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Research Triangle Park, NC 27711

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National Emissions Inventory of Mercury and Mercury Compounds: Interim Final Report



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**NATIONAL EMISSIONS INVENTORY OF MERCURY AND
MERCURY COMPOUNDS: INTERIM FINAL REPORT**

U.S. ENVIRONMENTAL PROTECTION AGENCY

**Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711**

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PREFACE

This report has been developed in support of the Mercury Study Report to Congress which is required by section 112(n)(1)(B) of the Clean Air Act, as amended in 1990 (CAA). The CAA requires the Environmental Protection Agency (EPA) to submit a study on mercury emissions which addresses the rate and mass of mercury emissions, the health and environmental effects of such emissions, analyzes the technologies that are available to control such emissions, and determines the cost of such technologies. The initial part of the EPA's analysis has been the development of a national mercury emissions inventory, which is described by this report.

This report is being released as an interim final report in order to make available for comment the mercury emissions inventory that the EPA has developed to date. The data contained in this report are expected to be incorporated into the Mercury Study Report to Congress, but these data could change prior to the EPA's submittal of the final report to Congress in November 1994.

The emission factors used in developing the mercury emissions inventory are consistent with those presented in the EPA document entitled Locating and Estimating Air Emissions from Sources of Mercury and Mercury Compounds (EPA 454/R-93-023, September 1993.) Some of the nationwide emission estimates may vary slightly between the two documents because this report used the most recently-available data, whereas the emission factor document mentioned above is based on a baseline year of 1990.

The reader should note that the mercury emission estimates presented in this document for utility boilers represent uncontrolled emissions and therefore are somewhat higher than

estimates that have been previously published by other sources. The reason for presenting uncontrolled (and therefore "worst-case") estimates is that a separate study on emissions from utility boilers is required by the CAA under section 112(n)(1)(A). The Utility Study Report to Congress will include results of an emissions testing program that is currently underway which will provide emissions data that reflect with more certainty the amount of mercury emissions control achieved by various control technologies. The mercury data presented in the Utility Study will supersede the mercury emissions data for utility boilers presented in this report.

Comments on this report may be submitted by February 15, 1994 to:

Martha H. Keating

MD-13

US Environmental Protection Agency

Research Triangle Park, NC 27711

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EXECUTIVE SUMMARY

Section 112(n) (1) (B) of the Clean Air Act, as amended in 1990, requires the U.S. Environmental Protection Agency (EPA) to submit a study on mercury emissions to Congress. The Mercury Study is to evaluate the rate and mass of mercury emissions, to determine the health and environmental effects of these emissions, to analyze the technologies that are available to control these emissions, and to determine the costs of such technologies. The sources of mercury emissions that must be addressed include electric utility steam generating units, municipal waste combustion units, and other emission sources, including area sources.

This report estimates emissions of mercury from natural, area, and point sources and provides abbreviated process descriptions, control technique options, emission factors, and activity levels for these sources. Also, if sufficient information is available, locations by city and State are given for point sources. The information contained in the report will be useful in identifying source categories that are major emitters of mercury, in selecting potential candidates for mercury emission reductions, and in evaluating possible control technologies or materials substitution/elimination that could be used to achieve these reductions. The emissions data presented here will also serve as input data to EPA's long-range transport model which will assess the dispersion of mercury emissions nationwide.

Sources of mercury emissions in the United States are ubiquitous. To provide a coherent characterization of these sources, the source categories of mercury emissions are divided into three groups as a function of their emission properties: natural, area, and point sources as outlined in Table ES-1. Natural sources are nonanthropogenic sources of mercury emissions unrelated to human activities. Area sources of mercury emissions are anthropogenic sources that are typically small and numerous

TABLE ES-1. SOURCES OF MERCURY EMISSIONS.

Natural	Anthropogenic			
	Area	Point		
		Combustion	Manufacturing	Miscellaneous
Oceans	Electric lamp breakage	Utility boilers	Chlor-alkali production	Oil shale retorting
Vegetation	Paints use	Commercial/ industrial boilers	Lime manufacturing	Mercury catalysts
Volcanoes	Laboratory use	Residential boilers	Primary mercury production	Pigment production
Rocks	Dental preparations	Municipal waste combustion	Mercury compounds production	Explosives manufacturing
Soils*	Crematories	Medical waste incinerators	Battery production	Geothermal power plants
Wildfires	Mobile Sources	Sewage sludge incinerators	Electrical apparatus manufacturing	Turf products
	Agricultural burning**	Hazardous waste incinerators**	Carbon black production	
	Landfills**	Wood combustion	Byproduct coke production Primary copper smelting Cement manufacturing Primary lead smelting	

* Emissions from soils may also be the result of the re-emission of previously deposited anthropogenic emissions.

**Potential anthropogenic sources of mercury emissions for which there is currently no data.

and usually cannot be readily located geographically. For the purpose of this report, mobile sources are included in the area source section. Point sources are those anthropogenic sources that are associated with a fixed geographic location. These point sources are further divided into combustion, manufacturing, and miscellaneous source categories.

For most source categories, an emission factor-based approach was used to develop both facility-specific estimates for modeling purposes and nationwide emission estimates. This approach requires an emission factor, which is a ratio of the mass of mercury emitted to a measure of source activity, and an estimate of the annual nationwide source activity level. Examples of measures of source activity include vehicle miles traveled for mobile sources, total heat input for fossil fuel combustion, and total raw material used or product generated for industrial processes. Emission factors are generated from emission test data, from engineering analyses based on mass balance techniques, or from transfer of information from comparable emission sources. Emission factors reflect the "typical control" achieved by the air pollution control measures applied across the population of sources within a source category.

The emission factor-based approach does not generate exact emission estimates. Uncertainties are introduced in the emission factors, the estimates of control efficiency, and the activity level measures. Ideally, emission factors are based on a substantial quantity of data from sources that represent the source category population. However, for trace pollutants like mercury, emission factors are frequently based on limited data that may not have been collected from representative sources. Also, changes in processes or emission measurement techniques over time may result in biased emission factors. Emission control estimates are also generally based on limited data; as such, these estimates are imprecise and may be biased. Finally, activity levels used in this study were based on the most recent

information that was readily available. However, the sources used vary in reliability, adding further uncertainty to the emission estimates.

Mercury is known to be emitted from natural sources (rock, soils, water and biota), but few direct measurements of mercury flux and speciation from natural sources are available in the literature. The principal natural sources of mercury emissions include, in order of probable importance, volatilization in marine and other aquatic environments, volatilization from vegetation, degassing of geologic materials, emissions during volcanic and geothermal activity, and wind-blown dust. Forest fires, brush fires, and agricultural burning are also known to emit mercury. The magnitude of these emissions from natural sources is unknown but is potentially significant. Recent studies strongly emphasize the importance of the air-water exchange of mercury as well as biologically-mediated volatilization in both marine and terrestrial environments. These sources represent a relatively constant flux to the atmosphere and may comprise 30 to 50 percent of total natural emissions. In contrast, volcanic, geothermal, and burning biomass activity is widely variable temporally and spatially. Volcanic eruptions, in particular, can cause massive perturbations in atmospheric trace metal cycles. Volcanic activity alone may comprise 40 to 50 percent of total natural mercury emissions at times. While the data on mercury emissions from natural sources are limited, the more recent estimates of global emissions cluster in the 2,000 to 3,000 Mg (2,200 to 3,300 tons) per year range. These levels account for approximately 40 percent of total global emissions from all sources.

The principal concern of this study is mercury emissions from anthropogenic sources. While the emission estimates for anthropogenic sources have limitations as described above, they do provide insight into the relative magnitude of emissions from different groups of sources. Figure ES-1 shows the distribution

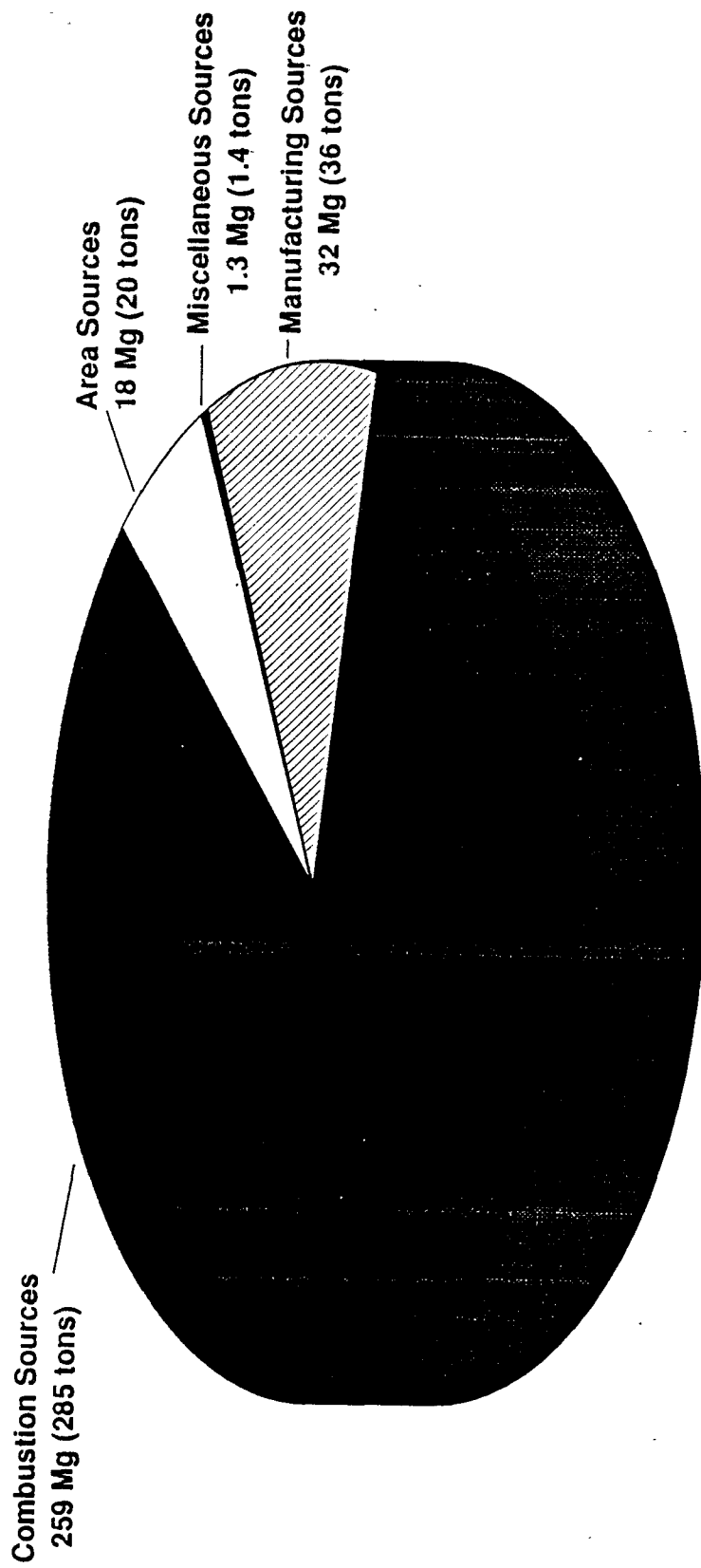


Figure ES-1. Estimated annual mercury emissions from four major source types..

of estimated emissions among the four major classes of sources of anthropogenic emissions (area sources, combustion point sources, manufacturing point sources, and miscellaneous point sources). Figures ES-2 through ES-4 illustrate the distributions among individual source categories for the first three of these four classes; these three classes represent well over 99 percent of the total anthropogenic emissions.

Of the estimated 309 Mg (341 tons) of mercury emitted annually into the atmosphere by anthropogenic sources in the United States, approximately 84 percent is from combustion point sources, 10 percent is from manufacturing point sources, and 5 percent is from area sources. Four specific source categories account for approximately 83 percent of the total anthropogenic emissions--utility boilers (36 percent), municipal and medical waste incineration (19 percent each), and commercial/industrial boilers (9 percent).

All of these sources represent high temperature fossil fuel or waste combustion processes. For each of these operations, the mercury is present as a trace contaminant in the fuel or feedstock. Because of its relatively low boiling point, mercury is volatilized during high temperature operations and discharged to the atmosphere with the exhaust gas.

