precise nature and capacity of each source in the above categories was obtained from various trade directories and other data sources which are of recent vintage (generally 1976 or 1977). The sections of this report which deal with individual emission sources list the specific references used.

Most of these references also provided street addresses and zip codes for individual plants. From USGS maps, street were identified within the zip code and in this way, relatively precise locations for each source were obtained.

This method of locating sources is relatively accurate, generally to within one to two km. This is a satisfactory level of accuracy given the accuracy of other data items. (The sections dealing with the individual source types include the location and size of each source).

In estimating emissions from each source, "best judgement" emission factors which were developed in the companion report to this study were used. Variability of emission factors for individual sources and among source types can be quite large. Emissions were computed assuming that facilities are operated at their nominal capacity.

C. Determination of Annual Concentrations

Annual concentrations for each type of plant were computed by using an EPA diffusion model, CRSTER.[9/] The annual concentration

of model plant types were then determined. These model plants were designed in such a way as to represent the probable ranges of typical industrial facilities. The factors which were varied to define the model plants were: stack height, flow rate and temperature. Surface meteorological data from Dallas/Fort Worth and upper air data from Oklahoma City were used in the analysis. These sets of data ever used because the meteorology is understood to be fairly typical of many areas in the country in terms of wind speed and stability classes. If a detailed analysis of any of the sources identified here were conducted in the future, more site-specific meteorological data would be sesirable.

Detailed descriptions of the particular assumptions used in the analysis of each source type are discussed in the following sections.

D. Population Data

The population data were obtained from the 1970 Master Enumeration District List (MED List)[10/] obtained from the Bureau of the Census. This list provides the population and geographic location of each enumeration district in rural areas and of each block group within urban areas. An enumeration district contains approximately 800 people and is no larger than the area one enumerator could reasonably be expected to cover. A block group consists of continguous city blocks with a total population of about 1,000. In a central business district, the block groups are further subdivided into individual blocks. The geographic locator for each of these three census divisions is the latitude and longitude coordinate of the centroid of the division.

The population data associated with these centroids were transferred to a grid which spans the contiguous United States. Each grid cell was 1/30 of a degree longitude by 1/30 of a degree latitude. Thus, this resulted in the average grid cell being

approximately ten square kilometers. With this grid cell size, reasonably adequate definition was developed. Figure II-1 illustrates an example of a medium size town and its environs. For this example, the population of the city itself shows up in six different grid cells. The city's suburbs show up in several additional cells. In the rural areas of the map, the population of individual enumeration districts appear as a single grid cell entry. In rural areas the grids which show zero population do not necessarily have no population but rather these areas are part of an enumeration district and all population in each enumeration is shown at the centroid of each enumeration district. Figure II-2 illustrates an example of a large metropolitan area. As one moves from the central city area westward towards the suburbs, a very definite population gradient can be observed. Grid cells within the city which contain large areas of public land appear as lower density grid cells.

The actual transfer to the grid was made as follows: the population of every enumeration district and of every block group whose centroid was located in a given two-minute-by-two-minute grid cell was summed to give the population of the grid cell. The information for each of 26 areas or maps which described the county was stoıed in a matrix. After all 26 maps were constructed, a count was made of the number of people loated by this method. The toal of 201,744,383 accounts for 99.5 percent of the 1970 population of the contiguous United States.

E. Population Exposed

The purpose of the model developed in this chapter is to integrate the data on source location, and resulting ambient concentrations caused by the source, with the population data described above thus determining the number of people exposed

FIGURE 1

POPULATION OF CHARLOTTESVILLE, VIRGINIA

x100'S OF PEOPLE

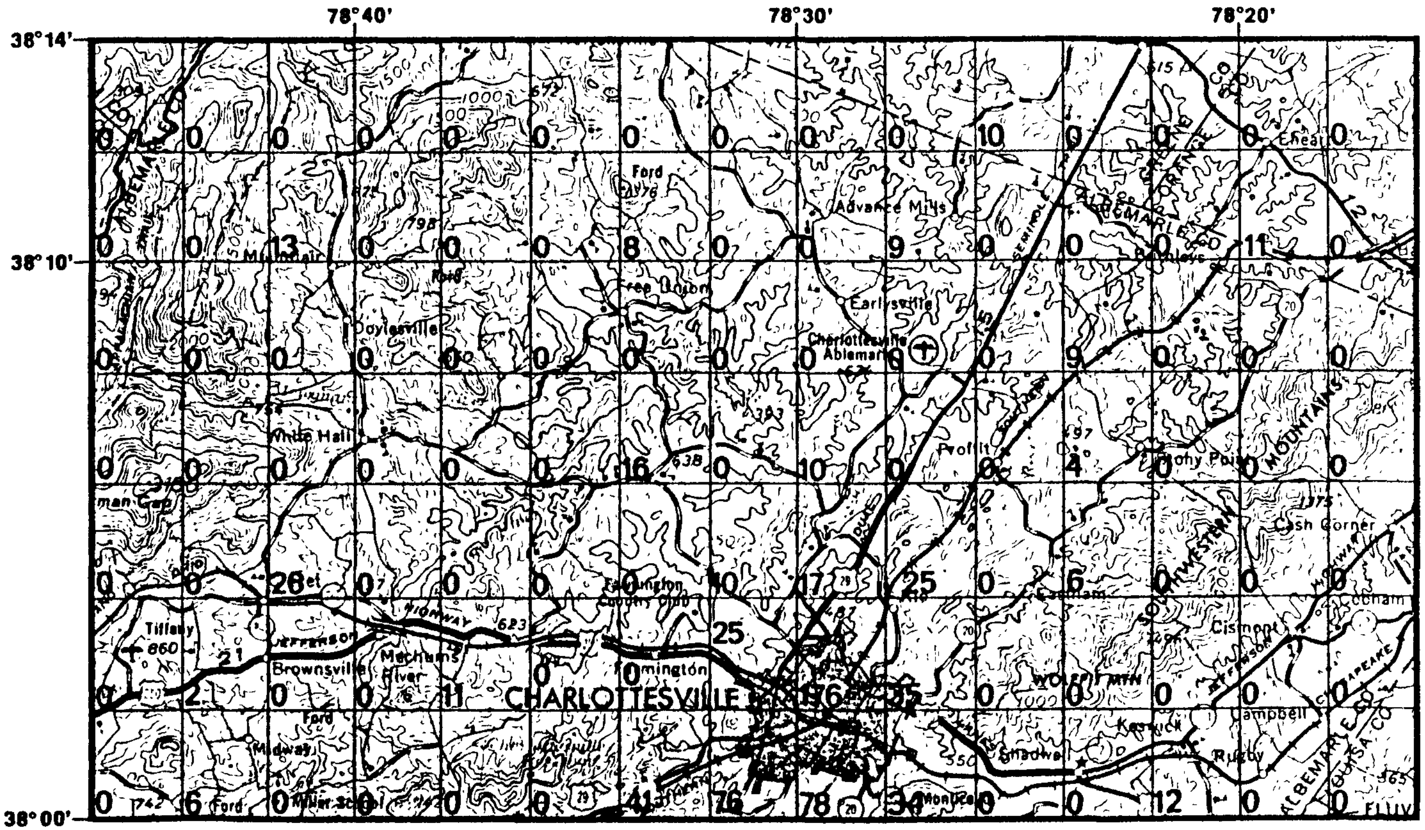
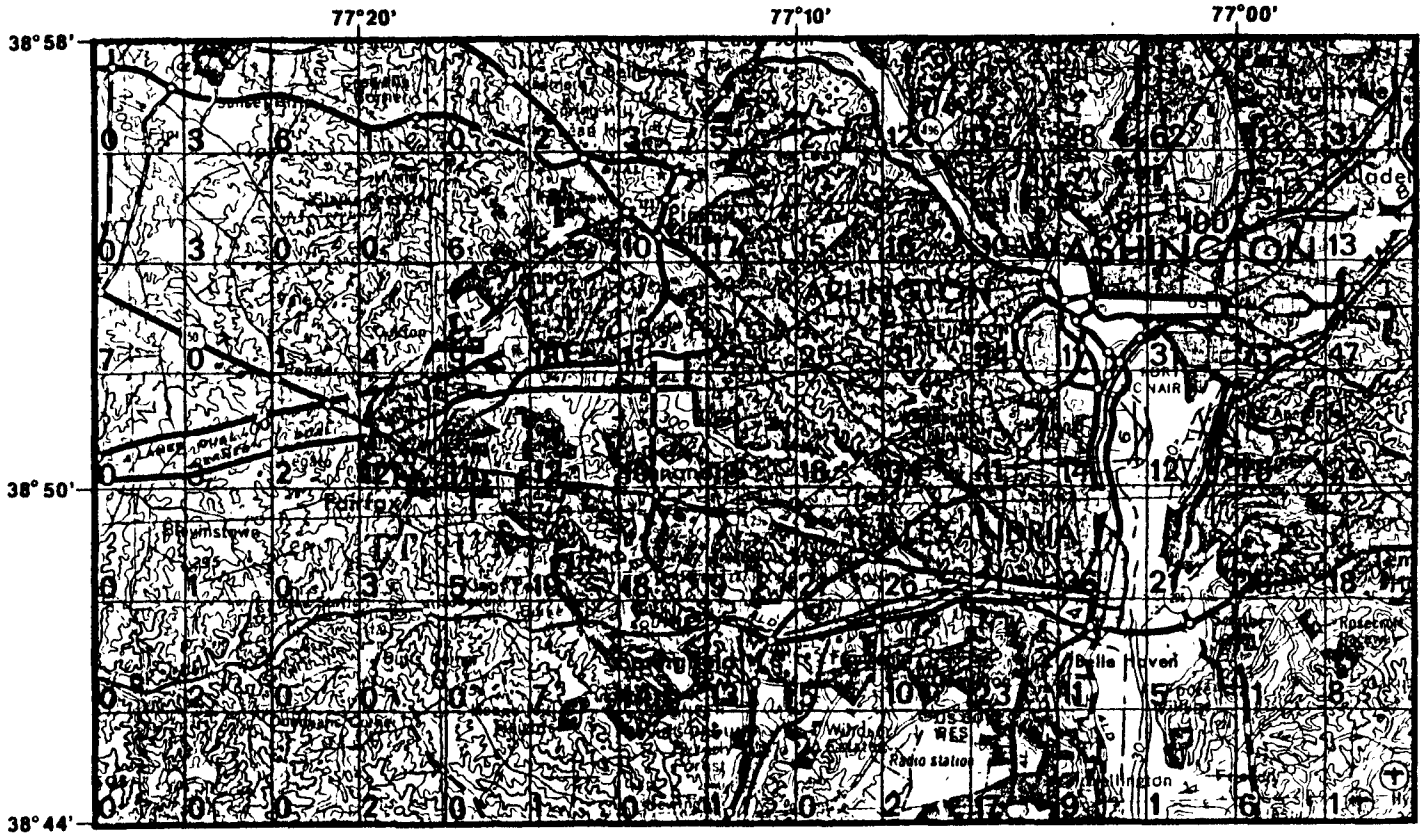


FIGURE 2

POPULATION OF WASHINGTON D.C.

x1000'S OF PEOPLE



to specified levels of cadmium. The methodology used is described in detail in Appendix A. As described in this Appendix, two independent procedures were used to estimate population exposed. In brief terms, the two procedures are:

1. Total Exposure

This procedure involves locating a source by latitude and longitude and, through emissions and diffusion modelling, determining the radius at which specified concentrations occur. Once the radius is determined, the population in population grids completely contained in the radius were determined. After this, the population in each partially covered grid is determined based on the percent of the grid circumscribed by the radius.