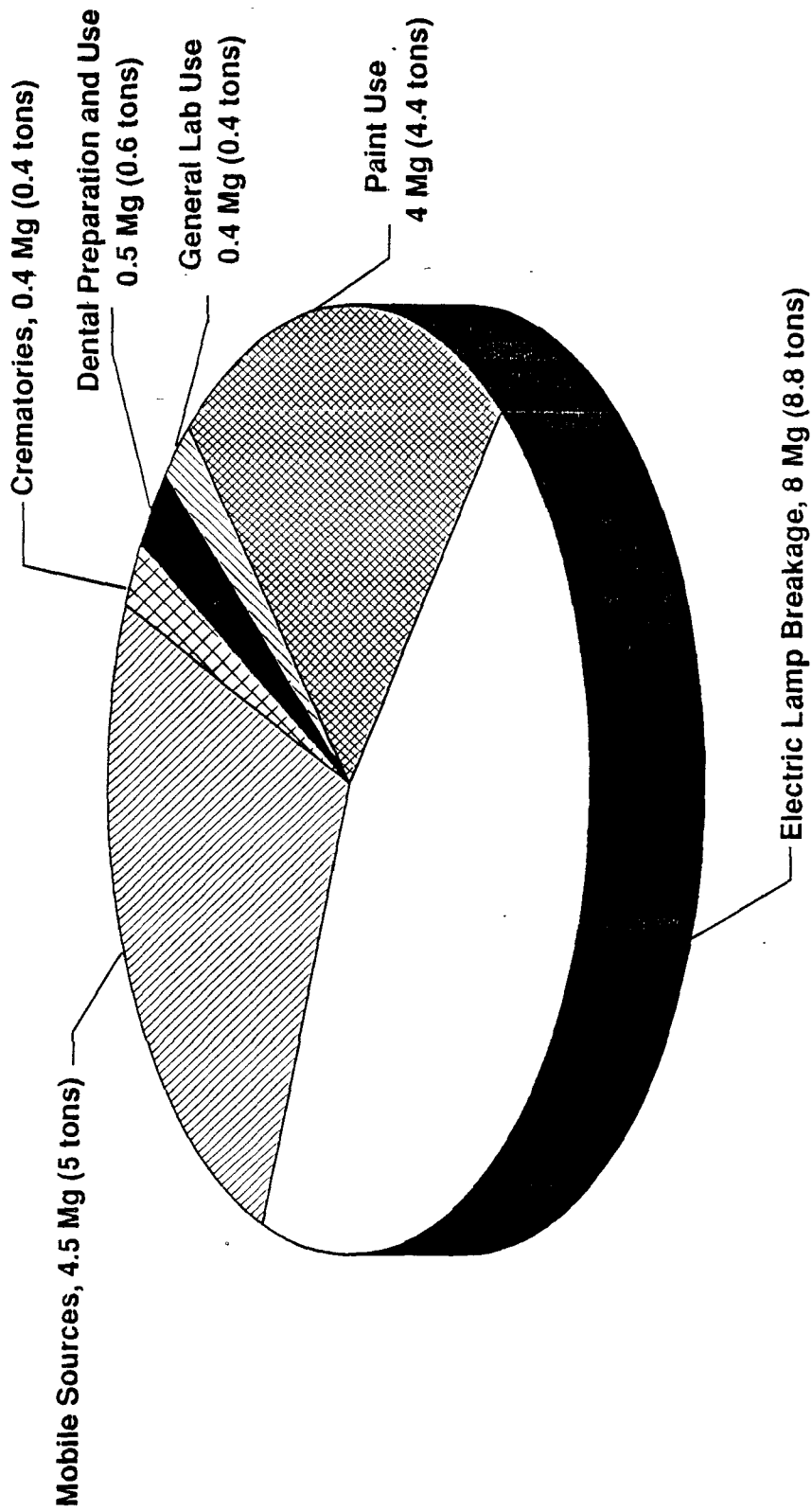
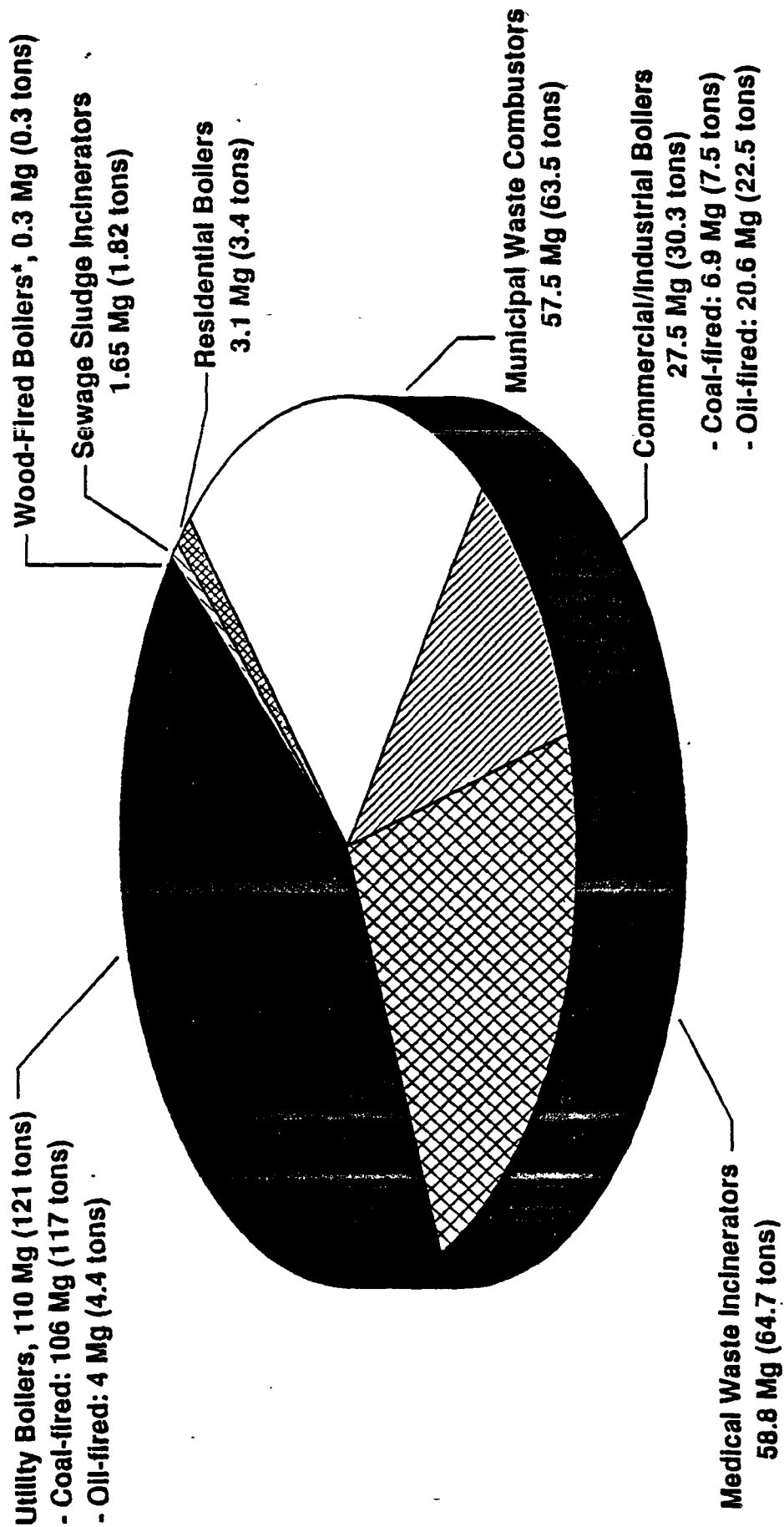
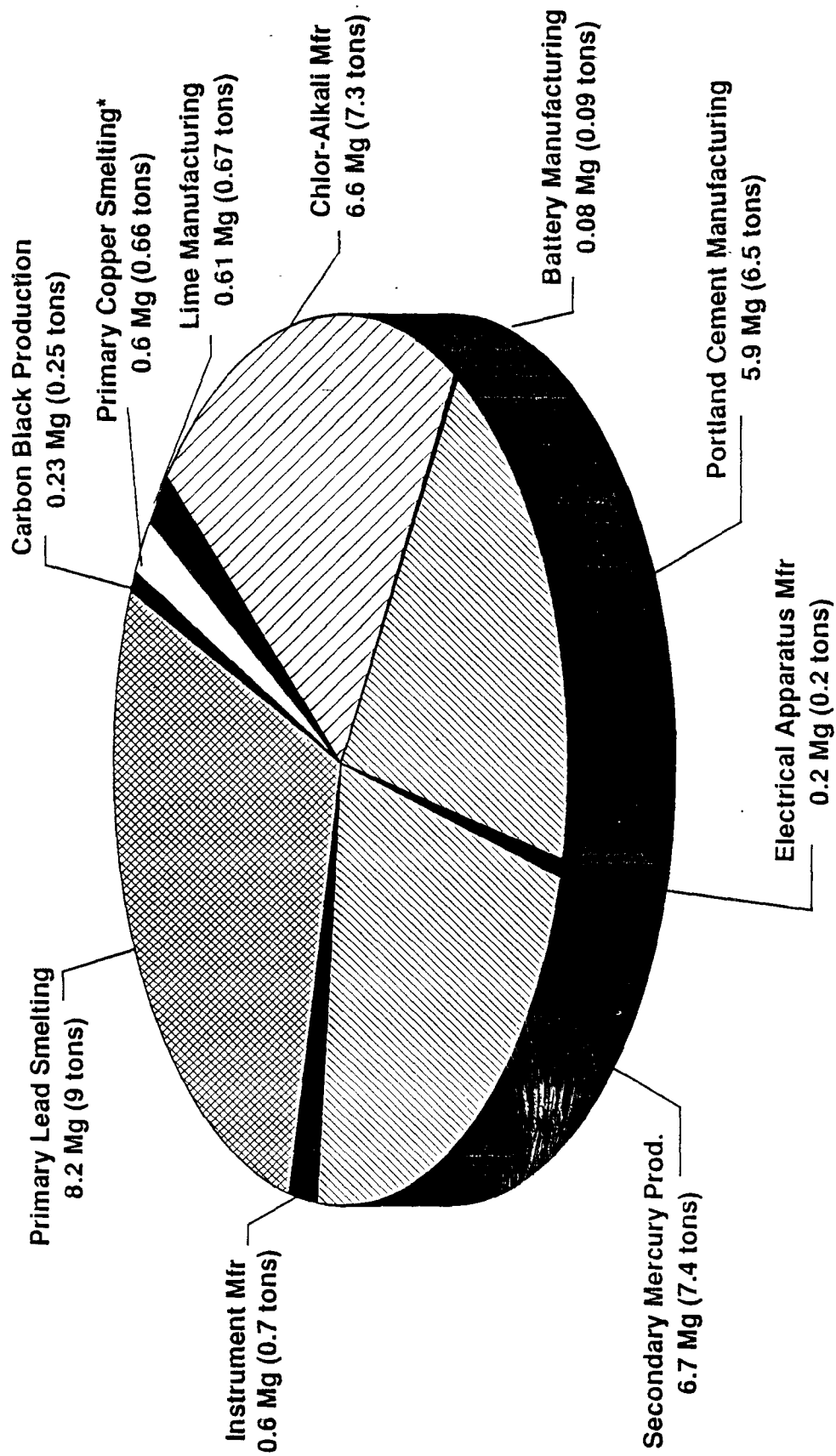


Figure ES-2. Estimated annual mercury emissions from area sources.



* Wood boilers only; does not include residential woodstoves.

Figure ES-3. Estimated annual mercury emissions from combustion point sources.



* Estimate includes one smelter only.

Figure ES-4. Estimated annual mercury emissions from manufacturing point sources.

SECTION 1.0 INTRODUCTION

1.1 BACKGROUND

Section 112(n) (1) (B) of the Clean Air Act, as amended in 1990, requires the U.S. Environmental Protection Agency (EPA) to submit a study on mercury emissions to Congress. This study is to evaluate the rate and mass of mercury emissions, to determine the health and environmental effects of these emissions, to analyze the technologies that are available to control these emissions, and to determine the costs of such technologies. The sources of mercury emissions that must be addressed include electric utility steam generating units, municipal waste combustion units, and other emission sources, including area sources.

This report estimates emissions of mercury from natural, area, and point sources and provides abbreviated process descriptions, control technique options, emission factors, and activity levels for these sources. Also, if sufficient information is available, locations by city and State are given for point sources. The information contained in the report will be useful in identifying source categories that are major emitters of mercury, in selecting potential candidates for mercury emission reductions, and in evaluating possible control technologies or materials substitution/elimination that could be used to achieve these reductions.

1.2 APPROACH

The information contained in this report was obtained primarily from the EPA document Locating and Estimating Air Emissions from Sources of Mercury and Mercury Compounds (L&E document), which contains the most recent mercury emission factors available.¹ Other sources of information, such as

recently published reports, journal articles, and information from trade associations, were also used. Mercury emission rates presented in this report are estimates only. These mercury emission estimates were typically calculated as a product of an emission factor, such as those found in the L&E document, and an annual estimate of source activity. Both the emission factors and the source activity level estimates contain inherent uncertainties. Typically, emission factors are based on a limited set of test data that have measurement errors and that may not be representative of the full population of sources being studied. Activity levels used in this report were compiled over different time periods and with a variety of survey procedures. Consequently, they are not exact estimates. To the degree that information is available, sources of uncertainty in the emission estimates will be discussed, at least qualitatively, as the estimates are discussed throughout the report.

The remainder of this report consists of three sections. Section 2 presents the physical and chemical properties of mercury. Section 3 characterizes the mercury emission source categories for natural, area, and point sources. It describes the emitting process and presents the basis for the emission estimates. Finally, Section 4 provides a summary of mercury emission estimates from natural, area, and point sources. Appendices A through D contain detailed information on activity levels, source locations, and emissions for select source categories.

1.3 REFERENCES

1. U. S. Environmental Protection Agency. Locating and Estimating Air Emissions from Sources of Mercury and Mercury Compounds. EPA 454/R-93-023. U. S. Environmental Protection Agency, Research Triangle Park, NC. September 1993.

SECTION 2.0

PHYSICAL/CHEMICAL PROPERTIES

2.1 THE NATURE OF MERCURY

Mercury, also called quicksilver, is a heavy, silver-white metal that exists as a liquid at room temperature. Its symbol, Hg, comes from the Latin word, hydrargyrum, meaning liquid silver. Mercury and its major ore, cinnabar (HgS), have been known and used for thousands of years. Table 2-1 summarizes mercury's chemical and physical properties.

At ambient temperatures, mercury is stable and unreactive with air, ammonia, carbon dioxide, nitrous oxide, or oxygen. It readily combines with halogens and sulfur but is little affected by hydrochloric acid. It is attacked by concentrated sulfuric acid. Mercury can be dissolved in either dilute or concentrated nitric acid, with the formation of mercurous salts if the mercury is in excess or no heat is applied, or mercuric salts if excess acid or heat is used. Mercury reacts with hydrogen sulfide in the air.

Elemental mercury is used primarily in electrical applications including batteries, electrical lamps, and wiring and switching devices. Its low electrical resistivity makes it one of the best electrical conductors among the metals.¹ Technically and commercially important mercury compounds include mercuric oxide, mercuric chloride, mercuric and mercurous sulfate, mercurous nitrate, and various organic mercury salts.

Metallic mercury can be found in small quantities in some ore deposits; however, it usually occurs as a sulfide, and sometimes as a chloride or an oxide, typically in conjunction with base and precious metals. Although cinnabar is by far the predominant mercury mineral in ore deposits, other common mercury-containing minerals include corderoite (Hg₃S₂Cl₂), livingstonite (HgSb₄S₇), montroydite (HgO), terlinguaite

TABLE 2-1. PHYSICAL AND CHEMICAL PROPERTIES OF MERCURY^{1,2}

Property	Value
Crystal system	Rhombohedral
CAS registry number	7439-97-6
Atomic number	80
Valences	1, 2
Outer electron configuration	5d ¹⁰ 6s ²
Metallic radius, Å	1.10 (Hg ²⁺) 1.50 (Hg ⁺)
Covalent radius, Å	1.440
Electrode reduction potentials, normal, V	
Hg ²⁺ + 2e → Hg	0.851
Hg ₂ ²⁺ + 2e → 2Hg	0.7961
2Hg ²⁺ + 2e → Hg ₂ ²⁺	0.905
Melting point, °C	-38.87
Boiling point, °C	356.9
Latent heat of fusion, J/g	11.80
Latent heat of vaporization, J/g	271.96
Specific heat, J/g	
Solid	
-75.6°C	1.1335
-40°C	0.141
-263.3°C	0.0231
Liquid	
-36.7°C	0.1418
210°C	1.1335
Electrical resistivity, Ω-cm	
20°C	95.8 × 10 ⁻⁶
Density, g/cm ³	
at 20°C	13.546
at melting point	14.43
at -38.8°C (solid)	14.193
at 0°C	13.595
Thermal conductivity, w/(cm ² •K)	0.092
Vapor pressure, 25°C	2 × 10 ⁻³ mm Hg
Solubility in water, 25°C	0.28 μmol/L

(Hg_2OCl), calomel (HgCl), and metacinnabar, a black form of cinnabar.¹

Mercury also has a tendency to form alloys or amalgams with almost all other metals except iron (although at higher temperatures it will even form alloys with iron).¹ Mercury amalgams with vanadium, iron, niobium, molybdenum, cesium, tantalum, and tungsten produce metals having good to excellent corrosion resistance.¹

2.2 REFERENCES

1. Drake, H.J. Mercury. (In) Kirk-Othmer Encyclopedia of Chemical Technology, Volume 15, 3rd ed., M. Grayson, exec. ed. A Wiley-Interscience Publication, John Wiley and Sons, New York. 1981. pp. 143-156.
2. Kleinberg, J., W.J. Argersinger, Jr., and E. Griswold. Inorganic Chemistry. D.C. Heath and Company, Boston. 1960. p. 609.

SECTION 3.0

MERCURY EMISSION SOURCE CATEGORY CHARACTERIZATION

3.1 INTRODUCTION

A prerequisite for developing strategies for reducing mercury concentrations in surface waters and ambient air is a comprehensive characterization of the sources of mercury air emissions. Such a characterization includes identifying significant mercury emission sources, both anthropogenic and nonanthropogenic, and estimating the emission potential of those sources. This section provides the basis for a nationwide mercury emission characterization. The potentially significant source categories are identified, and for each source category, the processes that yield mercury emissions are described, as well as the mercury emission control measures that are in place. The procedures used to estimate nationwide mercury emissions from each category are also described.

Sources of mercury emissions in the United States are ubiquitous. To provide a coherent characterization of these sources, the source categories of mercury emissions are divided into three groups as a function of their emission properties: natural, area, and point sources as outlined in Table 3-1. Natural sources are nonanthropogenic sources of mercury emissions unrelated to human activities. Area sources of mercury emissions are anthropogenic sources that are typically small and numerous

TABLE 3-1. SOURCES OF MERCURY EMISSIONS

	Anthropogenic			
	Area	Point		
		Combustion	Manufacturing	Miscellaneous
Natural				
Oceans	Electric lamp breakage	Utility boilers	Chlor-alkali production	Oil shale retorting
Vegetation	Paints use	Commercial/ industrial boilers	Lime manufacturing	Mercury catalysts
Volcanoes	Laboratory use	Residential boilers	Primary mercury production	Pigment production
Rocks	Dental preparations	Municipal waste combustion	Mercury compounds production	Explosives manufacturing
Soils*	Crematories	Medical waste incinerators	Battery production	Geothermal power plants
Wildfires	Mobile sources	Sewage sludge incinerators	Electrical apparatus manufacturing	Turf products
	Agricultural burning**	Hazardous waste incinerators**	Carbon black production	
	Landfills**	Waste combustion	Byproduct coke production Primary copper smelting Cement manufacturing Primary lead smelting	

*Emissions from soils may also be the result of the re-emission of previously deposited anthropogenic emissions.

**Potential anthropogenic sources of mercury emissions for which there is currently no data.

and usually cannot be readily located geographically. For the purpose of this report, mobile sources are included in the area source section. Point sources are those anthropogenic sources that are associated with a fixed geographic location. These point sources are further divided into combustion, manufacturing, and miscellaneous source categories.

For most source categories, an emission factor-based approach was used to develop nationwide emission estimates. This approach requires an emission factor, which is a ratio of the mass of mercury emitted to a measure of source activity, and an estimate of the annual nationwide source activity level. Examples of measures of source activity include vehicle miles traveled for mobile sources, total heat input for fossil fuel combustion, and total raw material used or product generated for industrial processes. Emission factors are generated from emission test data, engineering analyses based on mass balance techniques, or transfer of information from comparable emission sources. Emission factors used to estimate nationwide emissions reflect the "typical control" achieved by the air pollution control measures applied across the population of sources within a specific source category. The emission factors and control levels used to develop the emission estimates contained in this report were generally taken from the L&E document.¹

The emission factor-based approach does not generate exact nationwide emission estimates. Uncertainties are introduced in the emission factors, the estimates of control efficiency, and

the nationwide activity level measures. Ideally, emission factors are based on a substantial quantity of data from sources that represent the source category population. However, for trace pollutants like mercury, emission factors are frequently based on limited data that may not have been collected from representative sources. Also, changes in processes or emission measurement techniques over time may result in biased emission factors. In particular, analytical methods for detecting mercury have changed, especially since about 1985. Emission control estimates are also generally based on limited data; as such these estimates are imprecise and may be biased. Control efficiencies based on data collected using older test methods may be biased because the older test methods tended to collect mercury vapor inefficiently. In assessing mercury emissions from test reports, the revision number of the method indicates the level of precision and accuracy of the method. Currently, EPA Method 301 from 40 CFR Part 63, Appendix A can be used to validate the equivalency of new methods. Finally, activity levels used in this study were based on the most recent information that was readily available. However, the sources of data used vary in reliability, adding further uncertainty to the emission estimates.

Generally, quantitative estimates of the uncertainty in the emission factors, control efficiency estimates, and activity level measures are not available. However, these uncertainties

are discussed qualitatively in the sections below. Potential biases in the final emission estimates are also discussed.

3.2 NATURAL SOURCES OF MERCURY EMISSIONS

Mercury is emitted from natural sources (rock, soils, water and biota) primarily as elemental mercury vapor and to a lesser degree as particulate and vaporous oxides, sulfides and halides of mercury. Organomercuric compounds (methylmercury vapors) are also a significant component of natural emissions (some evidence of dimethyl-mercury emissions also exists).² However, few direct measurements of mercury flux and speciation from natural sources are available in the literature. There is general agreement that the principal natural sources of mercury emissions include, in order of probable importance, volatilization in marine and other aquatic environments, volatilization from vegetation, degassing of geologic materials, particulate matter (PM) and vapor emissions during volcanic and geothermal activity, wind-blown dust, and PM and vapor emissions during forest and brush fires. Recent studies strongly emphasize the importance of the air-water exchange of mercury as well as biologically mediated volatilization in both marine and terrestrial environments.²⁻⁵ These sources represent a relatively constant flux to the atmosphere and may comprise 30 to 50 percent of total natural emissions.⁵ In contrast, volcanic, geothermal, and burning biomass activity is widely variable temporally and spatially.

Volcanic eruptions, in particular, can cause massive perturbations in atmospheric trace metal cycles. Volcanic activity alone may comprise 40 to 50 percent of total natural mercury emissions at times.⁵

Published estimates of total global emissions of mercury from natural sources range widely from 100 to 30,000 megagrams (Mg) (110 to 33,000 tons) per year. However, the more recent estimates cluster in the 2,000 to 3,000 Mg (2,200 to 3,300 tons) per year range.²⁻⁵ O. Lindqvist, citing work done in 1988, estimated natural emissions to be 3,000 Mg (3,300 tons) per year or approximately 40 percent of total global emissions from all sources.² The supporting data for individual source categories are limited for each of these estimates, and it is clear that any quantitative understanding of natural mercury flux is lacking.

As a result of reemission, current levels of mercury emitted to the atmosphere by natural processes are elevated relative to preindustrial levels. More than two thirds of world mercury production has occurred since 1900, and mercury emissions have been widely dispersed and recycled. In other words, present day emissions from natural sources are comprised in part of yesterday's anthropogenic emissions. It is not possible to quantify the contribution of re-emitted mercury to the natural emissions estimates and, therefore, the estimates cited above for natural processes must be viewed with uncertainty.

3.3 AREA SOURCES OF MERCURY EMISSIONS

Area sources of mercury emissions were identified in Table 3-1. These sources account for approximately 5 percent of mercury emissions from anthropogenic sources. Figure 3-1 summarizes the estimated annual quantities of mercury emitted from area sources.

3.3.1 Mobile Sources

Mobile sources are defined in this study as diesel- and gasoline-powered, on-road, light-duty vehicles. Of these types, gasoline-powered vehicles make up the most significant mobile emission sources. A 1983 study indicated an estimated mercury emission factor of 1.3×10^{-3} milligram per kilometer (mg/km) (4.6×10^{-9} pound per mile [lb/mile]) traveled for motor vehicles.⁶ The population of vehicles studied was 81.9 percent gasoline-powered passenger cars, 2.4 percent gasoline-powered trucks, and 15.7 percent diesel trucks. However, because this emission factor is based on a 1977 ambient sampling study, which predated the use of catalytic converters and unleaded gasoline, widely mandated State-regulated inspection and maintenance programs, and diesel-powered vehicle emission control requirements, the data are of questionable reliability for the current vehicle population.

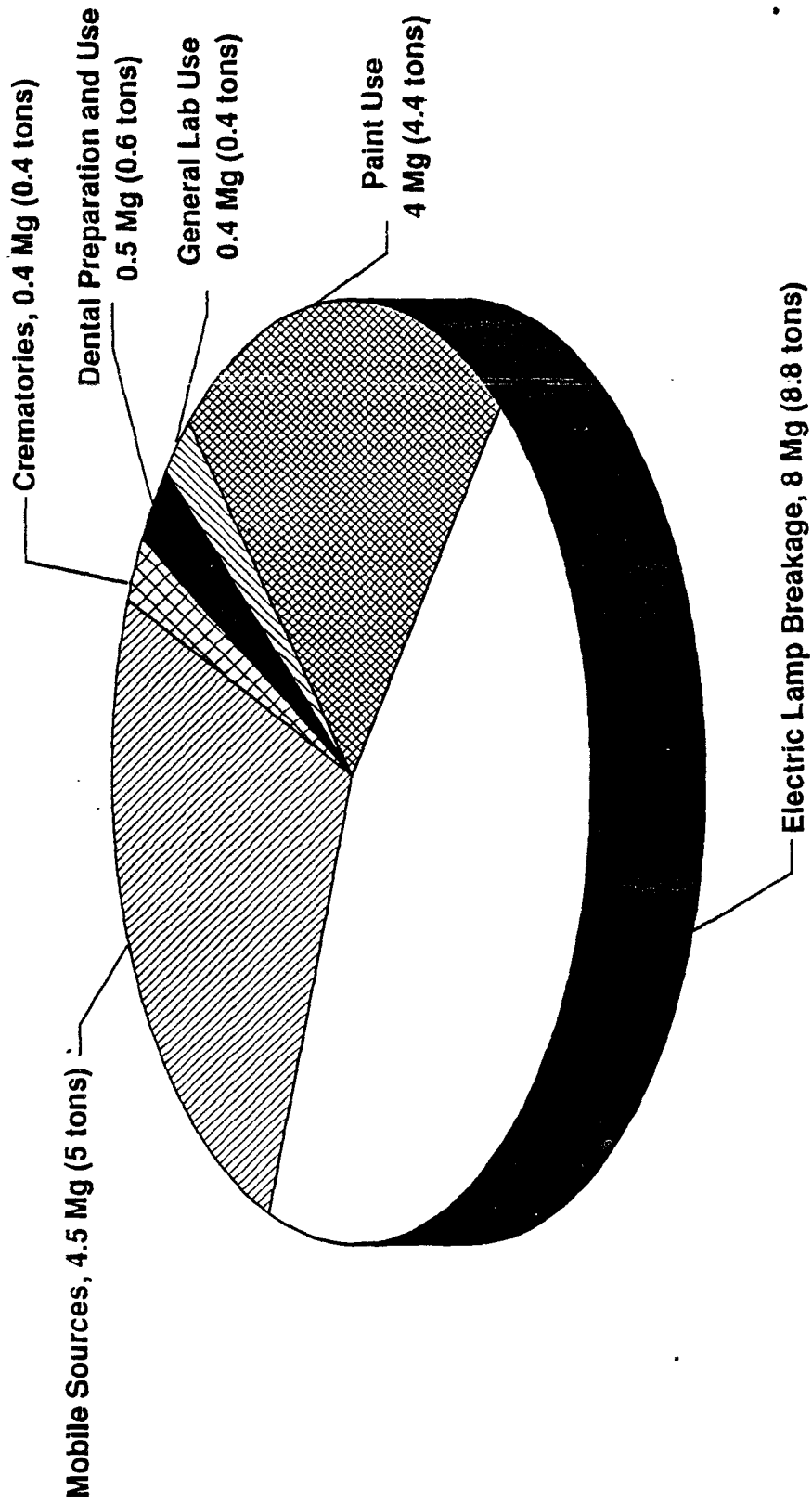


Figure 3-1. Estimated annual mercury emissions from area sources.

A 1979 study characterized regulated and unregulated exhaust emissions from catalyst and non-catalyst equipped light-duty gasoline-powered automobiles operating under malfunction conditions.⁷ An analysis for mercury was included in the study but no mercury was detected. The analytical minimum detection limit was not stated.

A more recent 1989 study measured the exhaust emission rates of selected toxic substances for two late model gasoline-powered passenger cars.⁸ The two vehicles were operated over the Federal Test Procedure (FTP), the Highway Fuel Economy Test (HFET), and the New York City Cycle (NYCC). Mercury was among the group of metals analyzed but was not present in detectable quantities. The analytical minimum detection limits for mercury in the three test procedures were: FTP 0.025 mg/km (8.9×10^{-8} lb/mile) HFET 0.019 mg/km (6.7×10^{-8} lb/mi), and NYCC 0.15 mg/km (53.2×10^{-8} lb/mi).⁹ Because these minimum detection limits are more than ten times higher than the estimated emission factor presented in the 1983 study, the emission factor in the 1983 study was used to estimate emissions from mobile sources.

An estimate of mercury emissions from mobile sources was calculated as a product of the emission factor cited above (albeit with its inherent limitations) and the total vehicle miles traveled (VMT) annually in the United States. Data from the EPA Office of Mobile Sources indicate that the total VMT in the United States in 1990 was 3,457,500 million kilometers

(2,147,500 million mi).¹⁰ The resultant calculated nationwide emission estimate from mobile sources is 4.5 Mg (5.0 tons).

3.3.2 Electric Lamp Breakage

Electric lamps containing mercury include fluorescent, mercury vapor, metal halide, and high-pressure sodium lamps. These lamps are used for both indoor and outdoor applications including lights for high-ceiling rooms, film projection, photography, dental exams, photochemistry, heat lamps, water purification, and street lighting. When these electric lamps are broken during use or disposal, a significant portion of the mercury contained in them is emitted to the atmosphere. It has been estimated that 22 percent of the mercury used in indoor electric lamps and 33 percent of the mercury used in outdoor lamps is lost to the atmosphere in this manner.¹

A total of 29 Mg (32 tons) of mercury were used in electric lamp production in 1991.⁶ In 1980, it was estimated that 50 percent of the mercury used was for indoor applications and 50 percent was used for outdoor applications.¹¹ An estimate of total mercury emissions from electric lamp breakage can be made from these data if it is assumed that there are no losses of mercury in electric lamp production, that the 1980 ratio of mercury use in indoor/outdoor lamps holds for 1991, that all lamps are eventually broken following disposal, and that mercury loss from breakage occurs in the open air rather than in a

municipal waste combustor. As such, of the 29 Mg (32 tons) of mercury used in total lamp production, annual emissions are calculated to be 3.2 Mg (3.5 tons) from indoor electric lamps and 4.8 Mg (5.3 tons) from outdoor lamps for a total of 8 Mg (8.8 tons).