This procedure is carried out on a source-by-source basis. If people are exposed to more than one source, they would be counted twice. The primary use for this result is in determining the total exposure (nanograms-person-year) caused by specific source types. This type of estimate is suitable for use in a linear health risk model (i.e., such models which treat two people exposed to one ng/m^3 as equivalent to the risk of health effects as one person exposed to two ng/m^3).

2. Population Exposed.

In addition to estimating total exposure, the model was applied to estimate the population exposed to specified levels of atmospheric cadmium. As in the case of the exposure modelling, the population estimate was developed from a source-by-source analysis. However, in this procedure, the result is the population exposed to a given concentration from at least one source.

This form of the model provides an estimate of the population exposed to specified concentrations. The purpose of this form of the model is to estimate the gradient in exposure levels caused by source catagories. However, the estimates do not take into account that a person can be exposed to more than one source and that the actual level of exposure is the sume of the concentrations produced by the sources. As such, the estimates of population, to some degree, may underestimate the population exposed to high concentrations.

SECTION IV

IRON AND STEEL MILLS

A. Introduction

The estimation of population exposure to atmospheric cadmium emitted from the production of iron and steel is discussed in this section.

The primary sources of cadmium emissions from iron and steel manufacturing are the use of scrap containing cadmium in steel-making furnaces and, to a much lesser degree, the cadmium in the coal used to make coke. Table IV-1 lists the emission factors used in analysis.

One of the source types listed in Table IV-1 (sinter plants) does not involve the use of cadmium scrap directly. Sincere plants agglomerate fine iron-containing material (iron ore, flue dust, etc.) into a material suitable for use in the blast furnace. Due to decreases in the amount of natural iron charged to blast furnaces and increasingly stringent air pollution control requirements on steel-making furnaces, more and more of the feed to sinter plants is fine dust collected from steel-making furnaces.[11/]

This resultant change in feed to sinter plants leads to the charging of relatively large amounts of cadmium to the sinter plant. Therefore, even with relatively high levels of air pollution control (90 percent), significant amounts of cadmium can be released. The companion volume of this report discusses the emissions of cadmium from iron and steel production in considerable detail.

TABLE IV-1

CADMIUM EMISSION FACTORS FOR

IRON AND STEEL MANUFACTURING [a/]

	Uncontrolled			Controlled		
	Minimum	Maximum	Best Judgement	Minimum	Maximum	Best Judgement
Sinter	1.6×10^{-3}	3×10^{-3}	2.32×10^{-3}	1.1×10^{-3}	1.3×10^{-3}	1.1×10^{-3}
Open Hearth Furnace	4.08×10^{-3}	6.48×10^{-3}	5.78×10^{-3}	$2,97 \times 10^{-5}$	$3,34 \times 10^{-4}$	1.1×10^{-4}
Basic Oxygen Furnace	-	-	4.1×10^{-5}	3.5×10^{-6}	2.8×10^{-5}	1.2×10^{-5}
Electric Arc Furnace	2.7×10^{-3}	5×10^{-3}	3.4×10^{-3}	2.7×10^{-4}	5×10^{-4}	3.4×10^{-4}

[a/] Expressed as pounds cadmium per ton of product produced, from Reference 12.

B. Geographic Distribution of Sources

The location of iron and steel-producing facilities in the United States is show in Appendix B. The primary source of capacity estimaded in this table comes from the American Iron and Steel Institute's Iron and Steel Works Directory of the United States and Canada.[13/] Locations of these facilities were determined from the Dun and Bradstreet Metal-Working Directory[14/] and USGS maps.

Appendix B also shows the estimated cadmium emission rates from each facility. These estimates were derived by multiplying the emission factors from Table IV-1 by the production for each facility type, assuming that all plants operate at the hours of operation defined by the Department of Commerce as full operation.[15/] It must be emphasized that these emission factors are average emissions based on national average uses of cadmium scrap or on a limited number of stack tests. As such, it is likely that some over-estimates of emissions result from some sources and underestimated emissions from others. However, on the average, these emission estimates probably provide an adequate basis for the purpose of this analysis.

C. Estimated Ambient Levels

Estimates of annual concentrations of cadmium from iron and steel manufacturing are complicated by the large size of integrated mills and their wide variation in size. Large integrated mills can cover hundreds of acres and may have many stacks. Mini-mills, or scrap reprocessing facilities with a low number of small electric arc furnaces, may cover only a few acres and have few stacks. Due to a lack of information on the physical size of all the facilities, it was assumed that all stacks were located together. In addition, conservative (i.e., conditions not conducive to good dispersion) assumptions were

made concerning stack characteristics. All stacks were assumed to have the characteristics as shown on Table IV-2. The flowrate assumed for the iron and steel stacks is an average figure for all types of units. The net effect of these assumptions is to overestimate the air quality impact of the facilities to some unknown degree.

Based on the stack conditions shown in Table IV-2 and the results of a CRSTER model run (with Dallas/Fort Worth meteorology) for a few selected distances from the source, a regression equation was developed which estimates the concentration resulting from a 1.0 g/sec emission rate at any distance. From iron and steel plants, the equation developed was:

$$LnY = 1.71\ (lnX) - 2.35\ (1/X) + 3.19 \qquad (1)$$

where: Y is the concentration (ng/m^3) caused by an emission rate of 1.0 g/sec of cadmium and X is the distance from the source to the receptor point (Km). This equation has a coefficient of determination of greater than 0.99 as a predictor of ambient concentrations computed by CRSTER run.

The emission rate for each plant was multiplied by the computed concentration ratio to provide and estimate of concentration at any distance. Modelling results were not carried out beyond 20 km due to the questionable validity of this type of dispersion modelling beyond these distances.

Current monitoring programs are not designed to measure maximum impacts of point sources such as iron and steel mills. However, some indication of the plausibility of both the modelling techniques and the emission estimates can be made by comparing measured levels in areas with major iron and steel facilities with the concentrations predicted by the modelling technique.

TABLE IV-2

ASSUMED STACK CHARACTERISTICS

FOR IRON AND STEEL MILLS

Stack Height	100 feet
Temperature	250^{o}F
Diameter	8 feet
Flow	125,000 cfm

Ambient cadmium levels can vary greatly from year to year the little data available shown (Table IV-3) that annual average levels from five to 10 ng/m^3 are not uncommon. Of course, in these cities, the observed levels cannot be attributable solely to iron and steel mills since other sources are quite likely present. Estimated annual cadmium levels from iron and steel mills developed in this study using the technique described above are also five to ten ng/m^3. This suggests that, although very conservative assumptions were used, the estimated concentrations from iron and steel mills are reasonable. However, the actual degree of precision of these predicted levels cannot be determined reasonably.

D. Population Exposed

Table IV-4 shows an estimate of the population exposed to cadmium concentrations greater than 0.1 ng/m^3 and the estimated average concentration to which each of the exposed populations is subjected. The regional breakdown shown on Table IV-5 is based on EPA regions as shown on Figure IV-1. As discussed in Section III, these estimates were obtained by super-imposing the modelled ambient concentrations caused by emissions from iron and steel mills on the distribution of population.

As would be expected, both the largest number of people exposed and the highest average exposures are in EPA Regions III, IV, and V. This is due to the large concentration of integrated steel mills in the Pittsburgh, Birmingham, and Gary areas, respectively.

Table IV-5 shows a breakdown of population by exposure level. As described in the methodology section, care must be used in interpreting the results of this table due to the potential for exposure caused by several sources. As explained in the methodology section and Appendix A, the results on Table IV-5 should

TABLE IV-3

MEASURED CADMIUM LEVELS IN CITIES
CONTAINING IRON AND STEEL MILLS [a/]

City	Annual Average (ng/m^3)	Year [b/]
East Chicago, IN	4.6	1974
Ashland, KY	6	1974
Youngstown, OH	5.6	1970
Cleveland, OH	8.8	1970
Allentown, PA	13.4	1974
Bethlehem, PA	6.8	1973

a/ Source: Reference 16.

b/ Data reported for the latest year measurements are available.

TABLE IV-4

ESTIMATE OF POPULATION EXPOSED

TO CONCENTRATIONS ≥ 0.1 ng/m^3

FROM IRON AND STEEL MILLS

Region	Average Exposure (ng/m^3)	Population (10^3 people)
1	0.4	93
2	1.4	1,649
3	2.7	4,543
4	2.8	1,611
5	1.5	8,710
6	1.5	1,575
7	1.2	108
8	-	-
9	1.2	778
10	0.7	833
TOTAL	1.8	19,900

TABLE IV-5

ESTIMATE OF CUMULATIVE POPULATION EXPOSED TO SPECIFIED CADMIUM CONCENTRATIONS FROM IRON AND STEEL MILLS

(10^3 people)

Region	Annual Concentration (ng/m^3)			
	>10	>5	>1	>0.1
1	0	0	0	93
2	0	49	470	1,649
3	52	137	1,965	4,543
4	177	341	578	1,610
5	143	339	1,852	8,710
6	0	29	521	1,575
7	0	0	23	108
8	0	24	176	224
9	0	15	161	774
10	0	0	33	833

be interpreted as the population exposed to a concentration greated than or equal to that specified from at least one source. As such, the total population estimated is accurate, but the distribution has some bias towards the lower concentration levels.

Appendix B shows the population exposed to individual sources.

SECTION V

MUNICIPAL INCINERATORS

A. Introduction

This section estimates the population exposed to cadmium emitted from municipal incinerators.

Cadmium emissions from incinerators originate from the combustion of cadmium-containing waste materials. These waste materials are plastics which contain cadmium as a stablizer, cadmium-plated materials, nickel cadmium batteries, and materials painted with cadmium-based pigments.

Cadmium is released from incinerators due to its low boiling point (765°C) and the considerable higher ($>1,400^{\circ}$ C) temperatures characteristic of incinerator combustion. The estimated cadmium emission factors for incinerators are shown in Table V-1.