3.3.3 Paint Use

Four mercury compounds--phenylmercuric acetate, 3-(chloromethoxy) propylmercuric acetate, di(phenylmercury) dodecenylsuccinate, and phenylmercuric oleate--have been registered as biocides for interior and exterior paint.¹² Mercury compounds are added to paints to preserve the paint in the can by controlling microbial growth. Prior to 1991, much larger amounts of mercury were used in paint to preserve the paint film from mildew after the paint is applied to a surface. During and after application of paint, these mercury compounds can be emitted into the atmosphere. As of May 1991, all registrations for mercury biocides used in paints were voluntarily canceled by the registrants, thus causing a drastic decrease in the use of mercury in paint.¹³ For example, the paint industry's demand for mercury in 1989 was 192 Mg (211 tons) but fell to 6 Mg (7 tons) in 1991.¹⁴

One source estimates that 66 percent of the mercury used in paints is emitted into the atmosphere; however, this emission rate, which was derived using engineering judgement, is based on

a 1975 study performed when the demand for mercury in paint was high.¹⁵ The age of the data and the method by which the emission factor was calculated limit the reliability of the factor, making emission estimates generated from it quite uncertain.

Furthermore, no conclusive information is available regarding the time frame over which mercury in paint is emitted into the atmosphere after it is applied to a surface. However, limited information suggests that emissions could occur for as long as 7 years after initial application, although the distribution of emissions over this time period is unknown.¹⁶

Based on the 1991 demand for mercury and the emission factor above (66 percent emitted), mercury emissions from paint use are estimated to be 4 Mg (4.4 tons). Note that this estimate presumes that all mercury emissions are generated from paint application in the year that the paint is produced.

3.3.4 General Laboratory Use

Mercury is used in laboratories in instruments, as a reagent, and as a catalyst. In 1991, an estimated 0.4 Mg (0.4 ton) of mercury were emitted into the atmosphere from general laboratory use. An emission factor of 40 kg of mercury emitted for each megagram of mercury used in laboratories was estimated in a 1973 report.¹⁷ Because this emission factor was based on engineering judgement and not on actual test data, and because it is quite dated, the reliability of this emission

factor is questionable. As with most industries using mercury, there was a decline in mercury consumption in general laboratory use, with consumption dropping from 32 Mg (35 tons) in 1990 to 10 Mg (11 tons) in 1991.¹⁶ The annual emission estimate is the product of this consumption rate and the emission factor noted above. The limitations of that emission factor make the emission estimates uncertain.

3.3.5 Dental Preparation and Use

Mercury is also used in the dental industry, primarily in amalgam fillings for teeth, although it may also be used in other dental equipment and supplies. In 1991, an estimated 0.5 Mg (0.6 ton) of mercury was emitted from dental preparation and use. However, this estimate is understated because it is derived using an emission factor (2 percent of mercury used is emitted into the atmosphere) that applies only to emissions of mercury from spills and scrap during dental preparation and use.¹¹ The total amount of mercury used in the dental industry is 27 Mg (30 tons) and includes mercury used in all dental equipment and supplies, not just the amount used in dental preparation and use.¹⁶ Mercury emissions not accounted for in dental preparation and use are most likely accounted for in the emission estimates for municipal waste combustors and crematories.

3.3.6 Crematories

Volatilization of mercury from the mercury alloys contained in amalgam tooth fillings during cremation of human bodies is a potential source of mercury air emissions. In 1991, there were 400,465 cremations in the slightly more than 1,000 crematories located throughout the United States.¹⁸ Table 3-2 lists the number of crematories located in each State and presents estimates of the number of cremations performed in each State. No information was available on the location of individual crematories.¹⁹

No data are available for the average quantity of mercury emitted for a cremation in the United States. Three estimated levels have been cited for European countries (Switzerland, Germany, and the United Kingdom) with an estimated emission rate of 1 gram of mercury per cremation recommended as a typical value.²⁰ However, this emission factor may not be applicable to cremations in the United States. There is a substantial difference in the frequency of cremations in Europe compared to the United States. Also, dental care programs in the United States differ markedly from those to Europe. Consequently, the average number of mercury amalgam fillings per person may differ considerably. Because the average number of fillings per person and the average mercury content per filling have a direct impact on the estimated mercury emissions, this European emission factor may not provide an accurate estimate of mercury emissions from

TABLE 3-2. 1991 U.S. CREMATORY LOCATIONS BY STATE¹⁹

State	No. of crematories	No. of cremations ^a	State	No. of crematories	No. of cremations
Alabama	6	1,138	Montana	12	2,502
Alaska	7	790	Nebraska	6	1,139
Arizona	26	10,189	Nevada	11	5,009
Arkansas	13	1,787	New Hampshire	6	1,842
California	141	86,374	New Jersey	16	14,427
Colorado	28	7,432	New Mexico	9	2,134
Connecticut	10	4,260	New York	40	23,946
Delaware	4	1,165	North Carolina	24	4,749
District of Columbia	1	b	North Dakota	1	b
Florida	95	46,775	Ohio	41	12,552
Georgia	14	2,684	Oklahoma	9	1,372
Hawaii	10	3,495	Oregon	34	9,020
Idaho	12	1,949	Pennsylvania	44	12,153
Illinois	44	12,083	Rhode Island	5	1,842
Indiana	21	3,636	South Carolina	10	1,764
Iowa	15	2,241	South Dakota	4	b
Kansas	10	1,559	Tennessee	8	1,712
Kentucky	5	1,192	Texas	36	9,340
Louisiana	6	1,853	Utah	5	769
Maine	4	2,656	Vermont	5	1,570
Maryland	17	5,587	Virginia	25	6,097
Massachusetts	13	8,104	Washington	46	15,673
Michigan	38	13,431	West Virginia	6	582
Minnesota	18	5,662	Wisconsin	29	5,541
Mississippi	4	450	Wyoming	2	b
Missouri	19	4,637	Total	1,015	366,864 ^a

¹⁹1990 data. 1991 data unavailable.

^aNo information available.

^bDoes not include the number of cremations in the District of Columbia, North Dakota, South Dakota, and Wyoming.

cremations in the United States. Multiplying the European emission factor of 1 gram of mercury per cremation by the total number of U.S. cremations in 1991 (400,465) gives a mercury emission estimate of 0.4 Mg/yr (0.4 tons/yr).

3.4 POINT SOURCES OF MERCURY EMISSIONS

A point source is a stationary location or fixed facility from which pollutants are discharged or emitted. Point sources of mercury emissions are identified by source type in Table 3-1. These sources account for approximately 94 percent of mercury emissions from anthropogenic sources. Figure 3-2 presents the estimated mercury emissions from combustion, manufacturing, and miscellaneous point sources. The subsections below discuss the basis of the point source estimates for each source category within these three groups.

3.4.1 Combustion Sources

Combustion sources include fossil fuel-fired boilers, medical and municipal waste incinerators, and wood-fired boilers and residential heaters. Mercury emissions from these sources (excluding wood-fired residential heaters) account for an estimated 259 Mg/yr (285 tons/yr) of the mercury emissions generated annually in the United States. These types of combustion units are commonly found throughout the country and

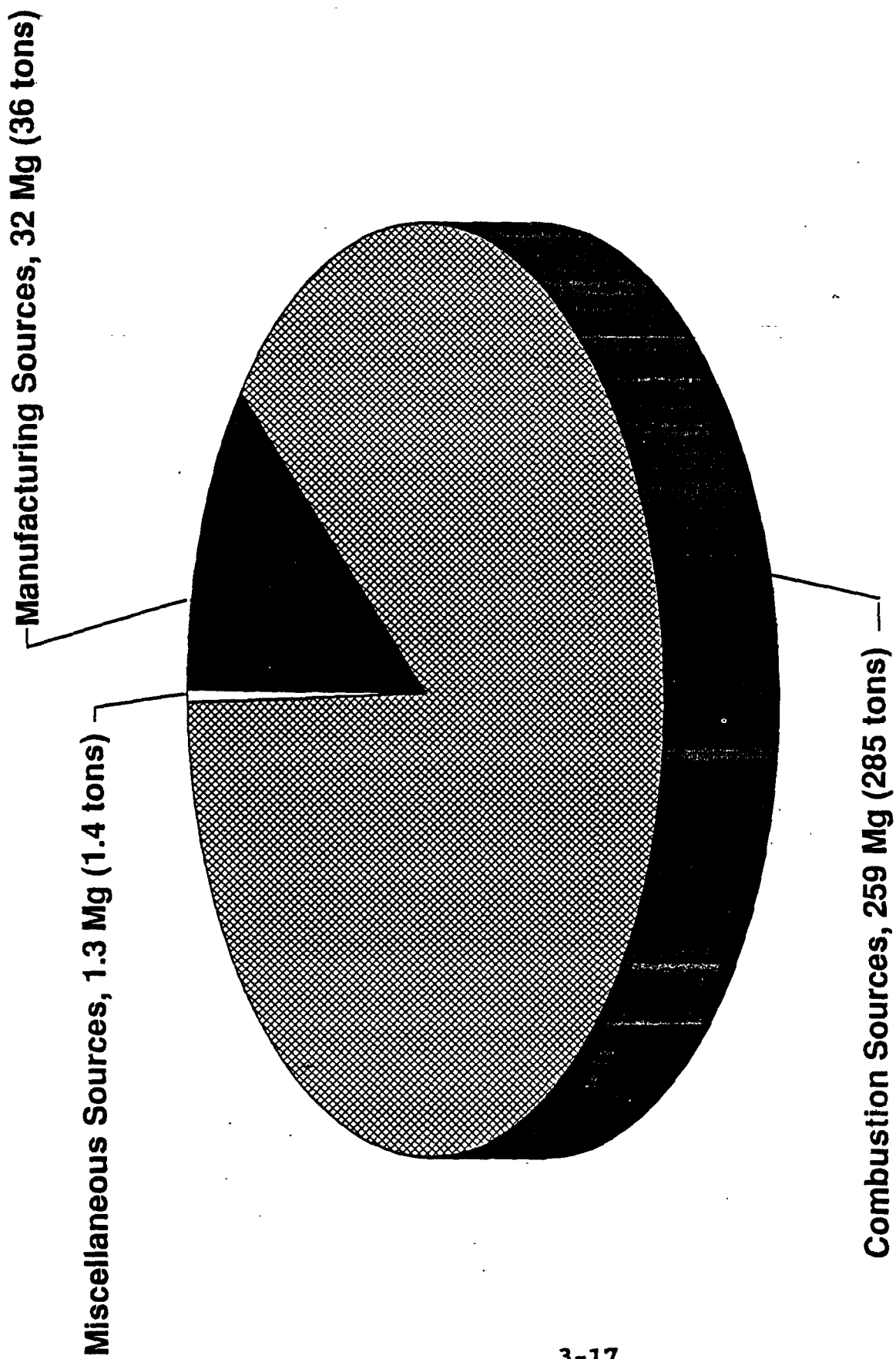


Figure 3-2. Estimated annual mercury emissions from combustion, manufacturing, and miscellaneous point sources.

are not concentrated in any one geographic region. Information concerning emissions, fossil fuel consumption on a per-State basis, and locations is presented in Appendix A.

Mercury exists naturally as a trace element in fossil fuels and can also be found in wastes. It is a highly volatile metal that vaporizes at the temperatures reached during the combustion zones of the processes discussed here. Consequently, mercury is emitted as a trace contaminant in the gas exhaust stream when fossil fuels (such as coal, oil, or wood) or waste materials containing mercury are fired.

This section provides background information on each of the combustion sources and discusses the methodology used to estimate mercury and mercury compound emissions from (1) utility boilers, (2) commercial/industrial boilers, (3) residential boilers, (4) municipal waste combustors (MWC's), (5) medical waste incinerators (MWI's), (6) sewage sludge incinerators (SSI's), and (7) wood combustors. For each of these combustion categories, processes and control measures currently in place will be discussed, along with emission estimates and the bases for those estimates. When a high degree of uncertainty within specific data is known, it will be noted.

Utility Boilers

Utility boilers, both coal-fired and oil-fired, are large boilers used by public and private utilities to generate

electricity. Natural gas also may be used to fire utility boilers; however, mercury emission estimates were not calculated for natural gas combustion because reliable information for calculating an emission factor does not exist.¹

The estimated annual mercury emissions presented in this report from coal- and oil-fired utility boilers represent uncontrolled emission levels. As a result, the mercury emission estimates presented here represent "worst-case" estimates. The reason for presenting uncontrolled estimates is that a separate study on emissions from utility boilers is required by the Clean Air Act under Section 112(n) (1) (A). The Utility Study Report to Congress, which will be completed in November 1995, will include results of a testing program sponsored by the EPA, the Electric Power Research Institute, and the U. S. Department of Energy. The testing program will provide emissions data which will then be used to develop emission factors that reflect with more certainty the amount of mercury emissions control achieved by various control devices. The mercury emissions data presented in the Utility Study will therefore supersede the mercury emissions data for utility boilers presented in this report.

The estimated annual uncontrolled mercury emissions from coal- and oil-fired utility boilers, 110 Mg/yr (121 tons/yr), are directly related to the amount of fuel used in the combustion process. Estimates of coal, natural gas, and oil consumption from utility boilers were obtained from the Edison Electric Institute (EEI) Domer Statistics data base managed by the Utility

Data Institute. This data base contains facility-specific information on fuel consumption.

In 1990, utility boilers consumed fossil fuel at an annual level of 21×10^{12} megajoules (MJ) (20×10^{15} British thermal units [Btu]). About 80 percent of this total energy consumption resulted from coal combustion, 6 percent from oil and petroleum fuels, and 14 percent from natural gas consumption.²¹ In terms of coal usage, the majority of total nationwide coal combustion (about 84 percent) is in utility boilers. Almost all of the coal burned is bituminous and subbituminous (95 percent for the two) and lignite (4 percent).²² The combustion processes used for these different coals are comparable. The most common liquid fuel used by utility boilers is fuel oil derived from crude petroleum. Fuel oils are classified as either distillate or residual.