TABLE V-1

CADMIUM EMISSION FACTORS[17/]

Emission Factor (lbs/ton of refuse)

	Controlled
Best Judgement	1.2×10^{-2}
Maximum	1.0×10^{-1}
Minimum	6.0×10^{-4}

A large amount of variability among incinerators in emissions can be expected because of variations in input feed rate, feed

composition, combustion temperature (and other operating conditions), and control equipment efficiency. This variability cannot be taken into account in this type of analysis.

B. Geographic Distribution of Sources

Appendix C lists the locations and capacities of municipal incinerators analyzed in this study. The primary source of this capacity data is Incinerator and Solid Waste Technology.[18/] The facilities were located by street address through a telephone survey of each town and city. Street addresses were translated into latitude and longitude coordinates from detailed USGS maps (seven and a half minute quadrangles) for integration with the population data.

Appendix C also shows the estimated cadmium emissions from each incinerator. The emissions shown are simply the product of the "best judgement" emission factors and daily capacity figures. As previously mentioned, wide variation in these estimates can be expected due to variation in cadmium feed and control efficiency.

C. Estimated Ambient Levels

Estimates of ambient levels due to cadmium emissions from incinerators were based on the results of CRSTER runs using Dallas/Fort Worth meteorology. Four combinations of stack height and flow rate were used to represent the range of current proactice. Table V-2 shows the stack parameters used in this analysis. The data in Table V-2 are based on engineering judgement; it is recognized that considerable divergence from these assumptions may be possible.

As in the case of the iron and steel analysis, the equations relating ambient concentrations to distance are based on the CRSTER runs. These equations extend the CRSTER results to cover

TABLE V-2

ASSUMED STACK PARAMETERS

FOR MUNICIPAL INCINERATORS

Incinerator Size (tons/day)	Stack Height (ft.)	Temperature (^{o}F)	Diameter (ft)	Flow (acfm)
>1,000	125	250	12	210,000
300-1,000	125	250	5	50,000
150-300	50	250	3	25,000
<150	50	250	2	5,000

all distances of interest. The equations developed are shown below:

- For capacities of 1,000 tons/day
  $LnY = -1.58\ (lnX) - 3.05\ (1/X) + 2.78$ (1)

- For capacities between 300 and 1,000 tons/day
  $LnY = -1.75\ (lnX) - 2.07\ (1/X) + 3.26$ (2)

- For capacities between 150 and 300 tons/day
  $LnY = -1.60\ (lnX) - 0.57\ (1/X) + 3.16$ (3)

- For capacities less than 150 tons/day
  $LnY = -1.53\ (lnX) - 0.05\ (1/X) + 3.04$ (4)

where: Y is the concentration (ng/m^3) caused by an emission of 1.0 g/sec of cadmium and X is the distance to the receptor point (km).

These equations all had a coefficient of determination greater than 0.99.

Concentrations caused by each plant were computed by multiplying the plant emission rate in grams/second by the concentration resulting from a 1 gram/second emission rate. As with the iron and steel mills, modelling results were not carried out beyond 20 km.

Very high cadmium concentrations were computed from some incinerators using this techniques. The relatively low stack heights, typical of many urban incinerators, lead to low plume rise and very high (> 100 ng/m^3) localized concentrations. These high concentrations occur very near (< 1.5 km) the source but drop off quickly so that within 5 km of the source they are down to less than 1 ng/m^3. Most incinerators are located in urban areas where there are multiple smaller sources of cadmium probably

distributed in a non uniform spatial pattern. Existing monitoring programs, therefore, do not provide an adequate basis to judge, even qualitatively, the precision of these modelling results.

D. Population Exposed

Table V-3 shows the estimate of the population exposed to cadmium concentrations greater than 0.1 ng/m^3 originating from incinerators and the average concentration to which each person is exposed. The regional breakdown shown on Table V-3 based on EPA regions.

The greatest number of people exposed and the highest average concentration are in EPA Region II, which includes New York and Pennsylvania. Each state has a large number of incinerators located in high density urban areas (New York City and Philadelphia). Region V has the second highest number of people exposed. In this region, the average concentration is much lower than in Region II. This is due primarily to the more dispersed nature of a smaller number of incinerators located in high density areas (Chicago). The opposite situation occurs in Region VI where a relatively small number of people (one million) are exposed, but the average concentration is high.

Table V-4 shows a breakdown of population exposure by level. As described in the methodology section, care must be used in interpreting these data. As the average exposure level decreases the population exposed increased very quickly, as does the degree of multiple counting. This happens because the concentrations decrease from their maximum rather slowly and concentrations above the 0.1 ng/m^3 can occur at distances out to 20 km and beyond.

TABLE V- 3

ESTIMATE OF POPULATION EXPOSED

TO CADMIUM CONCENTRATIONS ≥ 0.1 ng/m^3

FROM MUNICIPAL INCINERATORS

Region	Average Exposure (ng/m^3)	Population (10^3 people)
1	6.1	6,571
2	11.4	15,163
3	4.6	8,742
4	4.0	2,995
5	5.4	12,501
6	10.4	1,122
7	3.3	1,760
8	3.4	173
9	-	-
10	-	-
TOTAL	7.2	49,026

TABLE V-4

ESTIMATE OF CUMULATIVE POPULATION EXPOSED TO SPECIFIED CADMIUM CONCENTRATIONS FROM MUNICIPAL INCINERATORS

(10^3 people)

Region	Annual Concentration (ng/m^3)			
	>10	>5	>1	>0.1
1	409	1,209	4,762	6,570
2	336	3,319	11,697	15,163
3	369	1,390	5,363	8,742
4	31	390	2,315	2,995
5	458	2,252	8,182	12,501
6	59	310	906	1,122
7	0	133	1,022	1,760
8	3	36	128	173
9	0	0	0	0
10	0	0	0	0

At these distances, the areas of influence of many incinerators will overlap due to their proximity to each other in urban locations, and thus, include large proportions of densely populated urban areas.

Appendix C lists the population exposed to each municipal incinerator.

SECTION VI

PRIMARY NON-FERROUS SMELTERS

A. Introduction

Cadmium is found in significant quantities combined with zinc and to a much lesser degree, with lead and copper. The source of cadmium emissions from all smelters is basically the same. During high temperature pyrometallurgical processing cadmium, which has a lower boiling point than other metals, is vaporized and released. The differences in cadmium emissions among the primary smelters are briefly discussed below.

The amount of cadmium released into the atmosphere varies for different zinc production processes. The pyrometallurgical process used at older plants (of which only three are still in existence) first roasts the ore at temperatures between 900 and 1,000°C to drive off SO_2 and produce a concentrate. Following this operation, the ore is sintered to provide a product which is easier to handle and retort. The final step is the reduction of zinc oxide to zinc in a retort.

Both the roasting and sintering steps appear to have the highest potential for cadmium emissions. One recent report,[19] however, indicates that due to an excess of oxygen, close temperature control (900-1,000°C), and the high efficency of existing air pollution control, little cadmium is emitted from the roaster. This hypothesis is supportable.[a]

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[a] In all existing zinc smelter, the SO_2-rich offgas from the roaster goes to a sulfuric acid plant. Since cadmium oxide is soluble in sulfuric acid, the recovered acid should show high cadmium levels if large amounts of cadmium are leaving the roaster. Cadmium levels reported in the recovered acid are quite low.[19]

Sintering operations appear, therefore, to be the primary cadmium emission point.

Since electrolytic operations use concentrate directly from the roasting operation and do not subject the concentrate to elevated temperatures, there appears little potential for cadmium emissions. Thus, cadmium emissions from this process are assumed to be zero for this analysis.

Cadmium emissions from lead and copper smelting result from similar high temperature such as sintering operations. Cadmium is present in most lead ores and some copper ores, and is released during high temperature processing.

Table VI-1 shows the estimated emission factors for primary smelters which are considered to be upper bound estimates. This is especially true for primary zinc smelting where the data are based only on one plant which was operating relatively inefficiently (i.e., with high zinc losses).

B. Geographic Distribution of Sources

Table VI-2 shows the location of the primary smelters reviewed in this analysis. General location and capacity data were obtained from various EPA and industry reports;[20,21/] and specific locations were determined from USGS maps.

C. Estimated Ambient Levels

The annual levels of cadmium due to smelters were not estimated for two reasons. First, the estimates of emissions from any particular source due both to stack and operating characteristics are more variable than for any other source. Second, the terrain around many smelters is extremely rough; thus, generalized source modelling results under these circumstances are difficult to interpret.

TABLE VI-1

EMISSION FACTORS FOR PRIMARY SMELTERS[1/]

(Pounds of Cadmium/Ton of Product)

Smelter Type	Minimum	Maximum	Best Judgement
Zinc	1.43	2.96	2.50
Lead	5.20×10^{-2}	2.60×10^{-1}	1.10×10^{-1} [a/]
Copper	7.00×10^{-2}	2.90×10^{-1}	1.50×10^{-1} [b/]
Cadmium	25.00	30.50	28.00

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a/ Controlled level may be as low as 5.20×10^{-3} lbs/ton of product.

b/ Controlled level may be as low as 7.00×10^{-3} lbs/ton of product.

TABLE VI-2

PRIMARY SMELTERS

TYPE	PLANT	LOCATION	LATITUDE (N)	LONGITUDE (W)	CAPACITY (tons/yr)
Primary Zinc Smelters	St. Joseph	Monaca, PA	40° 41'	80° 18'	250,000
	Bunker Hill Co.	Kellogg, ID	47° 33'	116° 06'	125,000
	New Jersey Zinc	Palmerton, PA	40° 48'	75° 37'	118,000
	National Zinc	Bartlesville, OK	36° 45'	95° 58'	55,000
Primary Lead Smelters	St. Joseph	Herculaneum, MO	38° 15'	90°22'	185,889
	Asarco	E. Helena, MT	46° 35	111° 55'	235,500
	Bunker Hill	Kellogg, ID	47° 33'	116° 06'	246,945
	Asarco	Glover, MO	37° 36'	90° 41'	97,761
Primary Copper Smelters	Asarco	Tacoma, WA	47° 14'	122° 26'	100,000
	Asarco	Hayden, AZ	33° 01'	110° 48'	180,000
	Asarco	El Paso, TX	31° 55'	106° 35'	100,000
	Phelps - Dodge	Morenci, AZ	33° 05'	109° 22'	177,000
	Phelps - Dodge	Douglas, AZ	31° 21'	109° 33'	127,000
	Phelps - Dodge	Ajo, AZ	32° 02'	112° 38'	70,000

TABLE VI-2

PRIMARY SMELTERS

(Continued)

TYPE	PLANT	LOCATION	LATITUDE (N)	LONGITUDE (W)	CAPACITY (tons/yr)
	Kennecott	Hayden, AZ	33° 01'	110° 48'	80,000
	Kennecott	Garfield, UT	40° 43'	112° 10'	280,000
	Kennecott	Hurley, NM	32° 41'	108° 07'	80,000
	Anaconda	Anaconda, MT	46° 07'	112° 56'	180,000
	White Pine	White Pine, MI	46° 45'	89° 34'	90,000
	Cities Services	Copperhill, TN	35° 00'	84° 21'	90,000
Primary Cadmium Smelters	St.Joseph Lead	Monaca, PA	40° 41'	80° 18'	250,000
	Bunker Hill Co.	Kellogg, ID	47° 33'	116° 06'	125,000
	New Jersey Zinc	Palmerton, PA	40° 48'	75° 37'	118,000
	Asarco	Chorpus Christi, TX	27° 55'	97° 45'	108,000
	National Zinc Co.	Bartlesville,	36° 45'	95° 58'	55,000

TABLE VI-3

MEASURED CADMIUM LEVELS NEAR PRIMARY SMELTERS[a/]

City	State	Concentration (ng/m^3)	Year[b/]
Helena	Montana	15	1971
El Paso	Texas	24	1974
Kellogg	Idaho	247	1975
Jefferson County	Missouri	111	1975

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a/ SOURCE: Reference 22.

b/ Last year for which data is available.