Because there is no evidence to show that mercury emissions are affected by boiler type, this section presents only a brief discussion of different boiler types and combustion techniques. More information on boiler types may be found in the Air Pollution Engineering Manual, AP-42, Steam: Its Generation and Use, and the L&E document.^{1,23-25}

Although several options are available for each component of a utility operation, the overall process for coal-fired utility boilers is straightforward. Coal is received at the plant, typically by rail or barge, unloaded, and transferred to storage piles or silos. From storage, the coal is subjected to

mechanical sizing operations and then charged to the boiler. Coal-fired boilers are typically suspension-fired pulverized coal or cyclone systems. The other major process component is the ash handling system for the bottom ash and the fly ash that is collected in the air pollution control system.²³

Oil-fired utility boilers are even simpler and have less variation in design than do the coal-fired systems. Oil is received by barge, rail, truck, or pipeline and transferred to storage tanks. From there the oil is fired to the boiler system. The main components of the system are the burner and the furnace. The primary difference in systems that fire distillate and residual oils is the presence of an oil preheater in residual systems.^{23,25}

Although small quantities of mercury may be emitted as fugitive PM from coal storage and handling, the primary source of mercury from both coal and combustion in utility boilers is the combustion stack. Because the combustion zone in boilers operates at temperatures above 1100°C (2000°F), the mercury in the coal and oil is vaporized and exhausted as a gas. Some of the gas may cool and condense as it passes through the boiler and the air pollution control system. The specific air pollution control devices for coal-fired boilers that most likely affect mercury control are add-on PM and acid gas control devices. The primary types of control devices used for coal-fired utility boilers include electrostatic precipitators (ESP's); fabric filters (baghouses), which are typically used as a component of a

dry flue gas desulfurization system; and wet scrubbers.²⁵ Oil-fired utility boilers may use mechanical collectors or ESP's to control PM, and some use wet scrubbers to control SO₂.²⁵

Mercury emission factors for coal combustion were developed using mass-balance calculations with the assumption that all mercury fired with the coal is emitted in the stack gas as a function of coal type and control status.¹ Because the majority of coal-fired boilers are pulverized coal furnaces using bituminous coal with ESP controls, this combination contributes most of the nationwide emissions from coal-fired utilities.²² Bituminous coal combustion has an estimated uncontrolled emission factor of 7 kg/10¹⁵ J (16 lb/10¹² Btu), while the uncontrolled emission factor for anthracite coal combustion is estimated at 7.6 kg/10¹⁵ J (18 lb/10¹² Btu). The uncontrolled emission factor for lignite coal combustion is 9 kg/10¹⁵ J (21 lb/10¹² Btu). In estimating emissions, it was assumed that all facilities are controlled with respect to mercury emissions. It is recognized, therefore, that the aggregate emissions estimates presented are conservative.¹ Based on these assumptions, the 1990 nationwide mercury emissions from coal-fired utility boilers are estimated to be 106 Mg/yr (117 tons/yr).

Mercury emission factors for oil combustion are also based on mass-balance calculations with the assumption that all of the oil's mercury content exits the boiler or furnace in the exhaust gas with no substantial removal in air pollution control systems.¹ For distillate oil, the estimated uncontrolled mercury

emission factor is $2.9 \text{ kg}/10^{15} \text{ J}$ ($6.8 \text{ lb}/10^{12} \text{ Btu}$); the estimated uncontrolled emission factor for residual oil is $3.0 \text{ kg}/10^{15} \text{ J}$ ($7.2 \text{ lb}/10^{12} \text{ Btu}$). Based on these assumptions, 1990 nationwide mercury emissions from oil-fired utility boilers are estimated to be 4.0 Mg/yr (4.4 tons/yr).

Commercial/Industrial Boilers

Commercial/industrial boilers are large boilers found in businesses and industrial plants throughout the United States. These boilers may use coal, oil, or natural gas as fuels. As with utility boilers, mercury vaporizes during combustion and appears as a trace contaminant in the gas exhaust stream.

Mercury emissions from commercial/industrial boilers, 27.5 Mg/yr (30.3 tons/yr), are directly related to the amount of fuel used in the combustion process.¹ Again, mercury emissions from natural gas combustion could not be estimated because a reliable emission factor does not exist.¹ These boilers consume energy at an annual rate of $25 \times 10^{12} \text{ MJ/yr}$ ($23 \times 10^{15} \text{ Btu}$). About 12 percent of this energy consumption results from coal combustion, 39 percent from oil and petroleum fuel combustion, and 48 percent from natural gas combustion.²¹ Estimates of coal and oil consumption from these boilers on a per-State basis are presented in Table A-1, Appendix A.

Because there is no evidence to show that mercury emissions are affected by boiler type, this section presents only a brief

discussion of commercial/industrial boiler types and combustion techniques. More information on boiler types may be found in the Air Pollution Engineering Manual, AP-42, and the L&E document.^{1,23,25}

As with utility boilers, the configuration of commercial/industrial boilers can vary, but the overall system is straightforward. Coal or oil is received and transferred to storage where it is held until it is transferred to the boiler. Because this source category encompasses a wide range of boiler sizes, the types of boilers used are more varied than those used in the utility sector. Larger coal-fired industrial boilers are suspension-fired systems like those used in the utility sector, while moderate and smaller units are grate-fired systems that include spreader stokers, overfeed traveling and vibrating grate stokers, and underfeed stokers. Oil-fired furnaces, which may use either distillate or residual fuel oil, typically comprise a burner, a combustion air supply system, and a combustion chamber. All coal-fired facilities, and some oil-fired facilities, also have ash handling systems.

Mercury emission factors for coal combustion in commercial/industrial boilers are the same as those used for coal-fired utility boilers. An estimated emission factor of 7.0 kg/10¹⁵ J (16 lb/10¹² Btu) was used for bituminous coal combustion, and 7.6 kg/10¹⁵ J (18 lb/10¹² Btu) was used for anthracite coal combustion. Estimates of mercury emissions on a per-State basis from coal-fired commercial/industrial boilers are

provided in Table A-2, Appendix A. These values were determined by using the referenced emission factors and the coal consumption estimates for the States presented in Table A-1, Appendix A. In estimating emissions, it was assumed that mercury emissions from commercial/industrial boilers were not controlled. However, this assumption is most likely an overestimation of mercury emissions as PM and acid gas controls on these boilers may reduce the mercury emissions. The total estimated annual emissions for coal-fired boilers are 20.7 Mg/yr (22.8 tons/yr).

Mercury emissions for oil combustion in commercial/industrial boilers were estimated on a per-State basis using an emission factor of 2.9 kg/10¹⁵ J (6.8 lb/10¹² Btu) for residual oil and 3.0 kg/10¹⁵ J (7.2 lb/10¹² Btu) for distillate oil and the oil consumption estimates for States given in Table A-1, Appendix A. These calculated emission values are presented in Table A-3, Appendix A. The total estimated annual emissions for oil-fired commercial/industrial boilers are 5.46 Mg/yr (6.01 tons/yr).

Residential Boilers

Residential boilers are relatively small boilers used in homes and apartments. These boilers may use coal, oil, or natural gas as fuels; however, mercury emissions from natural gas combustion are negligible. As with the other types of boilers, mercury emissions vaporize during combustion of the coal- and

oil-fired residential boilers, and the emissions appear as a trace contaminant in the exhaust gas.

The estimated annual mercury emissions from residential boilers, 3.2 Mg/yr (3.5 tons/yr), are related to the amount of fuel used in the combustion process. Estimates of coal and oil consumption from these boilers on a per-State basis are presented in Table A-4, Appendix A. Residential boilers consume energy at an annual rate of 6.2×10^{12} MJ/yr (5.8×10^{15} Btu/yr). About 1 percent of this energy consumption results from coal combustion, 22 percent from oil and petroleum fuel combustion, and 77 percent from natural gas combustion.²¹

Because there is no evidence to link mercury emissions to boiler type, this section does not describe residential boiler types. Information on boiler types may be found in the Air Pollution Engineering Manual, AP-42, and the L&E document.^{1,23,25}

Estimated mercury emission factors for coal combustion in residential boilers are the same as those used for other coal combustion processes. These calculations include the assumption that all mercury fired with the coal is emitted as stack gas. An estimated emission factor of 7.0 kg/ 10^{15} J (16 lb/ 10^{12} Btu) was used for bituminous coal combustion, and 7.6 kg/ 10^{15} J (18 lb/ 10^{12} Btu) was used for anthracite coal combustion. Estimates of mercury emissions on a per-State basis from coal-fired residential boilers were determined by using these emission factors and the coal consumption estimates for the States as presented in Table A-4, Appendix A. These calculated emission

values are presented in Table A-5, Appendix A. In estimating emissions, it was assumed that mercury emissions from residential boilers were not controlled. However, as stated previously, this assumption may produce an overestimate of mercury emissions as PM and acid gas controls may reduce mercury emissions. The total annual estimated emissions for coal-fired residential boilers is 0.47 Mg/yr (0.5 tons/yr).

The estimated mercury emissions for oil combustion were estimated by using an emission factor of 2.9 kg/10¹⁵ J (6.8 lb/10¹² Btu) for residual oil and 3.0 kg/10¹⁵ J (7.2 lb/10¹² Btu) for distillate oil and the oil consumption estimates for the States given in Table A-4, Appendix A. These estimated emissions values are presented in Table A-6, Appendix A. The total annual estimated emissions for oil-fired residential boilers is 2.74 Mg/yr (3.0 tons/yr).

Municipal Waste Combustors (MWC's)

Municipal waste combustors are large incineration units, firing from 36 megagrams per day (Mg/d) (40 tons/d) to more than 230 Mg/d (250 tons/d) of refuse or municipal solid waste (MSW). Municipal solid waste consists primarily of household garbage and other nonhazardous commercial, institutional, and industrial solid wastes. The estimated annual mercury emissions from MWC's are 57.7 Mg/yr (63.5 tons/yr). These emissions occur when mercury, which exists in the solid waste, is combusted at high

temperatures, vaporizes, and then exits through the combustion gas exhaust stack.

Over 160 MWC's, with capacities greater than 36 Mg/d (40 tons/d), currently operate in the United States. These MWC's have a total capacity of about 100,000 Mg/d (110,000 tons/d) of MSW. A geographic distribution of MWC units and capacities is presented in Table A-7, Appendix A.²⁶

In addition to these large units, a number of smaller, specialized facilities in the United States also burn MSW. However, the total nationwide capacity of those smaller units is only a small fraction of the total capacity of units with individual capacities of 36 Mg/d (40 ton/d) and larger.

Within the MWC sector, a number of technologies and controls are used. Some of these technologies include mass burn combustors, refuse-derived fuel-fired combustors (RDF), and fluidized-bed combustors. Mass burn combustors, the predominant incineration technology, are found in three types: mass burn refractory wall (MB/REF), mass burn/waterwall (MB/WW), and mass burn/rotary waterwall (MB/RC). The two most common types are MB/REF and MB/WW. Mass burn combustors generally accept refuse that has undergone a minimal amount of processing (other than removing oversized items) prior to firing.¹

Mercury emissions from these combustors are controlled by condensing mercury vapors into particle form. The particle-phase mercury is then removed with a high-efficiency PM control device, usually an ESP or a fabric filter device. Some of the newer

MWC's use either (1) a combination of gas-cooling and duct sorbent injection (DSI) or (2) a spray dryer absorption system (SDA) upstream of the PM device to cool the inlet gas.²⁷

Emission factors for mercury have been developed from test data gathered at several MWC's. To calculate the emission factors, an F-factor (the ratio of the gas volume of the object being combusted to the heating value of the fuel) was assigned. The EPA Method 191 is used to determine the F-factor. For MWC's an F-factor of 0.275 dry standard cubic meters/megajoule (dscm/MJ) (9,570 dry standard cubic foot per million Btu [dscf]/10⁶ Btu) was used.²⁸ For all MWC combustor types, except RDF combustors, the assumed heating value is 10,500 kJ/kg (4,500 Btu/lb) of refuse. For RDF combustor units, the processed refuse has a higher heating value of 12,800 kJ/kg (5,500 Btu/lb).²⁸ The emission factors for various combinations of combustors and control devices are presented in Table A-8, Appendix A. Estimated mercury emissions were determined based on the tonnage of the waste being combusted (Table A-7, Appendix A.) and on the emission factors.^{28,29} Multiplying the process rates by the uncontrolled emissions and taking into account the different control efficiencies (all found in Table A-8, Appendix A) gives a total mercury emission estimate of 57.7 Mg/yr (63.5 tons/yr).

Medical Waste Incinerators (MWI's)

Medical waste incinerators are small incineration units that charge from 0.9 Mg/d (1 ton/d) to 55 Mg/d (60 tons/d) of infectious and noninfectious wastes generated from facilities involved in medical or veterinary care or research activities. These facilities include hospitals, clinics, offices of doctors and dentists, veterinary clinics, nursing homes, medical laboratories, medical and veterinary schools and research units, and funeral homes. The Resource Conservation and Recovery Act (as amended November 1, 1988) defines medical waste as "...any solid waste which is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals."³⁰

The estimated annual mercury emissions from MWI's are 58.8 Mg/yr (64.7 tons/yr). Mercury emissions occur when mercury, which exists as a contaminant in the medical waste, is combusted at high temperatures, vaporizes, and exits the combustion gas exhaust stack. Known mercury sources in medical waste include batteries, fluorescent lamps, high-intensity discharge lamps, thermometers, paper and film coatings, and plastic pigments.

Unpublished estimates by the EPA suggest that about 0.204×10^6 Mg/yr (0.268×10^6 tons/yr) of pathological waste and 1.431×10^6 Mg/yr (1.574×10^6 tons/yr) of general medical waste are processed annually in the United States.¹ Pathological waste is medical waste material consisting of only human and animal

anatomical parts and/or tissue. General medical waste may consist of any of the following, in any combination: sharps (syringes, needles, vials, etc.); fabrics (gauze, bandages, etc.); plastics (trash bags, IV bags, etc.); paper (disposable gowns, sheets, etc.); waste chemicals; and pathological waste. Most MWI's burn general medical waste, which may include a small percentage of pathological waste.

About 5,000 MWI's currently operate throughout the country; geographic distribution is relatively even (see Table A-9, Appendix A). Of these 5,000 units, about 3,000 are hospital incinerators, about 150 are commercial units, and the remaining units are distributed among veterinary facilities, nursing homes, laboratories, and other miscellaneous facilities.³¹

The primary functions of MWI's are to render the waste biologically innocuous and to reduce the volume and mass of solids that must be landfilled by combusting the organic material contained within the waste. Currently, three major MWI types operate in the United States: continuous-duty, intermittent-duty, and batch type. All three have two chambers that operate on a similar principle. Waste is fed to a primary chamber, where it is heated and volatilized. The volatiles and combustion gases are then sent to a secondary chamber, where combustion of the volatiles is completed by adding air and heat. All mercury in the waste is assumed to be volatilized during the combustion process and emitted with the combustion stack gases.

A number of air pollution control systems are used to control PM and gas emissions from MWI combustion stacks. Most of these systems fall into the general classes of either wet or dry systems. Wet systems typically comprise a wet scrubber, designed for PM control (venturi scrubber or rotary atomizing scrubber), in series with a packed-bed scrubber for acid gas removal and a high-efficiency mist elimination system. Most dry systems use a fabric filter for PM removal, but ESP's have been used on some of the larger MWI's. All of these systems have limited success in controlling mercury emissions. However, recent EPA studies indicate that sorbent injection/fabric filtration systems can achieve improved mercury control by adding activated carbon to the sorbent material.¹

The estimated mercury emission factors for MWI's were determined by analyzing test data from several MWI facilities tested by EPA. The emission estimate was generated by applying average emission concentrations obtained from these tests to the national population of incinerators using a model plant-based approach.³²

In a model plant-based approach all facilities that display certain characteristics are categorized into groups. Each group is referred to as a "model plant." An overall emission estimate is obtained by calculating the emission from each model plant, multiplying it by each facility within the model plant group, and summing all the groups together.