Monitoring data can be used to give a rough approximation of the ambient levels which occur around smelters. Table VI-3 lists observed atmospheric cadmium levels in areas near smelters. It is obvious that very high cadmium levels are not uncommon around smelters. As before, it is difficult to attribute all the measured cadmium to the smelters. However, due to the lack of population and industry around most smelters, it is very likely that most of the measured concentrations are due to smelter emissions.

To approximate the population exposed to cadmium emissions from smelters, the population living within 20 km of the smelter was assumed to be exposed to cadmium levels greater than 0.1 ng/m^3.

D. Population Exposed

Table VI-4 shows the estimated population exposed to cadmium emissions from primary smelters. It is obvious that in comparison to the preceding sources, fewer people are exposed to emissions from primary smelters. The distribution of population is very biased. Two regions (and two plants) account for the majority of the population exposed.

The low number of people exposed by smelters is due to the very low population density around the smelters. It appears, therefore, that while primary smelters are a large source of cadmium emissions to the atmosphere, they do not (with the exception of two plants) expose large numbers of people to these emissions. However, the exposure levels can be quite high as is evident from Table VI-3.

TABLE VI-4

ESTIMATE OF POPULATION EXPOSED TO CADMIUM CONCENTRATIONS FROM PRIMARY SMELTERS

(10^3 people)

Region	Primary Zinc	Primary Lead	Primary Copper	Primary Cadmium
1	-	-	-	-
2	-	-	-	-
3	258	-	-	100
4	-	-	19	-
5	100	-	3	86
6	-	-	16	41
7	-	35	-	-
8	-	28	92	-
9	-	-	29	-
10	41	17	461	17
TOTAL	399	80	620	245

SECTION VII

SECONDARY SMELTERS

A. Introduction

The recycling of zinc and copper can potentially lead to emissions fo cadmium due to the cadmium contained in metals. The high temperatures involved with the melting of the scrap will release most of the cadmium. The cadmium associated with the metal will be vaporized and potentially release into the atmosphere.

Table VII-1 shows the assumed emission factors for secondary smelting. The high degree of control shown is based on the assumption that fabric filters are used for control.

B. Geographic Distribution of Sources

Table VII-2 shows the geographic distribution of secondary copper and zinc smelters in the United States. Location data were determined from various trade directories.[15,16/] Latitude and longitude coordinates were obtained from detailed USGS maps.

Information on the size of each smelter was not available. Accordingly, the assumption was made that all smelters were of "average" size. One reference[23/] does indicate a relatively small size range for these types of smelters. Therefore, the assumption may be reasonable.

C. Estimated Ambient Levels

Estimates of ambient cadmium levels resulting from emissions of secondary smelters were based on CRSTER runs using Dallas/

TABLE VII-1

EMISSION FACTORS FOR SECONDARY SMELTERS

(Pounds of Cadmium/Ton of Product)

	UNCONTROLLED			CONTROLLED[a/]
Smelter Type	Minimum	Maximum	Best Judgement	Best Judgement
Zinc	8.0×10^{-3}	1.4×10^{-2}	1.0×10^{-2}	5.0×10^{-4}
Copper	2.6	4.0	3.0	3.0×10^{-1}

a/ Fabric filter assumed.

TABLE VII-2

LOCATION OF SECONDARY ZINC AND COPPER SMELTERS

	Plant	Location	Latitude (N)	Longitude (W)
Secondary Zinc Smelters	Asarco, Federated Metals Division	Sand Springs, OK	36°08'	96°07'
	American Zinc Co. of Illinois	Hillsborough, IL	39°09'	89°29'
	Asarco	Long Beach, CA	34°05'	118°12'
Secondary Copper Smelters	Asarco	Perth Amboy, NJ	40°31'	74°15'
	Asarco	Whiting, IN	41°40'	87°29'
	Asarco	Houston, TX	29°45'	95°12'
	Asarco	Long Beach, CA	34°05'	118°12'
	Asarco	San Francisco, CA	37°45'	122°22'
	Kennecott	Magna, UT	40°42'	112°06'
	Kennecott	Hurley, NM	32°41'	108°07'

Fort Worth meteorology. Different stack conditions were assumed for copper and zinc smelters. Table VII-3 shows the assumed stack conditions.

As in the case of other industries, a regression equation was developed based on the CRSTER runs. The equations developed are shown below:

- For secondary copper smelters--

$$LnY = -1.57\,(LnX) - 0.35\,(1/X) + 3.12$$

- For secondary zinc smelters--

$$LnY = -1.75\,(lnX) - 2.07\,(1/X) + 3.26$$

where: X is the concentration (ng/m^3) caused by an emission rate of one g/sec of cadmium, X is the distance to the receptor point (Km).

Concentrations caused by each plant were computed by multiplying the plant emission rate in grams/second, by the concentration resulting from one g/sec emission rate. As with other industries, no modelling was carried out beyond 20 Km.

D. Population Exposed

Table VII-4 shows the estimated cumulative population exposed to specified cadmium concentrations and the average concentration each person is exposed to. Though there are only very few secondary copper smelters, the population exposed is high. This is due to the urban location of the smelters and the high (even when controlled) emission factor.

TABLE VII-3

ASSUMED STACK CONDITIONS FOR

SECONDARY SMELTERS

STACK PARAMETER	SMELTER TYPE	
	Zinc	Copper
Height (ft)	120	50
Temperature (^{o}F)	250	250
Flow (ACFM)	40,000	10,000
Diameter (ft)	4	2

TABLE VII-4

ESTIMATE OF POPULATION EXPOSED TO SPECIFIED LEVELS FROM SECONDARY SMELTERS (10^3 People)

	Concentration (ng/m^3)				
Smelter	≥10	≥5	≥1	≥0.1	Average Exposure
Secondary Copper	296	798	5710	9891	2.3
Secondary Zinc	0	0	0	37	0.47

Secondary zinc smelting appears to be an insignificant source of atmospheric cadmium with few people exposed and very low emissions. However, it must be pointed out that it was not possible to take into account the difference in plant sizes. It is not clear how this would affect the results.

Appendix E shows the estimated population exposed to each secondary smelter.

APPENDIX A

POPULATION EXPOSURE METHODOLOGY

The population exposure model is used to calculate the number of people who live within a fixed distance of a specific set of latitude and longitude. The imputs to the model are the location of the center point and the radius under consideration. The data base for the model is the set of population maps that were constructed from the Medalist data. The center point corresponds to the smoke stack of a point source polluter. The radius corresponds to the maximum distance from the stack that a specific concentration of a pollutant could be found. The estimate of the radius is determined by the predominant methodology (in the Dallas Fort Worth data set). The circle drawn around the point is therefore an overestimate since this, in effect, assumes every direction from the source is downwind.

Given the imputs, the first step is to identify the map on which the source is located. This is accomplished by comparing the latitude and longitude of the source to the set of map boundaries. Next, the latitude and longitude of the source are converted to the appropriate map grid point using the same method that was used to locate the population data on the maps. This, however, may not fully access the data on the population affected by the source. If the source is located near a map boundary, the affected population may be located on up to three additional maps. If a source is located within 20 kilometers of another map, that map may also be accessed.

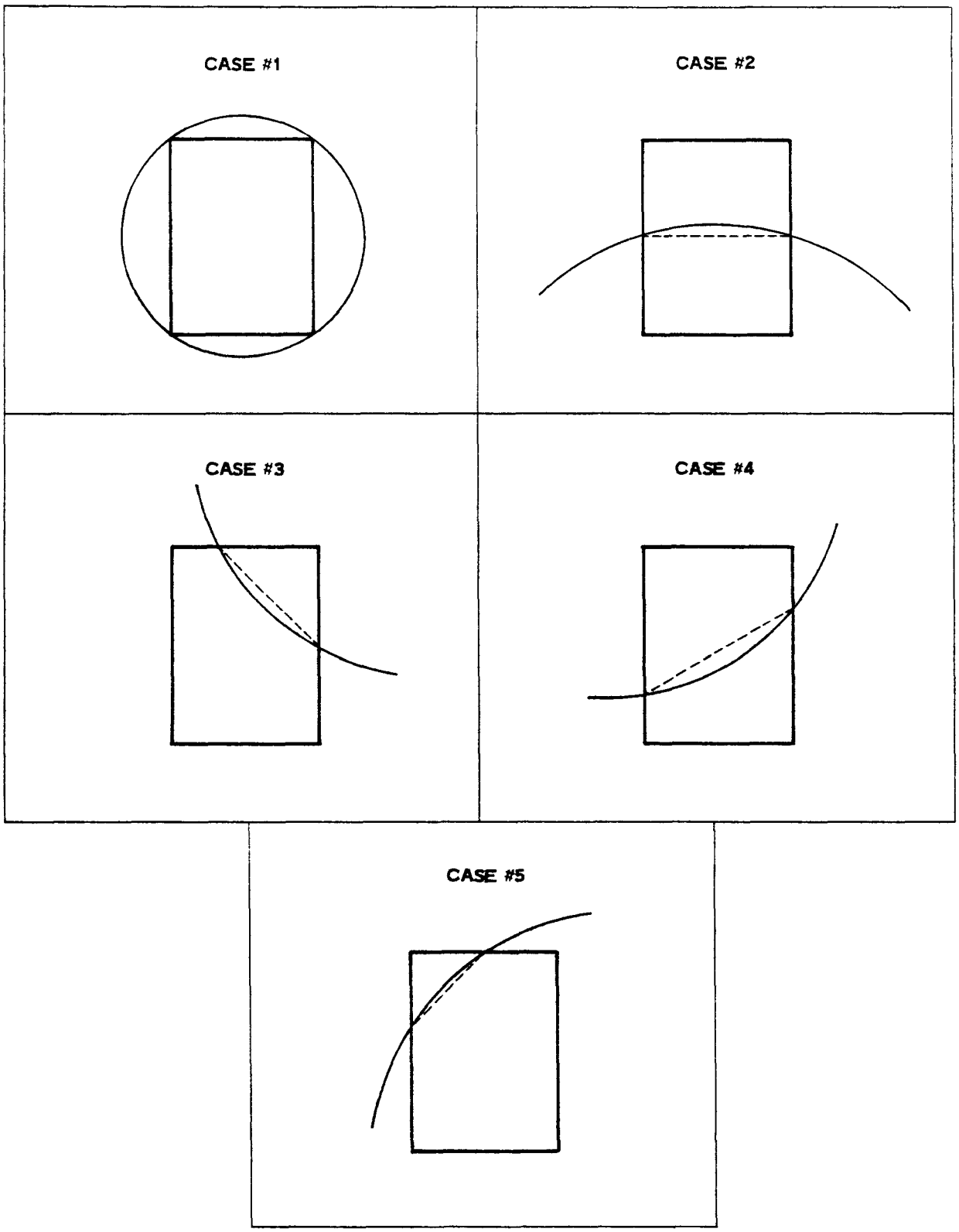
After loading the appropriate map file from computer tape into core and reading the necessary information onto the map grid, the next step is to construct a coordinate system centered at the same location since all grids are not the same size. The grid points at which the source has been located becomes the origin. The value which is calculated is based on the latitude of the source. The distance between any point and the origin or source is therefore easily calculated by triangulation from the coordinates of that point with the origin.