Sewage Sludge Incinerators (SSI's)

Sewage sludge incinerators are operated primarily by U.S. cities and towns as a final stage of the municipal sewage treatment process. Only a small percentage of U.S. cities use sewage sludge incinerators. The estimated annual mercury emissions from SSI's account for 1.65 Mg/yr (1.82 tons/yr). Mercury emissions occur when mercury, which exists in the sewage, is combusted at high temperatures, vaporizes, and exits through the gas exhaust stack.

About 210 SSI's currently operate in the United States. An estimated 1.5×10^6 Mg (1.65×10^6 tons) of sewage sludge on a dry basis are incinerated annually.³³ Table A-10, Appendix A shows the geographic distribution of sewage sludge incinerators throughout the country. Most facilities are located in the Eastern United States, but a substantial number also are located on the West Coast. New York has the largest number of SSI facilities with 33, followed by Pennsylvania and Michigan with 21 and 19, respectively.

Within the SSI category, three combustion techniques are used: multiple-hearth, fluidized-bed, and electric infrared. Multiple-hearth units predominate; over 80 percent of the identified SSI's are multiple hearth. About 15 percent of the SSI's in operation are fluidized bed units, about 3 percent are electric infrared, and the remainder cofire sewage sludge with municipal waste.³³

The sewage sludge incinerator process involves two primary steps: dewatering the sludge and incineration. The primary source of mercury emissions from SSI's is the combustion stack. Most SSI's are equipped with some type of wet scrubbing system for PM control. Because wet systems provide gas cooling, as well as PM removal, these systems can potentially provide some mercury control.

The recently updated AP-42 for SSI's lists five emission factors for various types of SSI's and controls: 0.005 g/Mg (1.0×10^{-5} lb/ton) for multiple hearth combustors controlled with a combination of venturi and impingement scrubbers, 0.03 g/Mg (6.0×10^{-5} lb/ton) for fluidized bed combustors controlled with a combination of venturi and impingement scrubbers, 2.3 g/Mg (4.6×10^{-3} lb/ton) for multiple hearth combustors controlled with a cyclone scrubber, 1.6 g/Mg (3.2×10^{-3} lb/ton) for multiple hearth combustors controlled with a combination of cyclone and venturi scrubbers, and 0.97 g/Mg (1.94×10^{-3} lb/ton) for multiple hearth combustors controlled with an impingement scrubber.³³ Given that combustor and control types are not known for all SSI's currently operating in the United States, average emission factors were calculated: 0.0175 g/Mg (3.5×10^{-5} lb/ton) for SSI's controlled with a combination of venturi and impingement scrubbers and 1.623 g/Mg (3.25×10^{-3} lb/ton) for SSI's controlled by any other type or combination of types of scrubbers. Of the SSI's where data is available, 32.6 percent of SSI's are controlled by a combination

of venturi and impingement scrubbers and 67.4 percent are controlled by some other means. These percentages were assumed to apply to the total population of SSI's. Multiplying the total amount of sewage sludge incinerated annually, 1.5×10^6 Mg (1.65×10^6 tons), by the appropriate percentage and emission factor gives a mercury emission estimate of 0.009 Mg/yr (0.01 tons/yr) for SSI's controlled with a combination of venturi and impingement scrubbers and an estimate of 1.64 Mg/yr (1.81 tons/yr) for SSI's controlled by some other means. Therefore, the overall mercury emissions estimate from SSI's is 1.65 Mg/yr (1.82 tons/yr).

Wood Combustion

Wood and wood wastes are used as fuel in both the industrial and residential sectors. In the industrial sector, wood waste is fired to industrial boilers to provide process heat, while wood is fired to fireplaces and wood stoves in the residential sectors. No data are available on the mercury content of wood and wood wastes. Consequently, this section briefly describes the three combustion processes (boilers, fireplaces, and wood stoves) and the control measures used for wood-fired processes and provides data on emission factors.

Wood waste combustion in boilers is mostly confined to industries in which wood waste is available as a byproduct. These boilers, which are typically of spreader stoker or

suspension-fired design, generate energy and alleviate possible solid waste disposal problems. In boilers, wood waste is normally burned in the form of hogged wood, sawdust, shavings, chips, sanderdust, or wood trim. Heating values for this waste range from about 9,300 to 12,000 kJ/kg (4,000 to 5,000 Btu/lb) of fuel on a wet, as-fired basis. The moisture content is typically near 50 weight percent but may vary from 5 to 75 weight percent, depending on the waste type and storage operations. As of 1980, about 1,600 wood-fired boilers were operating in the United States, with a total capacity of approximately 30.5 gigawatts (GW) (1.04×10^{11} Btu/hr).³⁴ No specific data on the distribution of these boilers were identified, but most are likely to be located in the Southeast, the Pacific Northwest States, Wisconsin, Michigan, and Maine.¹

Wood stoves, which are commonly used as space heaters in residences, are found in three different types: (1) the conventional wood stove, (2) the noncatalytic wood stove, and (3) the catalytic wood stove. Fireplaces are used primarily for aesthetic effects and secondarily as a supplemental heating source in homes and other dwellings. Wood is most commonly used as fuel, but coal and densified wood "logs" also may be burned.

All of the systems described above operate at temperatures that are above the boiling point of mercury. Consequently, any mercury contained in the fuel will be emitted with the combustion gases via the exhaust stack.

Although some wood stoves use emission control measures to reduce volatile organic compound (VOC) and carbon monoxide (CO) emissions, these techniques are not expected to affect mercury emissions. However, wood waste boilers do use PM control equipment, which may provide some reduction. The most common control devices used to reduce PM emissions from wood-fired boilers are mechanical collectors, wet scrubbers, ESP's, and fabric filters. Only the last three have the potential for mercury reduction. The most widely used wet scrubbers for wood-fired boilers are venturi scrubbers, although no data have been located on the performance of these systems relative to mercury emissions. No data are available on mercury emission reduction for fabric filters for wood combustors, but results for other combustion sources suggest that efficiencies will be low, probably 50 percent or less.¹

The data on mercury emissions from wood combustion are limited. A recent AP-42 study provided a range and average typical emission factor for wood waste combustion in boilers based on the results of seven tests. The average emission factor of 0.34×10^{-5} kg/Mg (0.67×10^{-5} lb/ton) of wood burned is recommended as the best typical emission factor for wood waste combustion in boilers.³⁵ Dividing the total capacity of wood-fired boilers, 30.5 GW (1.04×10^{11} Btu/hr), by the average heating value of wood, 10,600 kJ/kg (4,560 Btu/lb), gives the total hourly rate, 10,367 Mg/hr (11,404 tons/hr).³⁴ Assuming that wood-fired boilers operate at capacity at 8,760 hr/yr and

multiplying by the above emission factor gives a mercury emission estimate for wood-fired boilers of 0.3 Mg/yr (0.33 tons/yr).

For residential wood combustion, only one emission factor, 1.3×10^{-2} kg/Mg (2.6×10^{-5} lb/ton), was found, which was based on a single test burning a single type of wood (pine) at a single location.³⁶ In 1987, the Department of Energy estimated that 22.5 million households burned approximately 42.6 million cords of wood.³⁷ However, given that the densities of wood vary greatly depending on wood type and the wetness of the wood and that the above emission factor is from a single test, nationwide emissions of mercury for residential wood combustion were not estimated.

3.4.2 Manufacturing Sources

Manufacturing sources, including processes that use mercury directly and those that produce mercury as a byproduct, account for an estimated 94 Mg/yr (103 tons/yr) of mercury emissions generated in the United States. These sources are identified in Table 3-1 and discussed below.

Chlor-alkali Production Using the Mercury Cell Process

Chlor-alkali production using the mercury cell process, which is the only chlor-alkali process using mercury, accounted for 17 percent of all U.S. chlorine production in 1988.¹ The

chlor-alkali industry is currently moving away from mercury cell production and toward a membrane cell process because it does not use mercury, is more energy efficient, and produces a higher-quality product than the mercury cell process.³⁸ Estimated mercury emissions from chlor-alkali production using the mercury cell process (18 facilities) were approximately 6.6 Mg (7.3 tons) in 1991.

The mercury-cell chlor-alkali process consists of two electrochemical cells, the electrolyzer and the decomposer. A purified solution of saturated sodium or potassium brine flows from the main brine saturation section, through the inlet end box, and into the electrolyzer. The brine flows between stationary activated titanium anodes suspended in the brine from above and a mercury cathode, which flows concurrently with the brine over a steel base.³⁹

Chlorine gas is formed at the electrolyzer anode and is collected for further treatment. The spent brine is recycled from the electrolyzer to the main brine saturation section through a dechlorination stage. Sodium is collected at the electrolyzer cathode, forming an amalgam containing from 0.25 to 0.5 percent sodium. The outlet end box receives the sodium amalgam from the electrolyzer, keeping it covered with an aqueous layer to reduce mercury emissions. The outlet end box also allows removal of thick mercury "butter" that is formed through the outlet end box into the second cell (the decomposer).³⁹

The decomposer is a short-circuited electrical cell in an electrolytic of sodium hydroxide solution. This cell has the sodium amalgam as the anode and graphite or metal as the cathode. Water added to the decomposer reacts with the sodium amalgam to produce elemental mercury, sodium hydroxide, and hydrogen gas (a byproduct). The mercury, stripped of sodium, is recirculated to the cell through the inlet end box. The caustic soda solution typically leaves the decomposer at a concentration of 50 percent (by weight) and is filtered and further concentrated by evaporation. The byproduct hydrogen gas may be vented to the atmosphere, burned as a fuel, or used as a feed material for other processes.³⁹

Table 3-3 lists U.S. mercury-cell chlor-alkali production facilities and their capacities. With the downward trend of chlor-alkali production, there are no plans for construction of new mercury-cell chlor-alkali facilities.³⁸

The three primary sources of mercury air emissions are the (1) byproduct hydrogen stream, (2) end box ventilation air, and (3) cell room ventilation air. The byproduct hydrogen stream from the decomposer is saturated with mercury vapor and may also contain fine droplets of liquid mercury. The quantity of mercury emitted in the end box ventilation air depends on the degree of mercury saturation and the volumetric flow rate of the air. The amount of mercury in the cell room ventilation air is variable and comes from many sources, including end box sampling, removal of mercury butter from end boxes, maintenance operations, mercury

**TABLE 3-3. 1991 U.S. MERCURY-CELL CHLOR-ALKALI
PRODUCTION FACILITIES⁴⁰**

Facility	Location	Capacity, 10 ³ Mg/yr	Capacity, 10 ³ tons/yr	1991 TRI emissions, lbs/yr
Akzo Chemicals, Inc.	Le Moyne, AL	70	78	840
Georgia-Pacific Corp., Chemical Division	Bellingham, WA	82	90	1,250
BF Goodrich, Chemical Group	Calvert City, KY	109	120	980
Hanlin Group, Inc., LCP Chemicals Division	Reigelwood, NC	48	53	1,095
	Brunswick, GA	96	106	1,425
	Moundsville, WV	79	87	812
	Orrington, ME	76	80	890
Lin Chem, Inc.	Ashtabula, OH	36	40	N/A
Occidental Petroleum Corporation, Electrochemicals Division	Deer Park, TX	347	383	1,230
	Delaware City, DE	126	139	532
	Mobile, AL	34	37	N/A
	Muscle Shoals, AL	132	146	182
Olin Corporation, Olin Chemicals	Augusta, GA	102	112	1,270
	Charleston, TN	230	254	1,423
Pioneer Chlor Alkali Company, Inc.	St. Gabriel, LA	160	176	1,297
PPG Industries, Inc., Chemicals Group	Lake Charles, LA	1,041	1,148	N/A
	New Martinsville, WV	313	345	1,085
Vulcan Materials Company, Vulcan Chemicals Division	Port Edwards, WI	65	72	N/A
TOTAL		3,146	3,466	14,311 (6,546 kg/yr)

N/A = Not available in the 1991 Toxic Release Inventory (TRI). It is assumed that facilities not reporting mercury emissions in the 1991 TRI produce no mercury emissions.

spills, equipment leaks, cell failure, and other unusual circumstances.³⁹

The control techniques that are typically used to reduce the level of mercury in the hydrogen streams and in the ventilation stream from the end boxes are (1) gas stream cooling, (2) mist eliminators, (3) scrubbers, and (4) adsorption on activated carbon or molecular sieves. Mercury emissions via the cell room air circulation are not subject to specific emission control measures. However, concentrations are maintained at acceptable worker exposure levels through good housekeeping practices and equipment maintenance procedures.³⁹

Gas stream cooling may be used as the primary mercury control technique or as a preliminary removal step to be followed by a more efficient control device. The hydrogen gas stream from the decomposer exits at 93° to 127°C (200° to 260°F) and passes into a primary cooler. In this indirect cooler, a shell-and-tube heat exchanger with ambient temperature water is used to cool the gas stream to 32° to 43°C (90° to 110°F). A knockout container following the cooler is used to collect the mercury. If additional mercury removal is desired, the gas stream may be passed through a more efficient cooler or another device. Direct or indirect coolers using chilled water or brine provide for more efficient mercury removal by decreasing the temperature of the gas stream to 3° to 13°C (37° to 55°F). Regardless of the gas stream treated, the water or brine from direct contact coolers

requires water treatment prior to reuse or discharge because of the dissolved mercury in the liquid.³⁹

Mist eliminators (most commonly the filter pad type) can be used to removed mercury droplets, water droplets, or PM from the cooled gas streams. Particles trapped by the pad are removed by periodically spraying the pad and collecting and treating the spray solution.³⁹

Scrubbers are used to absorb the mercury chemically from both the hydrogen stream and the end box ventilation streams. The scrubbing solution is either depleted brine from the mercury cell or a sodium hypochlorite (NaOCl) solution. These solutions are used in either sieve plate scrubbing towers or packed-bed scrubbers. Mercury vapor and mist react with the sodium chloride or hypochlorite scrubbing solution to form water-soluble mercury complexes. If depleted brine is used, the brine solution is transferred from the scrubber to the mercury cell, where it is mixed with fresh brine, and the mercury is recovered by electrolysis in the cell.³⁹

Sulfur- and iodine-impregnated carbon adsorption systems are commonly used to reduce the mercury levels in the hydrogen gas stream if high removal efficiencies are desired. This method requires pretreatment of the gas stream by primary or secondary cooling followed by mist eliminators to remove about 90 percent of the mercury content of the gas stream. As the gas stream passes through the carbon adsorber, the mercury vapor is initially adsorbed by the carbon and then reacts with the sulfur

or iodine to form the corresponding mercury sulfides or iodides. Several adsorber beds in series can be used to reduce the mercury levels to the very low parts per billion (ppb) range.³⁹

The most recent source of mercury emission data is a 1984 EPA report containing test data from 21 chlor-alkali production facilities.³⁹ The daily mercury emission rates presented in Table 3-4 were calculated based on these test data. Emission control measures used at the facilities ranged from no controls to a combination of control methods. However, emission factors were not calculated from these data because the chlorine production rates cited in the report for each of the facilities appear to be based on process design capacity values rather than actual production levels during the test. Daily production rates based on capacities are not considered to be a reliable method for estimating emission factors.

Data are also available from the 1991 Toxics Release Inventory (TRI), which provides the mercury emissions reported by individual companies.⁴¹ The 1991 reported mercury emissions were 6.6 Mg (7.3 tons) and included 14 of the 18 mercury cell chlor-alkali production facilities listed in Table 3-3. Emission estimates based on these data do have some uncertainty because the estimates are mostly based on engineering judgment, not on emission tests, and the companies reporting to TRI are not audited for accuracy. However, they are deemed to be the best data available, and were used as the nationwide estimate for mercury emissions from chlor-alkali production. Those facilities

TABLE 3-4. MERCURY EMISSION RATES FOR CHLOR-ALKALI PRODUCTION FACILITIES³⁹

Emission source	Controls	No. of facilities	No. of tests ^a	Emission rate, g/d (lb/d)		
				Range	Average	
End box ventilation system	Uncontrolled	1	3	23-163	(0.05-0.36)	100 (0.22)
	Scrubber	5	8	3-549	(0.006-1.21)	200 (0.44)
	Cooler/chiller	8	9	1-390	(0.003-0.86)	136 (0.30)
	Scrubber & cooler	2	2	2-426	(0.004-0.94)	213 (0.47)
	Scrubber & carbon adsorber	1	6	5-118	(0.01-0.26)	32 (0.07)
Hydrogen gas stream	Scrubber	1	2	86-236	(0.19-0.52)	163 (0.36)
	Cooler/chiller	8	14	1-689	(0.002-1.52)	308 (0.68)
	Cooler & carbon adsorber	4	12	9-159	(0.02-0.35)	73 (0.16)
	Cooler & molecular sieve	4	8	5-295	(0.01-0.65)	95 (0.21)
	Cooler & scrubber	1	1	59	(0.13)	59 (0.13)
	Cooler & molecular sieve & carbon adsorber	1	1	263	(0.58)	263 (0.58)

^aNumber of tests at each facility ranged from one to seven.

not reporting mercury emissions in the 1991 TRI were assumed to produce no mercury emissions.

Cement Manufacturing

United States cement kiln capacity data for 1990 showed a total of 212 U.S. cement kilns with a combined total capacity of 73.5×10^6 Mg (81×10^6 tons).¹ Of this total, 201 kilns were active and had a total clinker capacity of 71.8×10^6 Mg (79.1×10^6 tons).¹ Because the majority (95.7 percent) of this cement was portland cement, portland cement production processes and emissions will be the focus of this section.¹ Total mercury emissions from the portland cement process are estimated to be 5.9 Mg (6.5 tons). In 1990, 68 percent of portland cement was produced by the dry process and 32 percent by the wet process.⁴²

The portland cement manufacturing process can be divided into four major steps: raw material acquisition and handling, kiln feed preparation, pyroprocessing, and finished cement grinding.¹

The initial step in the production of portland cement manufacturing is acquiring raw materials, including calcium, ores, and minerals. Mercury is expected to be present in the ores and minerals extracted from the earth. However, no data pertaining to mercury content in these minerals are available.

Raw material preparation, the second step in the process, includes a variety of blending and sizing operations designed to provide a feed with appropriate chemical and physical properties. Raw material processing differs somewhat for the wet and dry processes. At dry process facilities, the moisture content in the raw material, which can range between 2 and 35 percent, is reduced to less than 1 percent. Heat for drying is provided by the exhaust gases from the pyroprocessor. At facilities where the wet process is used, water is added to the raw material during the grinding step, thereby producing a pumpable slurry containing approximately 65 percent solids.

Pyroprocessing (thermal treatment) of the raw material is carried out in a rotary kiln, which is the heart of the Portland cement manufacturing process. During pyroprocessing, the raw material is transformed into clinkers, which are gray, glass-hard, spherically shaped nodules that range from 0.32 to 5.1 cm (0.125 to 2.0 in.) in diameter.

The rotary kiln is a long, cylindrical, slightly inclined, refractory-lined furnace. The raw material mix is introduced in the kiln at the elevated end, and the combustion fuels are introduced into the kiln at the lower end, in a countercurrent manner. The rotary motion of the kiln transports the raw material from the elevated end to the lower end. Fuel such as coal or natural gas (or occasionally oil) is used to provide energy for calcination. Other fuels, such as shredded municipal garbage, chipped rubber, coke, and waste solvents are also being

used more frequently. Mercury is present in coal and oil and may also be present in appreciable quantities in the waste-derived fuels mentioned above. Because mercury evaporates at approximately 350°C (660°F), most of the mercury present in the raw materials can be expected to be emitted during the pyroprocessing step. Combustion of fuel during the pyroprocessing step also contributes to mercury emissions.

Pyroprocessing can be accomplished by one of four different processes: wet process, dry process, dry process with a preheater, and dry process with a preheater/precalciner. These processes essentially accomplish the same physical and chemical steps described above. Depending on the prevalence of preheaters and precalciners at facilities where portland cement is manufactured by the dry process, these segments of the process can be the primary sources of mercury emissions. This is because mercury present in the raw material can evaporate readily during the preheating and precalcining steps.

The last step in the pyroprocessing is cooling the clinker. This process step recoups up to 30 percent of the heat input to the kiln system, locks in desirable product qualities by freezing mineralogy, and makes it possible to handle the cooled clinker with conventional conveying equipment. Finally, after the cement clinker is cooled, a sequence of blending and grinding operations is carried out to transform the clinker into finished portland cement.

The primary sources of mercury emissions from portland cement manufacturing are expected to be from the kiln and preheating/precalcining steps. However, small quantities of mercury may be emitted as a contaminant in the PM from process fugitive emission sources. Process fugitive emission sources include materials handling and transfer, raw milling and drying operations in dry process facilities, and finish milling operations. Typically, PM emissions from these process fugitive sources are captured by a ventilation system comprising one or more mechanical collectors with a fabric filter in a series. Because the dust from these units is returned to the process, they are considered to be process units as well as air pollution control devices. Because the mercury is in particle form, the performance of these systems relative to mercury control is expected to be equivalent to this overall PM performance, but no data are available on mercury performance of fugitive control measures.

In the pyroprocessing units, PM emissions are controlled by fabric filters ESP's, and electrified gravel bed (EGB) filters. Clinker cooler systems are controlled most frequently with pulse jet or pulse plenum fabric filters, but reverse air fabric filters, ESP's, and EGB's are becoming increasingly popular. No data are available on the performance of these control systems for mercury emissions. However, because they typically operate at temperatures of 170°C (325°F) or greater, mercury removal is expected to be substantially less than overall PM control.

Particle phase mercury emissions may be generated from all four processing steps. Additionally, vapor phase mercury emissions can be expected from the rotary kiln and preheater/precalciner. Mercury present in the raw material and the fuel is likely to be emitted from these high-temperature processes.

Cement kiln test reports were reviewed for facilities performing Certification of Compliance (COC) tests required of all kilns burning waste derived fuel (WDF). Fifteen of the test reports contained sufficient process information to allow calculation of mercury emission factors for the kiln stack. The results from these 15 kilns showed a range in average emission factors from 2.23×10^{-3} to 0.49 g/Mg (4.5×10^{-6} to $9.7 \times 10^{-4} \text{ lb/ton}$) of clinker. The average emission factor for all 15 facilities was $8.7 \times 10^{-2} \text{ g/Mg}$ ($1.7 \times 10^{-4} \text{ lb/ton}$) of clinker. These data are based on all test runs.¹

The total production of portland cement in 1990 was $67.5 \times 10^6 \text{ Mg}$ ($74.5 \times 10^6 \text{ tons}$) (95.7 percent of the total cement production).¹ Of the total production of portland cement, 96 percent was clinker, and the remaining 4 percent was other ingredients.¹ Multiplying the total amount of clinker produced in 1990 (total production of portland cement multiplied by 96 percent) by the above average emission factor gives an estimate of 5.9 Mg (6.5 tons) of mercury emissions from portland cement manufacturing for 1990.

Battery Production

Prior to the late 1980's, most primary batteries and some storage batteries contained mercury in the form of mercuric oxide (HgO), zinc amalgam (Zn-Hg), mercuric chloride (HgCl_2), or mercurous chloride (Hg_2Cl_2). However, from 1989 to 1991, the use of mercury in battery production decreased 69 percent, with further reductions expected in 1992.¹ Because only one type of battery, mercuric oxide batteries, still used mercury to any measurable degree as of the end of 1992, it will be the only battery discussed in this section. In 1991, an estimated 0.08 Mg (0.09 ton) of mercury was emitted from the production of batteries. Table 3-5 lists the manufacturers of mercuric oxide, alkaline manganese, and zinc-carbon batteries and the associated emissions reported in the 1990 TRI.⁴¹ The data base made no distinction of the type of battery each facility produces.

Mercuric oxide batteries are small, circular, relatively flat batteries that are used in transistorized equipment, walkie-talkie's, hearing aids, electronic watches, and other items requiring small batteries. The mercuric oxide-zinc cells use mercuric oxide (mixed with graphite and manganese dioxide) as the cathode and a zinc amalgam at the anode.

In producing the cathodes, mercuric oxide, manganese dioxide, and graphite are manually metered through a hopper to the blending area.³⁹ The resulting mixture is sent to a processing unit in which it is compacted into tablets by

TABLE 3-5. 1992 U.S. MERCURIC OXIDE, ALKALINE MANGANESE,
OR ZINC-CARBON BUTTON CELL BATTERY MANUFACTURERS¹

Manufacturer	Production site	1990 TRI emissions kg (lb) ⁴¹
Alexander Manufacturing Company (AMC, Inc.)	Mason City, IA	0 (0)
Duracell, USA	Cleveland, TN	NR
	LaGrange, GA	NR
	Lancaster, SC	9 (20)
	Lexington, NC	3 (70)
Eagle-Picher Industries, Inc.	Colorado Springs, CO	NR
Eveready Battery Company, Inc.	Maryville, MO	14 (30)
	Red Oak, IA	NR
	Fremont, OH	NR
	Bennington, VT	1 (2)
	Asheboro, NC (2 plants)	2 (5)
Mutec ^a	Columbus, GA (Corporate offices)	NR
Rayovac Corp.	Madison, WI	0 (0)
	Fennimore, WI	5 (10)
	Portage, WI	NR

^aMutec is a joint venture between Eastman Kodak and Panasonic.

NR = Not reported, company did not appear in 1990 TRI.

"slugging" (compression in a rotary pressing device to a specified density). These tablets are then granulated into uniformly sized particles and pelletized in a rotary press. The pellets are consolidated into small metal cans that have a diameter of less than 1.3 millimeters (mm) (0.05 in.).⁴³

For the production of the anodes, elemental mercury and zinc powder are metered from hoppers or holding tanks into an enclosed blender to produce a zinc amalgam.⁴³ The amalgam is sent to a processing area, where it is blended and the anode gel formed.

The completed anodes and cathodes are then sent to the cell manufacturing area. Separators, electrolytes, and other components are assembled with the anode and cathode to produce the HgO-Zn cell. Assembly may be automatic or semiautomatic. The assembled cathode, anode, electrolyte, and cover are sealed with a crimper. Depending on the design, other components may be added. Those additional components may include an insulator, an absorber, and a barrier. An integrated mercuric oxide battery plant may also produce HgO and recycled mercury onsite.¹

During the manufacture of mercuric oxide batteries, mercury may be emitted from grinding, mixing, sieving, pelletizing, and/or consolidating operations as PM and as vapor emissions. Baghouses are used to control PM emissions from the mixing/blending and processing steps in the production of cathodes. Mercury vapor emissions from the anode processing and cell manufacturing areas are generally discharged to the atmosphere uncontrolled. Ventilation air in the assembly room is

recirculated through PM filters. One plant reported an average of 73 percent mercury vapor removal efficiency in the cell assembly room when an air handler system, consisting of a PM prefilter and a charcoal filter, was operated using 75 percent recirculating air and 25 percent fresh air.⁴³

The only reported emission factor for a mercuric oxide production facility was for one plant in Wisconsin.⁴⁴ This facility used a combination of a baghouse and charcoal filter to treat the exhaust ventilation air. Annual use of mercury was 36.07 Mg (39.8 tons) and annual emissions were reported as 36.3 kg (80 lb) of mercury as HgO particles. The mercury emission factor for battery manufacture based on these data is 1.0 kg/Mg (2.0 lb/ton) of mercury used. No mercury emissions were reported for this facility in the 1990 TRI.⁴¹

Several factors limit the reliability of this emission factor. First, the data are over 10 years old, and both processes and emission controls may have changed in the interim. Second, no information is presented on the bases of the emission factor, but the mercury emission quantity is presumed to be an engineering estimate by the manufacturer because no reference is made to any emissions testing performed at the facility. Finally, this factor is based on only one specific site, and that facility may not represent all mercuric oxide battery manufacturing facilities.

Emission source data from a study of an integrated mercury button cell plant are summarized in Table 3-6.³⁹ Major emission

**TABLE 3-6. EMISSION SOURCE PARAMETERS FOR AN INTEGRATED
MERCURY BUTTON CELL MANUFACTURING FACILITY³⁹**

Building/source description ^a	Emission rate ^b		Exit temp. (K); control device
	g/d	lb/d	
Main plant			
Control room			
1. Blending, slugging, compacting, granulating	6.12	0.0135	297; Baghouse
2. Slugging, granulating	1.22	0.0027	297; Baghouse
3. Pelleting, consolidating	1.63 ^c	0.0036 ^c	295; Baghouse
4. Pelleting, consolidating	42.46	0.0936	297; Baghouse
4a. Pelleting, consolidating	6.53	0.0144	297; Baghouse
5. Blending, compacting, granulating, pelleting, consolidating	1.36 ^c	0.003 ^a	297; Baghouse
Anode room			
6. Amalgam, dewatering	1.82 ^c	0.004 ^c	297; Uncontrolled
6a. Vacuum dryer	0.46 ^c	0.001 ^c	297; Uncontrolled
6b. Blending	0.91 ^c	0.002 ^c	297; Uncontrolled
7. Pelleting, zinc amalgam	4.08 ^c	0.009 ^c	295; Baghouse
Cell assembly area			
8. Assembling calls	28.58	0.0630	295; Baghouse for PM. Vapor by recirculating air through prefilters and charcoal filters

^aSource names are those used by facility.

^bEmission rates were measured by facility except where noted.

^cEstimated emission rate by facility.

points were the pelletizing and consolidating operations (up to 42.46 g/d [0.094 lb/d]) and cell assembly (28.58 g/d [0.063 lb/d]). Emission controls were not in place for mercury vapor emissions from the main plant.³⁹ This plant reported total mercury emissions of 3.2 kg (7 lb) in the 1990 TRI.⁴¹

In 1991, 78 Mg (86 tons) of mercury was were in the production of batteries in the United States.¹⁴ Multiplying the mercury usage by the emission factor developed for the facility in Wisconsin gives a mercury emission estimate of 0.08 Mg (0.09 tons) for 1991. However, this estimate is highly uncertain because of the concerns discussed above about the reliability of the emission factors.¹ Mercury emission to the atmosphere when batteries are disposed of are accounted for in the emission estimate for MWC's and MWI's, as discussed in Section 3.4 of this report.