Each grid cell within 20 kilometers of the source is systematically examined. First, the corners of the cell are located on the coordinate system. With this information, the total amount of area inside the cell and included within the selected radius from the source is calculated. The symmetry of the analysis allows the computer program to actually look only at the grid blocks that lie in or border the first quadrant. The values for each of the blocks outside the first quadrant can be inferred from the results of the first quadrant.

There are five distinct cases encountered when one attempts to calculate the area of a grid block which is included within a circle of given radius (see Figure A-1):

- The first case encountered is the area of the grid cell that has the source located at its center and is larger than the circle enclosed by the selected radius. Here, a simple approximation is made. The area included is taken to be the area of the circle of the given radius divided by the area of the grid cell to obtain the fraction of the cell included in the circle. Once the area of the circle exceeds the area of the grid block, it is assumed that the entire areas of the grid cell is included within the radius.

FIGURE A-1



- The second case involves grid cells located along either the x-axis or the y-axis. Here, the area included is taken to be the arc of the rectangle defined by the interesection of the radius and the block boundaries included, plus the area of the remaining arc defined by the radius. Special cases occur when the radius intersects the edges of the grid cells which are perpendicular to the axis. The general form of the solution remains the same.

- Case three occurs where only one of the vertices of the cell is included; the area included is the sum of the area of the enclosed triangle and the area of the enclosed arc.

- Case four occurs when two vertices are included or all are included. In this case, the area covered equals the sume of the area of the trapezoid and the area of the enclosed arc.

- Case five occurs when three vertices are included. The area of the cell included equals the area of the cell minus the area of the excluded triangle plus the area of the included arc.

Once the area of the grid cell which is included in the exposed area has been calculated, it is divided by the area of the grid cell yielding the percentage of the area included. In order to calculate the number of people who live within the included area, it is assumed that the population is uniformly distributed throughout the grid cell. Therefore, the population affected is the product of the percentage of the area included times the population of the grid cell. By summing up the population included in all the cells, the total number of people who live within a given radius of a source can be estimated.

By choosing several radii for each source, the number of people who reside between a given pair of radii can be calculated by a simple subtraction. Since each radius corresponds to a specific pollution level, this type of calculation yields an estimate of the number of people who are exposed to various concentration levels for a single source.

By summing up the effects of several sources, either by source type or location, one can gain insight into which type of source appears to effect the largest number of people. However, the total number of people exposed may be misleading. In areas where there are many point sources located close together, much multiple-counting will occur. (For example, a person exposed to a given ambient concentration produced separately by three sources will counted three times). Therefore, this approach does not give an accurate estimate of population exposed to specific levels from sources. However, the model does give an accurate respresentation of total exposure (expressed as concentration per person-year) for use in linear health models (i.e., those in which one person exposed to two ng/m^3 is treated the same as two people each exposed to one ng/m^3).

To obtain an estimate of the population exposed to various concentrations, a slightly different approach is used. The major difference is that once people are determined to lie within any radius of any plant, they are subtracted from the map. In other words, no single person is ever counted by more than one source. In addition, the model is not run source-by-source as before, but pollution level-by-pollution level. By choosing several pollution levels and starting with the level that yields the smallest radius and working out the actual number of people who are exposed to at least one source at each, a pollution level can be estimated.

This model also has its limitations. Individual source totals are meaningless since the sources which are run first will tend to count more people simply because there are more people initially on the map. There is also no way to arrive at the total pollutant concentration times person estimate because no account is made of cumulative effects.

APPENDIX B-1

LOCATION AND CAPACITY (THOUSAND TONS/YEAR)

CITY	LATITUDE (N)	LONGITUDE (W)	TOTAL CAPACITY	TYPE OF OPERATION					EMISSION RATES
				BLAST FURNACE	SINTER STRAND	ELECTRIC ARC	BASIC OXYGEN	OPEN HEARTH	Q GM/SEC
ALABAMA									
1. Birmingham	33°32'	86°50'	1,250,897	1,250,564		333			2.13×10^{-3}
2. Fairfield	33°29'	86°52'	5,908,881	5,897,738	7,783		3,360		1.63×10^{-1}
3. Gadsden	34°01'	86°02'	1,816,446	1,812,580	310	036	2,520		1.35×10^{-2}
ARKANSAS									
4. Newport	35°36'	91°15'	140			140			9.4×10^{-4}
CALIFORNIA									
5. Carson	33°48'	118°17'	123			123			7.54×10^{-4}
6. Emeryville	37°50'	122°17'	126			126			7.54×10^{-4}
7. Fontana	34°06'	117°26'	4,678,242	4,675,042	1,240	70		1,890	2.89×10^{-2}
8. Union City	37°36'	122°01'	630					630	1.32×10^{-3}
COLORADO									
9. Pueblo	38°16'	104°37'	3,042,042	3,038,420	968	672	1,982		2.55×10^{-2}
CONNECTICUT									
10. Bridgeport	41°10'	73°10'	84			84			5.66×10^{-4}
FLORIDA									
11. Jacksonville	30°20'	81°41'	210			210			1.32×10^{-3}
12. Indiantown	27°01'	80°28'	182			182			1.13×10^{-3}
13. Tampa	27°57'	82°26'	238			238			1.5×10^{-3}
GEORGIA									
14. Cartersville	34°09'	84°47'	280			280			1.69×10^{-3}
15. Atlanta	33°46'	84°25'	476			476			3.02×10^{-3}

APPENDIX B-1 (Continued)

LOCATION AND CAPACITY (THOUSAND TONS/YEAR)

CITY	LATITUDE (N)	LONGITUDE (W)	TOTAL CAPACITY	TYPE OF OPERATION					EMISSION RATES
				BLAST FURNACE	SINTER STRAND	ELECTRIC ARC	BASIC OXYGEN	OPEN HEARTH	Q GM/SEC
ILLINOIS									
16. Alton	38°53'	90°10'	1,260		1,260				8.11×10^{-3}
17. Chicago	41°45'	87°25'	481			481			3.02×10^{-3}
18. Chicago Heights	41°30'	87°37'	204			204			1.32×10^{-3}
19. Granite City	38°42'	90°08'	696,003	691,067	988		3,948		2.16×10^{-2}
20. Lemont	41°40'	88°00'				336			2.07×10^{-3}
21. Morton Grove	42°02'	87°45'	39			39			1.88×10^{-4}
22. Sterling	41°47'	89°41	2,940			2,940			1.86×10^{-2}
KENTUCKY									
23. Ashland	38°27'	82°38'	2,832,255	2,828,391	840		3,024		1.81×10^{-3}
INDIANA				11,566,510					
24. East Chicago	41°38'	87°28'	17,519,213	5,944,219		675	7,812		6.06×10^{-3}
25. Fort Wayne	41°04'	85°10'	151			151			$9,43 \times 10^{-4}$
26. Gary	41°35'	87°19'	15,098,769	15,079,325	5,311		10,458	36	1.2×10^{-1}
27. Kokomo	40°29'	86°08'	980			980			6.22×10^{-3}
28. New Castle	39°55'	85°21'	117			117			7.54×10^{-4}
MARYLAND									
29. Baltimore	39°17'	76°33'	448			448			2.83×10^{-3}
30. Sparrow's Point	39°13'	76°28'	10,239,193	10,228,288	4,122		3,696	3,087	9.2×10^{-2}
MICHIGAN									
31. Dearborn	40°21'	83°11'	3,303,957	3,299,925			4,032		9.05×10^{-4}
32. Ferndale	42°27'	83°08'	56			56			3.77×10^{-4}
33. Trenton	42°08'	83°11'	2,574,140	2,597,980	1,120		5,040		8.31×10^{-3}
Warren	42°31'	83°02'	1,120			1,120			7.5×10^{-3}

APPENDIX B-1 (Continued)

LOCATION AND CAPACITY (THOUSAND TONS/YEAR)

CITY	LATITUDE (N)	LONGITUDE (W)	TOTAL CAPACITY	TYPE OF OPERATION					EMISSION RATES
				BLAST FURNACE	SINTER STRAND	ELECTRIC ARC	BASIC OXYGEN	OPEN HEARTH	Q GM/SEC
NEBRASKA									
34. Norfolk	42°01'	97°25'	224			224			1.5×10^{-3}
NEW JERSEY									
35. Roebling	40°07'	74°46'	417			417			2.64×10^{-3}
36. Sayreville	40°27'	74°21'	364			364			2.26×10^{-3}
NEW YORK									
37. Auburn	42°56'	76°34'	168			168			1.13×10^{-3}
38. Buffalo	42°56'	78°52'	2,916,391	2,914,711			1,680		3.77×10^{-4}
39. Dunkirk	42°29'	79°19'	319			319			2.07×10^{-3}
40. Lackawanna	42°49'	78°49'	7,241,389	7,231,936		1,641	7,812		3.57×10^{-2}
41. Lockport	43°10'	78°41'	126			126			7.54×10^{-4}
42. Syracuse	43°03'	76°10'	201			201			1.32×10^{-3}
NORTH CAROLINA									
43. Charlotte	35°14'	80°52'	154			154			9.43×10^{-4}
OHIO									
44. Campbell	41°04'	80°36'	3,522,732	3,519,366	720			2,646	2.04×10^{-2}
45. Canton	40°45'	81°21'	421,834	418,880		2,954			2.04×10^{-2}
46. Cleveland	41°28'	81°40'	6,477,830	1,762,576	306	1,036	3,696		1.88×10^{-2}
				4,709,166					1.60×10^{-2}
47. Lorain	41°26'	82°08'	4,576,200	4,572,260	160		3,780		4.17×10^{-3}
48. Mansfield	40°46'	82°31'	6,187,557	6,186,997		560			3.58×10^{-3}
49. Middletown	39°30'	84°24'	3,893,817	1,299,760	860		3,360	4,177	2.74×10^{-2}
				2,585,660					
50. Portsmouth	38°44'	82°59'	1,262,260	1,261,260				1,008	2.07×10^{-3}

APPENDIX B-1 (Continued)

LOCATION AND CAPACITY (THOUSAND TONS/YEAR)

CITY	LATITUDE (N)	LONGITUDE (W)	TOTAL CAPACITY	TYPE OF OPERATION					EMISSION RATES
				BLAST FURNACE	SINTER STRAND	ELECTRIC ARC	BASIC OXYGEN	OPEN HEARTH	Q GM/SEC
OHIO (Continued)									
51. Steubinville	40°21'	80°37'	4,620				4,620		1.13×10^{-3}
52. Toledo	41°38'	83°31'	1,670,900	1,670,900					0
53. Warren	41°14'	80°49'	1,260			1,260			8.1×10^{-3}
54. Youngstown	41°07'	80°41'	3,483,508	422,249	1,260			2,021	3.06×10^{-2}
OKLAHOMA									
55. Sand Springs	36°08'	96°06'	420			420			2.6×10^{-3}
PENNSYLVANIA									
56. Alquippa	40°36'	80°14'	4,807,308	4,805,570			1,738		3.96×10^{-4}
57. Beaver Falls	40°45'	80°19'	1,680			1,680			1.07×10^{-2}
58. Bethlehem	40°36'	75°21'	4,657,327	4,650,661	1,892	238	4,536		4.18×10^{-2}
59. Braddock	42°21'	79°52'	5,034,516	5,030,820			3,696		8.30×10^{-4}
60. Bridgeville	40°21'	80°07'	224			224			1.5×10^{-3}
61. Butler	40°51'	79°53'	1,554			1,554			1.0×10^{-2}
62. Clairton	40°17'	79°52'	1,053,364	1,053,364					0
63. Duquesne	40°22'	79°50'	4,552,908	4,548,246		966	3,696		7.0×10^{-3}
64. Erie	42°06'	80°05'	762,748	762,230		518			3.32×10^{-3}
65. Fairless Hills	41°10'	74°52'	5,296,070	5,289,770	1,400	1,120		3,780	4.3×10^{-2}
66. Homestead	40°24'	79°54'	3,696						7.73×10^{-3}
67. Houston	40°15'	80°12'	252			252			1.69×10^{-3}
68. Irwin	40°19'	79°42'	182						1.13×10^{-2}
69. Johnstown	40°18'	78°55'	4,150,702	4,148,467	1,000	100		1,134	2.3×10^{-4}
70. Latrobe	40°19'	79°23'	42			42			1.88×10^{-3}
71. McKeesport	40°21'	79°51'	2,699,556	2,699,258	298				6.03×10^{-3}
72. Midland	40°15'	80°12'	1,632,260	1,631,014		1,245			8.0×10^{-2}
73. Monessen	40°09'	79°53'	1,991,216	1,987,331	525		3,360		1.16×10^{-4}
74. New Castle	41°05'	80°21'	246					246	5.66×10^{-4}
75. Oil City	41°25'	79°42'	98			98			5.66×10^{-4}
76. Phoenixville	40°07'	75°31'	315					315	5.66×10^{-4}

APPENDIX B-1 (Continued)

LOCATION AND CAPACITY (THOUSAND TONS/YEAR)

CITY	LATITUDE (N)	LONGITUDE (W)	TOTAL CAPACITY	TYPE OF OPERATION					EMISSION RATES
				BLAST FURNACE	SINTER STRAND	ELECTRIC ARC	BASIC OXYGEN	OPEN HEARTH	Q GM/SEC
PENNSYLVANIA (Continued)									
77. Pittsburgh	40°27'	79°57'	3,593,721	3,589,740		999	840	2,142	1.1×10^{-2}
78. Reading	40°18'	75°58'	196			196			1.13×10^{-3}
79. Sharon	41°14'	80°31'	1,647,576	1,643,180		616	3,780		4.77×10^{-3}
80. Steelton	40°13'	76°49'	1,316			1,316			8.49×10^{-3}
81. Washington	40°10'	80°14'	168			168			1.13×10^{-3}
SOUTH CAROLINA									
82. Darlington	34°17'	79°52'	268			268			1.69×10^{-3}
83. Georgetown	33°22'	79°17'	630			630			3.97×10^{-3}
TENNESSEE									
84. Harrisman	35°56'	84°33'	210			210			1.32×10^{-3}
TEXAS									
85. Baytown	29°43'	94°58'	2,352			2,352			1.5×10^{-2}
86. Ft. Worth	42°40'	97°20'	210			210			1.32×10^{-3}
87. Houston	29°47'	95°18'	1,004,199	1,001,000	248	2,951			2.4×10^{-2}
88. Jewett	31°21'	96°08'	224			224			$1.5 \times .0^{-3}$
89. Lone Star	32°55'	94°42'	1,011,773	1,010,869	253	336		315	8.05×10^{-3}
90. Longview	32°29'	94°44'	140			140			9.43×10^{-4}
91. Pampa	35°32'	100°57'	61			61			3.77×10^{-4}
UTAH									
92. Geneva	40°12'	111°37'	411,199	407,829	850			2,520	2.3×10^{-2}
VIRGINIA									
93. Chesapeake	36°43'	76°17'	112			112			7.54×10^{-4}

APPENDIX B-1 (Continued)
LOCATION AND CAPACITY (THOUSAND TONS/YEAR)

CITY	LATITUDE (N)	LONGITUDE (W)	TOTAL CAPACITY	TYPE OF OPERATION					EMISSION RATES
				BLAST FURNACE	SINTER STRAND	ELECTRIC ARC	BASIC OXYGEN	OPEN HEARTH	Q GM/SEC
WASHINGTON									
94. Kent	47°23'	122°13'	196			196			1.13×10^{-3}
95. Seattle	47°34'	122°19'	896			896			5.6×10^{-3}
WEST VIRGINIA									
96. Weirton	40°24'	80°35'	6,405,785	6,397,183	2,050		6,552		4.29×10^{-2}

APPENDIX B-2

IRON AND STEEL

State	Source	Thousands of People Exposed to Concentration Range (ng/m^3) >10	5-10	1-5	.1-1	Total
ALABAMA	1.	0	0	0	286	286
	2.	182	171	192	0	545
	3.	0	0	51	34	85
ARKANSAS	4.	0	0	0	8	8
CALIFORNIA	5.	0	0	0	93	93
	6.	0	0	0	120	120
	7.	0	18	146	319	483
	8.	0	0	0	54	54
COLORADO	9.	0	21	86	3	110
CONNECTICUT	10.	0	0	0	63	63

APPENDIX B-2 (Continued)

IRON AND STEEL

Thousands of People Exposed to Concentration Range (ng/m^3)

State	Source	>10	5-10	1-5	.1-1	Total
FLORIDA	11.	0	0	0	[illegible]	[illegible]
	12.	0	0	0	[illegible]	[illegible]
	13.	0	0	0	[illegible]	[illegible]
GEORGIA	14.	0	0	0	[illegible]	[illegible]
	15.	0	0	0	[illegible]	[illegible]
ILLINOIS	16.	0	0	25	[illegible]	[illegible]
	17.	0	0	0	[illegible]	[illegible]
	18.	0	0	0	[illegible]	[illegible]
	19.	0	16	89	[illegible]	[illegible]
	20.	0	0	0	[illegible]	[illegible]
	21.	0	0	0	[illegible]	[illegible]
	22.	0	0	33	[illegible]	[illegible]
KENTUCKY	23.	0	0	59	[illegible]	[illegible]

APPENDIX B-2 (Continued)

IRON AND STEEL

Thousands of People Exposed to Concentration Range (ng/m^3)

State	Source	>10	5-10	1-5	.1-1	TOTAL
INDIANA	24.	0	0	47	996	1043
	25.	0	0	0	75	75
	26.	140	98	366	0	604
	27.	0	0	29	59	88
	28.	0	0	0	17	17
MARYLAND	29.	0	0	0	895	895
	30.	0	0	0	39	39
MICHIGAN	31.	0	0	0	207	207
	32.	0	0	0	0	0
	33.	0	0	21	425	446
NEBRASKA	34.	0	0	85	2051	2136
NEW JERSEY	35.	0	0	0	18	18
NEW YORK	36.	0	0	6	178	184
	37.	0	0	0	225	225

APPENDIX B-2 (Continued)

IRON AND STEEL

Thousands of People Exposed to Concentration Range (ng/m^3)

State	Source	>10	5-10	1-5	.1-1	Total
NEW YORK (cont'd)	38.	0	0	0	35	35
	39.	0	0	0	0	0
	40.	0	0	0	31	31
	41.	0	59	422	451	932
	42.	0	0	0	11	11
NORTH CAROLINA	43.	0	0	0	209	209
OHIO	44.	0	0	0	78	78
	45.	0	8	211	209	428
	46.	0	0	95	218	313
	47.	0	0	396	1205	1601
	48.	0	0	4	207	211
	49.	0	0	0	99	99
	50.	0	26	67	132	225
	51.	51	71	1112	0	1234
	52.	0	0	0	44	44
	53.	0	0	0	0	0
	54.	0	0	48	281	329
OKLAHOMA	55.	0	42	251	179	472
PENNSYLVANIA	56.	0	0	0	51	51

APPENDIX B-2 (Continued)

IRON AND STEEL

Thousands of People Exposed to Concentration Range (ng/m^3)

State	Source	>10	5-10	1-5	.1-1	Total
PENNSYLVANIA (cont'd)	57.	0	0	0	0	0
	58.	0	0	42	186	228
	59.	8	49	227	164	448
	60.	0	0	0	103	103
	61.	0	0	0	101	101
	62.	0	0	27	65	92
	63.	0	0	0	0	0
	64.	0	0	49	1120	1169
	65.	0	0	0	186	186
	66.	0	0	7	19	26
	67.	0	0	92	1355	1447
	68.	0	0	0	34	34
	69.	0	0	0	36	36
	70.	0	21	81	52	154
	71.	0	0	0	0	0
	72.	0	0	55	1003	1058
	73.	0	0	20	240	260
	74.	0	0	50	180	230
	75.	0	0	0	1	1
	76.	0	0	0	6	6
	77.	0	0	0	9	9
	78.	0	0	330	1158	1488
	79.	0	0	0	80	80
	80.	0	0	15	120	135
	81.	0	0	31	299	330
SOUTH CAROLINA	82.	0	0	0	28	28
	83.	0	0	0	16	16
TENNESSEE	84.	0	0	0	1	1

APPENDIX B-2 (Continued)

IRON AND STEEL

Thousands of People Exposed to Concentration Range (ng/m^3)

State	Source	>10	5-10	1-5	.1-1	Total
TEXAS	85.	0	0	0	15	[illegible]
	86.	0	0	43	[illegible]	[illegible]
	87.	0	0	0	[illegible]	[illegible]
	88.	0	41	456	859	1356
	89.	0	0	0	0	0
	90.	0	0	1	17	18
	91.	0	0	0	27	[illegible]
UTAH	92.	0	0	0	0	0
VIRGINIA	93.	0	1	66	44	111
WASHINGTON	94.	0	0	0	0	0
	95.	0	0	0	[illegible]	[illegible]
WEST VIRGINIA	96.	0	0	56	[illegible]	[illegible]
	97.	3	29	85	[illegible]	[illegible]

APPENDIX C-1

MUNICIPAL INCINERATORS

	State	Latitude (N)	Longitude (W)	Capacity (tons/day)	Q (gms/sec)
CONNECTICUT					
1	Ansonia	41 20′	73 4′	190	1.30X10-2
2	Bridgeport	41 12′	73 10′	190	1.30X10-2
3	Darien	41 4′	73 28′	128	8.80X10-3
4	East Hartford	41 46′	72 37′	351	2.40X10-2
5	Hartford	41 47′	72 40′	600	1.10X10-2
6	New Canaan	41 8′	73 29′	124	8.50X10-3
7	New Haven	41 18′	72 52′	717	4.90X10-2
8	New London	41 21′	72 6′	120	8.20X10-3
9	Stamford	41 2′	73 32′	395	2.70X10-2
10	Stamford	41 4′	73 31′	351	2.40X10-2
11	Stratford	41 12′	73 8′	263	1.80X10-2
12	Waterbury	41 34′	73 1′	293	2.00X10-2
13	West Hartford	41 47′	72 45′	293	2.00X10-2
FLORIDA					
14	Broward County	26 6′	80 11′	293	2.00X10-2
15	Dade County	25 51′	80 11′	293	2.00X10-2
16	Fort Lauderdale (Broward C.)	26 8′	80 10′	439	3.00X10-2
17	Miami (Dade C.)	25 44′	80 12′	893	6.10X10-2
18	Tampa	28 0′	82 26′	996	6.80X10-2
ILLINOIS					
19	Chigaco	41 53′	87 44′	1201	8.20X10-2
20	Chigaco	41 49′	87 39′	1611	1.10X10-1
21	Chicago (S. Doty)	41 37′	87 34′	1201	8.20X10-2
22	Cicero	41 49′	87 45′	498	3.40X10-2

APPENDIX C-1 (Continued)

MUNICIPAL INCINERATORS

	State	Latitude (N)	Longitude (W)	Capacity (tons/day)	Q (gms/sec)
INDIANA					
23	East Chicago	41 39′	87 28′	454	3.10X10-2
KENTUCKY					
24	Louisville	38 12′	85 47′	996	6.80X10-2
LOUISIANA					
25	Shreveport	32 19′	94 17′	190	1.30X10-2
26	New Orleans	29 58′	90 5′	190	1.30X10-2
27	New Orleans	30 2′	90 3′	395	2.70X10-2
28	New Orleans	29 56′	90 1′	395	2.70X10-2
29	New Orleans	30 0′	90 3′	439	3.00X10-2
30	New Orleans	29 56′	90 6′	395	2.70X10-2
MARYLAND					
31	Baltimore	39 18′	76 31′	805	5.50X10-2
MASSACHUSETTS					
32	Belmont	42 23′	71 10′	146	1.00X10-2
33	Braintree	42 13′	71 0′	234	1.60X10-2
34	Brockton	42 5′	71 1′	600	4.10X10-2
35	Brookline	42 19′	71 7′	175	1.20X10-2
36	Fall River	41 40′	71 11′	600	4.10X10-2
37	Framingham	42 18′	71 24′	498	3.40X10-2
38	Lowell	42 37′	71 21′	395	2.70X10-2
39	Marblehead	42 30′	70 51′	79	5.40X10-3
40	Salem	42 31′	70 53′	139	9.50X10-3
41	Saugus	42 30′	71 1′	1201	8.20X10-2
42	Watertown	42 21′	71 11′	307	2.10X10-2
43	Winchester	42 27′	71 8′	99	6.80X10-3
44	Weymouth	42 13′	70 57′	293	2.00X10-2
45	Reading	42 31′	71 06′	143	9.80x10-3

APPENDIX C-1 (Continued)

MUNICIPAL INCINERATORS

	State	Latitude (N)	Longitude (W)	Capacity (tons/day)	Q (gms/sec)
MICHIGAN					
46	Central Wayne County	42 16′	83 25′	805	5.50X10-2
47	Detroit (Southfield)	42 28′	83 12	190	1.30X10-2
48	Grosse Point	42 35′	82 52′	600	4.10X10-2
49	S.E. Oakland County	42 30′	83 6′	600	4.10X10-2
MISSOURI					
50	St. Louis (North)	38 40′	90 12′	395	2.70X10-2
51	St. Louis (South)	38 35′	90 12′	395	2.70X10-2
NEW HAMPSHIRE					
52	Manchester	43 0′	71 28′	99	6.80X10-3
NEW JERSEY					
53	Ewing	40 15′	74 48′	234	1.60X10-2
54	Red Bank	40 20′	74 5′	46	3.10X10-3
NEW YORK					
55	Babylon	40 41′	73 19′	395	2.70X10-2
56	Beacon	41 29′	73 58′	99	6.80X10-3
57	Buffalo	42 54′	78 53′	600	4.10X10-2
58	Eastchester	40 57′	73 48′	190	1.30X10-2
59	Freeport	40 39′	73 35′	161	1.10X10-2
60	Garden City	40 43′	73 38′	175	1.20X10-2
61	Hempstead	40 37′	73 37′	600	4.10X10-2
62	Hempstead	40 39′	73 39′	747	5.10X10-2
63	Huntington	40 52′	73 25′	293	2.00X10-2
64	Islip	40 43′	73 12′	293	2.00X10-2

APPENDIX C-1 (Continued)

MUNICIPAL INCINERATORS

	State	Latitude (N)	Longitude (W)	Capacity (tons/day)	Q (gms/sec)
(NEW YORK)					
65	Lackawanna	42 49′	78 49′	161	1.10X10-2
66	Lawrence	40 36′	73 44′	190	1.30X10-2
67	Long Beach	40 35′	73 39′	190	1.30X10-2
68	Mount Vernon	40 53′	73 45′	600	4.10X10-2
69	New Rochelle	40 55′	73 47′	395	2.70X10-2
70	North Hempstead	40 45′	73 37′	600	4.10X10-2
71	Oyster Bay	40 52′	73 32′	498	3.40X10-2
72	Rye	40 57′	73 41′	146	1.00X10-2
73	Scarsdale	40 59′	73 48′	146	1.00X10-2
74	Tonawanda	43 2′	78 53′	249	1.70X10-2
75	Valley Stream	40 40′	73 44′	190	1.30X10-2
NEW YORK CITY					
76	New York City	40 37′	74 0′	996	6.80X10-2
77	New York City	40 43′	73 59′	996	6.80X10-2
78	New York City	40 40′	73 51′	996	6.80X10-2
79	New York City	40 36′	73 58′	996	6.80X10-2
80	New York City	40 43′	73 55′	996	6.80X10-2
OHIO					
81	Euclid	41 36′	81 0′	190	1.30X10-2
82	Franklin	39 33′	84 18′	146	1.00X10-2
83	Lakewood	41 28′	81 46′	293	2.00X10-2
84	Miami County	40 2′	84 12′	146	1.00X10-2
85	Parma	41 25′	81 47′	219	1.50X10-2
86	Sharonville	39 16′	84 24′	498	3.40X10-2

APPENDIX C-1 (Continued)

MUNICIPAL INCINERATORS

	State	Latitude (N)	Longitude (W)	Capacity (tons/day)	Q (gms/sec)
PENNSYLVANIA					
87	Philadelphia	39 56′	75 14′	600	4.10X10-2
88	Philadelphia	39 58′	75 11′	600	4.10X10-2
89	Ambridge	40 35′	80 13′	146	1.00X10-2
90	Bradford	41 57′	78 37′	190	1.30X10-2
91	Delaware County	39 51′	75 23′	791	5.40X10-2
92	Delaware County	39 54′	75 16′	498	3.40X10-2
93	Delaware County	39 59′	75 21′	498	3.40X10-2
94	Shippensburg				
TEXAS					
95	Amarillo	35 11′	101 52′	351	2.40X10-2
UTAH					
96	Ogden	41 14′	111 58′	439	3.00X10-2
VIRGINIA					
97	Alexandria	38 50′	77 6′	293	2.00X10-2
98	Newport News	37 58′	76 25′	395	2.70X10-2
99	Norfolk	36 53′	76 19′	395	2.70X10-2
100	Portsmouth	36 50′	76 20′	337	2.30X10-2
WISCONSIN					
101	Oshkosh	44 1′	88 34′	337	2.30X10-2
102	Port Washington	43 23′	87 52′	74.7	5.10X10-3
103	Sheboygan	43 45′	87 44′	234	1.60X10-2
104	Sturgeon Bay	44 50′	87 22′	146	1.00X10-2
105	Waukesha	43 0′	88 13′	337	2.30X10-2

APPENDIX C-2

MUNICIPAL INCINERATORS

Thousands of People Exposed to Concentration Range (ng/m^3)

State	Source	>10	5-10	1-5	.1-1	Total
CONNECTICUT	1.	15	10	66	[illegible]	[illegible]
	2.	20	32	215	[illegible]	[illegible]
	3.	3	8	131	[illegible]	[illegible]
	4.	0	22	237	[illegible]	[illegible]
	5.	61	83	540	[illegible]	[illegible]
	6.	2	5	103	[illegible]	[illegible]
	7.	45	71	214	[illegible]	[illegible]
	8.	11	10	45	[illegible]	[illegible]
	9.	0	14	141	[illegible]	[illegible]
	10.	0	30	133	[illegible]	[illegible]
	11.	14	23	240	[illegible]	[illegible]
	12.	0	10	135	[illegible]	[illegible]
	13.	0	17	[illegible]	[illegible]	[illegible]
FLORIDA	14.	0	30	172	[illegible]	[illegible]
	15.	0	26	694	[illegible]	[illegible]
	16.	4	53	254	[illegible]	[illegible]
	17.	24	80	699	[illegible]	[illegible]
	18.	0	78	311	[illegible]	[illegible]
ILLINOIS	19.	0	[illegible]	[illegible]	[illegible]	[illegible]
	20.	302	[illegible]	[illegible]	[illegible]	[illegible]
	21.	0	157	[illegible]	[illegible]	[illegible]
	22.	19	129	1035	[illegible]	[illegible]

APPENDIX C-2 (Continued)

MUNICIPAL INCINERATORS

State	Source	Thousands of People Exposed to Concentration Range (ng/m^3) >10	5-10	1-5	.1-1	Total
INDIANA	23.	2	43	362	1	[illegible]
KENTUCKY	24.	0	168	568	[illegible]	[illegible]
LOUISIANA	25.	0	0	1		[illegible]
	26.	56	73	461	[illegible]	[illegible]
	27.	0	46	466	[illegible]	[illegible]
	28.	0	38	452	[illegible]	[illegible]
	29.	2	55	508	[illegible]	[illegible]
	30.	0	83	501	[illegible]	[illegible]
MARYLAND	31.	40	135	1079	[illegible]	[illegible]
MASSACHUSETTS	32.	21	35	45	[illegible]	[illegible]
	33.	12	24	390	[illegible]	[illegible]
	34.	42	42	171	[illegible]	[illegible]
	35.	43	64	665	[illegible]	[illegible]
	36.	38	47	115	[illegible]	[illegible]
	37.	9	30	104	[illegible]	[illegible]
	38.	0	35	142	[illegible]	[illegible]
	39.	3	5	53	[illegible]	[illegible]
	40.	15	19	143	[illegible]	[illegible]
	41.	43	153	1156	[illegible]	[illegible]
	42.	0	35	687	[illegible]	[illegible]
	43.	2	7	318	[illegible]	[illegible]

APPENDIX C-2 (Continued)

MINICIPAL INCINERATORS

State	Source	Thousands of People Exposed to Concentration Range (ng/m^3) >10	5-10	1-5	.1-1	Total
MASSACHUSETTS (cont'd)	44.	0	23	158	[illegible]	[illegible]
	45.	9	10	125	[illegible]	[illegible]
MICHIGAN	46.	22	49	581	[illegible]	[illegible]
	47.	15	30	389	[illegible]	[illegible]
	48.	22	34	301	[illegible]	[illegible]
	49.	35	90	872	[illegible]	[illegible]
MISSOURI	50.	0	01	647	[illegible]	[illegible]
	51.	0	66	606	[illegible]	[illegible]
NEW HAMPSHIRE	52.	1	3	70	[illegible]	[illegible]
NEW JERSEY	53.	12	21	203	[illegible]	[illegible]
	54.	0	0	23	[illegible]	[illegible]
NEW YORK	55.	0	29	[illegible]	[illegible]	[illegible]
	56.	0	2	48	[illegible]	[illegible]
	57.	41	114	604	[illegible]	[illegible]
	58.	24	44	387	[illegible]	[illegible]
	59.	20	32	291	[illegible]	[illegible]
	60.	25	34	490	[illegible]	[illegible]

APPENDIX C-2 (Continued)

MINICIPAL INCINERATORS

State	Source	Thousands of People Exposed to Concentration Range (ng/m^3) >10	5-10	1-5	.1-1	Total
NEW YORK (cont'd)	61.	11	70	757	11[illegible]	[illegible]
	62.	80	146	1378	1[illegible]	[illegible]
	63.	0	14	124	[illegible]	[illegible]
	64.	0	11	165	[illegible]	[illegible]
	65.	14	18	150	[illegible]	[illegible]
	66.	14	25	360	[illegible]	[illegible]
	67.	19	14	134	[illegible]	[illegible]
	68.	3	44	157[illegible]	[illegible]	[illegible]
	69.	0	109	860	[illegible]	[illegible]
	70.	34	93	1204	1[illegible]	[illegible]
	71.	4	7	210	[illegible]	[illegible]
	72.	1	6	80	1[illegible]	[illegible]
	73.	12	19	266	[illegible]	[illegible]
	74.	19	34	288	[illegible]	[illegible]
	75.	0	0	1	[illegible]	[illegible]
	76.	0	551	4045	1[illegible]	[illegible]
	77.	0	908	6761	1[illegible]	[illegible]
	78.	0	559	6301	1[illegible]	[illegible]
	79.	0	827	4030	1[illegible]	[illegible]
	80.	0	1014	6832	[illegible]	[illegible]
OHIO	81.	0	0	3	[illegible]	[illegible]
	82.	3	5	46	1[illegible]	[illegible]
	83.	0	52	331	[illegible]	[illegible]
	84.	0	2	21	[illegible]	[illegible]
	85.	14	38	458	[illegible]	[illegible]
	86.	2	11	192	[illegible]	[illegible]

APPENDIX C-2 (Continued)

MINICIPAL INCINERATORS

Thousands of People Exposed to Concentration Range (ng/m^3)

State	Source	>10	5-10	1-5	.1-1	Total
PENNSYLVANIA	87.	64	255	1580	[illegible]	[illegible]
	88.	152	364	1809	[illegible]	[illegible]
	89.	7	8	58	[illegible]	[illegible]
	90.	1	5	16	[illegible]	[illegible]
	91.	61	66	564	[illegible]	[illegible]
	92.	18	70	906	[illegible]	[illegible]
	93.	11	53	746	[illegible]	[illegible]
	94.	2	3	5	[illegible]	[illegible]
TEXAS	95.	0	30	81	[illegible]	132
UTAH	96.	2	36	92	[illegible]	[illegible]
VIRGINIA	97.	0	33	360	[illegible]	[illegible]
	98.	0	0	1	[illegible]	[illegible]
	99.	0	34	365	[illegible]	[illegible]
	100.	0	36	242	[illegible]	[illegible]
WISCONSIN	101.	0	14	48	[illegible]	[illegible]
	102.	1	2	3	[illegible]	[illegible]
	103.	13	11	36	[illegible]	[illegible]
	104.	1	1	5	[illegible]	[illegible]
	105.	0	21	54	[illegible]	[illegible]

APPENDIX D

PRIMARY SMELTERS

Type Zinc [b]	Plant	Location	Latitude (N)	Longitude (W)	Capacity (tons/yr)	>10	5-10	1-5	.1-1	Total
	St. Joseph	Monaca, PA	40° 41'	80° 18'	250,000	258	0	0	0	258
	New Jersey Zinc	Palmerton, PA	40° 48'	75° 37'	118,000	100	0	0	0	100
	National Zinc	Bartlesville, OK	36° 45'	95° 58'	55,000	40	0	0	0	40
Lead										
	St. Joseph	Herculaneum, MO	38° 15'	90° 58'	55,000	25	0	0	0	25
	Asarco	E. Helena, MT	46° 35'	111° 55'	235,500	28	0	0	0	28
	Bunker Hill	Kellogg, ID	47° 33'	116° 06'	246,945	17	0	0	0	17
	Asarco	Glover, MO	37° 36'	90° 41'	97,761	10	0	0	0	10
Copper										
	Asarco	Tacoma, WA	47° 14'	122° 26'	100,000	461	0	0	0	461
	Asarco	Hayden, AZ	33° 01'	110° 48'	180,000	6	0	0	0	6
	Asarco [a]	El Paso, TX	31° 55'	106° 35'	100,000	180	0	0	0	180
	Phelps - Dodge	Morenci, AZ	33° 05'	109° 22'	177,000	8	0	0	0	8
	Phelps - Dodge	Douglas, AZ	31° 21'	109° 33'	127,000	14	0	0	0	14
	Phelps - Dodge	Ajo, AZ	32° 02'	112° 38'	70,000	0	0	0	0	0
	Kennecott	Hayden, AZ	33° 05'	110° 49'	80,000	6	0	0	0	6
	Kennecott	Garfield, UT	40° 43'	112° 10'	280,000	75	0	0	0	75
	Kennecott	Hurley, NM	32° 41'	108° 07'	80,000	16	0	0	0	16
	Anaconda	Anaconda, MT	46° 07'	112° 56'	180,000	16	0	0	0	16
	White Pine	White Pine, MI	46° 45'	89° 34'	90,000	2	0	0	0	2
	Cities Services	Copperhill, TN	35° 00'	84° 21'	90,000	18	0	0	0	18
Cadmium										
	St. Joseph Lead	Monaca, PA	40° 41'	80° 18'	250,000	86	0	0	0	86
	Bunker Hill Co.	Kellog, ID	47° 33'	116° 06'	125,000	17	0	0	0	17
	New Jersey Zinc	Palmerton, PA	40° 48'	75° 37'	118,000	100	0	0	0	100
	Asarco [b]	Corpus Christi, TX	27° 55'	97° 45'	108,000	32	0	0	0	32
	National Zinc Co.	Bartlesville, OK	36° 45'	95° 58'	55,000	40	0	0	0	40

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a/ Asarco plant in El Paso, Texas has combined production capacity for lead and copper of 100,000 tons/year.

b/ Asarco plant in Corpus Christi, Texas has combined production capacity for zinc and cadmium of 108,000 tons/year. The plant uses the electrolytic zinc process and therefore, emits a negligible amount of cadmium.

APPENDIX E

SECONDARY SMELTERS

Copper

Plant	Location	Latitude (N)	Longitude (W)	>10	5-10	1-5	.1-1	Total
Asarco	Perth Amboy, NJ	40°31'	74°15'	38	42	609	743	1432
Asarco	Whiting, IN	41°40'	87°29'	20	35	862	969	1886
Asarco	Houston, TX	29°45'	95°12'	21	38	579	386	1024
Asarco	Long Beach, CA	34°05'	118°12'	107	183	1838	1279	3407
Asarco	San Francisco, CA	37°45'	122°22'	76	171	866	493	1606
Kennecott	Magna, UT	40°42'	112°06'	5	2	62	124	193
Kennecott	Hurley, NM	32°41'	108°07'	1	0	7	6	14
Olin Mathieson Chemicals, Metals Division	East Alton, IL	38°53'	90°07'	25	24	85	177	311

Zinc

Plant	Location	Latitude (N)	Longitude (W)	10	5-10	1-5	.1-1	Total
Asarco, Federated Metals Division	Sand Springs, OK	36°08'	96°07'	0	0	0	3	3
American Zinc Co. of Illinois	Hillsborough, IL	39°09'	89°29'	0	0	0	3	3
Asarco	Long Beach, CA	34°05'	118°12'	0	0	0	40	40

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