Electrical Apparatus Manufacturing

Mercury is rated as one of the best electrical conductors among the metals and is used in five areas of electrical apparatus manufacturing: electric switches, thermal sensing elements, tungsten bar sintering, copper foil production, and fluorescent light production. Overall mercury emissions from electrical apparatus manufacturing was estimated to be 0.2 Mg (0.2 ton) in 1991. No information on locations of manufacturers

of electrical apparatus that specifically contain mercury is available.

The primary use of elemental mercury in electrical apparatus manufacturing is in the production of electric switches (electric wall switches and electric switches for thermostats). Wall switches consist of mercury, metal electrodes (contacts), and an insulator in button-shaped metal cans. The wall switches are manufactured by first assembling a component consisting of a metal ring, a glass preform, a ceramic center, and a center contact. This subassembly is then transferred to a rotating multistation welding machine, located in an isolation room, where it is filled with approximately 3 g (0.11 ounce) of mercury. The filled subassembly is placed in the button-shaped can, evacuated, and welded shut. The assembled buttons then leave the isolation room and are cleaned, zinc-plated, and assembled with other components to form the completed wall switches.⁴³

Thermostat switches are constructed using a short glass tube with wire contacts sealed in one end of the tube. First, metal electrodes (contacts) are inserted into small tubes. The tubes are then heated at one end, constricted, and crimped closed around the electrodes (sealing the electrodes into the glass tube), and the apparatus is cleaned. The subassembly is then transferred to the isolation fill room where mercury is added. The open end of the mercury-filled tube is then heated, constricted, and sealed. The filled tubes then leave the

isolation room, and wire leads are attached to the electrode contacts, which completes the switch assembly.⁴³

A thermal sensing instrument consists of a temperature-sensing bulb, a capillary tube, a mercury reservoir, and a spring-loaded piston. The bulbs are made by cutting metal tubing to the correct size, welding a plug to one end of the tube, and attaching a coupling piece to the other end. A capillary is cut to a specified length and welded to the coupling at the open end of the bulb. The other end of the capillary is welded to a "head" that houses the mechanical section of the sensor. The bulb and capillary assembly are filled with mercury by a multistation mercury filling machine that is housed in a ventilated enclosure. After filling, the sensor is transferred to a final assembly station, where a return spring and plunger are set into a temporary housing on the head of the sensor. In order to complete the temperature instrument, the sensor is then attached to a controller and/or indicating device.⁴³

Mercury is also used in tungsten bar sintering. Tungsten is used as a raw material in manufacturing incandescent lamp filaments. The manufacturing process starts with tungsten powder pressed into long, thin bars of a specified weight. These bars are presintered and then sintered using a high-amperage electrical current. During the tungsten bar sintering process, mercury is used as a continuous electrical contact. The mercury contact is contained in pools (mercury cups) located inside the sintering unit.

After the sintering process is completed, the bars are cooled to ambient temperature to determine the density of the tungsten bar. Metallic mercury is normally used in these measurements because of its high specific gravity. In order to calculate the density of the tungsten bar, the tungsten bars are dipped into a pool of mercury, and the weight of the displaced mercury is determined. When the bar is removed from the mercury pool, the mercury is brushed off into a tray of water that is placed in front of the pool.⁴³

High-purity copper foil, used as a laminate in printed circuit boards, is produced by an electrodeposition process using mercury as the electrical contacts. The initial step in the foil production process is the dissolution of scrap copper in sulfuric acid to form copper sulfate. The solution is then fed to the plating operation, where the copper ions are electrodeposited on rotating drums as copper metal. During the electrodeposition process, a current passes between a lead anode and a rotating drum cathode. As the drum rotates, the copper metal is electrodeposited on the drum surface in the form of a continuous thin foil sheet. The rotating drum requires using a rotating electrical contact between the electrical connection and the drum surface. Elemental mercury is used as the continuous contact between the rotating shaft of the drum and the electric connections. The liquid mercury is contained in a well located at one end of the rotating drum shaft.⁴³

In fluorescent lamp production, precut glass tubes are washed, dried, and coated with a liquid phosphor emulsion that deposits a film on the inside of the lamp tube. Mount assemblies are fused to each end of the glass lamp tube, which is then transferred to an exhaust machine. On the exhaust machine, the glass tube is exhausted and a small amount (15 to 250 mg [3.3×10^{-5} to 5.5×10^{-4} lb]) of mercury is added. This mercury adheres to the emulsion coating on the interior of the tube. The excess mercury is then removed using a vacuum, after which the glass tube is filled with inert gas and sealed. After the lamp tubes are sealed, metal bases are attached to the ends and are cemented in place by heating.

The names and division headquarters of the fluorescent lamp manufacturers in the United States in 1992 are shown in Table 3-7. The Sylvania/GTE facilities are currently being purchased by Siemens Energy and Automation/OSRAM Corporation.¹

TABLE 3-7. 1992 U.S. FLUORESCENT LAMP
MANUFACTURERS' HEADQUARTERS¹

Company	Division headquarters
Duro-Test Corp.	North Bergen, NJ
General Electric	Cleveland, OH
Sylvania/GTE	Danvers, MA
Philips Lighting Company	Somerset, NJ

During electric switch manufacture, mercury may be emitted during welding or filling operations, as a result of spills or breakage, during product testing, and as a result of product transfer. Often, emissions can be controlled by using effective

gaskets and seals to containment of mercury in the process streams. Also, good work practices such as discarding rejected and broken switches under water and reducing the temperature in the fill room can effectively suppress mercury vaporization. Furthermore, local exhaust ventilation, custom-designed to fit specific equipment, can reduce mercury vapor and mercury PM.⁴³

During copper foil production, mercury can be emitted from the drum room and the treatment room of the copper plating process. Ventilated enclosures, with exhaust gases directed to mercury vapor filters, can be used to control mercury emissions, as can reducing the temperature of the mercury wells.⁴³

During fluorescent lamp manufacturing, mercury can be emitted by mercury purification, transfer, and parts repair during mercury handling; by the mercury injection operation; and from broken lamps, spills, and waste material. Mercury air levels during lamp production steps are reduced by process modifications, containment, ventilated enclosures, local exhaust ventilation, and temperature control.⁴³

No specific information on emission control measures for thermal sensing elements and tungsten bar sintering was found in the literature. It is assumed that mercury is emitted during the filling process for thermal sensing elements and during sintering and final density measurements for tungsten bar sintering.

While mercury may be emitted from all of the aforementioned areas of electrical apparatus manufacturing, no specific data for mercury emissions from these areas were found in the literature,

and no emission test data were available to calculate mercury emissions from each area. However, one 1973 EPA report presents an emission factor of 4 kg of mercury emitted for each megagram of mercury used (8 lb/ton) in overall electrical apparatus manufacture.¹⁷ This emission factor should be used with extreme caution, however, as it was based on engineering judgement and not on actual test data and because production and mercury control methods have probably changed considerably since 1973.

In 1991, 54 Mg (59 tons) of mercury was used in all electrical apparatus production (29 Mg [32 tons] for electric lighting and 25 Mg [27 tons] for wiring devices and switches).¹⁴ Multiplying the emission factor above by the 1991 usage gives a mercury emission estimate of 0.2 Mg (0.2 ton) for electrical apparatus manufacture. However, because of the lack of reliability of the emission factor, a high degree of uncertainty is associated with this emission estimate.

Instrument (Thermometers) Manufacture

Mercury is used in many medical and industrial instruments for measurement and control functions. These instruments include thermometers, pressure-sensing devices, and navigational devices. In 1991, an estimated 0.6 Mg (0.7 ton) of mercury was emitted from instrument manufacture; however, this estimate should be used with caution as discussed below.

It is beyond the scope of this study to discuss all instruments that use mercury in some measuring or controlling function. Although there is potential for mercury emissions from all instruments containing mercury, this section will focus only on the production of thermometers because they represent the most significant use and more information is available on thermometer manufacture than on the manufacture of other instruments.

The production of glass thermometers begins by cutting glass tubes into required lengths and bore sizes. Next, either a glass or metal bulb, used to contain the mercury, is attached to the base of the tube. The tubes are filled with mercury in an isolated room. A typical mercury filling process is conducted inside a bell jar. Each batch of tubes is set with open ends down into a pan, and the pan set under the bell jar, which is lowered and sealed. The tubes are heated to approximately 200°C (390°F), and a vacuum is drawn inside the bell jar. Mercury is allowed to flow into the pan from either an enclosed mercury addition system or a manually filled reservoir. When the vacuum in the jar is released, the resultant air pressure forces the mercury into the bulbs and capillaries. After filling, the pan of tubes is manually removed from the bell jar. Excess mercury in the bottom of the pan is refiltered and used again in the process.⁴³

Excess mercury in the tube stems is forced out the open ends by heating the bulb ends of the tubes in a hot water or oil bath. The mercury column is shortened to a specific height by flame-

heating the open ends (burning-off process). The tubes are cut to a finished length just above the mercury column, and the ends of the tubes are sealed. All of these operations are performed manually at various work stations. A temperature scale is etched onto the tube, completing the assembly.⁴³

During the production of thermometers, mercury emissions can be generated from mercury purification and transfer, the mercury filling process, the heating-out/burning-off steps, and spills of mercury, broken thermometers, and other accidents.¹ Within the industry, vapor emissions from mercury purification and transfer are typically controlled by containment procedures, local exhaust ventilation, temperature reduction to reduce the vapor pressure, dilution ventilation, or isolation of the operation from other work areas. The bore sizing step can be modified to reduce the use of mercury and be performed in an isolated room. Other measures that may be applied to this step are use of local exhaust ventilation, dilution ventilation, and temperature control.¹

No specific data for mercury emissions from manufacturing thermometers or any other instrument containing mercury were found in the literature. However, one 1973 EPA report presents an emission factor of 9 kg of mercury emitted for each megagram of mercury used (18 lb/ton) in overall instrument manufacture.¹⁷ This emission factor should be used with extreme caution, however, as it was based on survey responses gathered in the 1960's and not on actual test data. Instrument production and

the mercury control methods used in instrument production have probably changed considerably since the time of the surveys.

In 1991, 70 Mg (77 tons) of mercury was used in all instrument production.¹⁷ Multiplying the emission factor above by the 1991 usage gives a mercury emission estimate of 0.6 Mg (0.7 ton) for instrument manufacture. Again, a large degree of uncertainty is associated with this estimate because of the concerns about the reliability in the emission factor.

Primary Mercury Production

Mercury is currently only produced in the United States as a byproduct from the mining of gold ores and is no longer produced from mercury ore. The last U.S. mercury ore mine, the McDermitt Mine in McDermitt, Nevada, ceased operation in 1990, and all its equipment has since been dismantled, sold, landfilled, or scrapped.¹

In 1991, eight U.S. gold mines (six in Nevada, one in California, and one in Utah) produced metallic mercury as a byproduct. The names and locations of these mines are shown in Table 3-8. No information was available on the amount of mercury recovered at each facility, although the Bureau of Mines reported that 58 Mg (64 tons) of mercury was produced as a byproduct of gold ore mining in 1991 (51 percent less than in 1990).¹⁴ Data

TABLE 3-8. 1991 U.S. BYPRODUCT MERCURY-PRODUCING
GOLD MINES¹⁴

Mine	County/State	Operator
Getchell	Humboldt, NV	FMC Gold Co.
Carlin Mines Complex	Eureka, NV	Newmont Gold Co.
Hog Ranch	Washoe, NV	Western Hog Ranch Co.
Jerritt Canyon (Enfield Bell)	Elko, NV	Independence Mining Co., Inc.
McLaughlin	Napa, CA	Homestake Mining Co.
Mercur	Tooele, UT	Barrick Mercur Gold Mines, Inc.
Paradise Peak	Nye, NV	FMC Gold Co.
Pinson and Kramer Hill	Humboldt, NV	Pinson Mining Co.

are insufficient at this time to estimate the quantity of mercury emissions generated as a byproduct of gold ore mining.

Since the closure of the McDermitt Mine, recovery of mercury as a byproduct from gold ores is the only remaining ore-based production process. The incoming gold ore is crushed using a series of jaw crushers, cone crushers, and ball mills. If the incoming ore is an oxide-based ore, no pretreatment is required, and the crushed ore is mixed with water and sent to the classifier. If the ore is a sulfide-based ore, it must be pretreated using either a fluid bed or multiple hearth pretreatment furnace (roaster) to convert metallic sulfides to metallic oxides. The exhaust gas from either of these units is sent through wet ESP's and, if necessary, through carbon condensers. The exhaust gas then passes through a lime sulfur dioxide (SO_2) scrubber prior to discharging to the atmosphere. If the treated sulfide ore is high in mercury content, the primary mercury recovery process occurs from the wet ESP's. If the concentration is low, no attempt is made to recover the mercury for sale. The pretreated ore is mixed with water and sent to the classifier, where the ore is separated (classified) according to size. Ore pieces too large to continue in the process are returned to the crusher operation.¹

From the classifier, the slurry passes through a concentrator and then to a series of agitators containing the cyanide leach solution. From the agitators, the slurry is filtered, the filter cake sent to disposal, and the filtrate

containing the gold and mercury is transferred to the electrowinning process. If the carbon-in-pulp (CIP) process is used, the cyanide pulp in the agitators is treated with activated carbon to adsorb the gold and mercury. The carbon is filtered from the agitator tanks and treated with an alkaline cyanide-alcohol solution to desorb the metals. This liquid is then transferred to the electrowinning tanks. In the electrowinning process, the gold and mercury are electrodeposited onto a stainless steel wool cathode, which is sent to a retort to remove mercury and other volatile impurities. The stainless steel wool, containing the gold, is transferred from the retort to a separate smelting furnace, where the gold is volatilized and recovered as crude bullion.¹

The exhaust gas from the retort, containing mercury, SO_2 , PM, water vapor, and other volatile components, passes through condenser tubes, where the mercury condenses as a liquid and is collected under water in the launders. From the launders, the mercury is purified and sent to storage. After passing through the condenser tubes, the exhaust gas goes through a venturi and impinger tower to remove PM and water droplets and then moves through the SO_2 scrubber prior to discharging to the atmosphere.¹

Gold ores in open heaps and dumps can also be treated by cyanide leaching. In this process, the gold ore is placed on a leaching pad and sprayed with the cyanide solution. The solution migrates down through the ore to a collection system on the pad and then is sent to a pregnant solution pond. From this pond,

the leachate liquors, containing gold and mercury, are transferred to the gold recovery area. In this area, the liquor is filtered and sent to the electrowinning process.¹

Potential sources of mercury emissions from gold processing facilities are at locations where furnaces, retorts, or other high-temperature sources are used in the process and where the mercury is removed from the launders. The treated gas discharged to the atmosphere is also a source of mercury emissions.¹

When pretreatment roasting is required, the exhaust gases from the furnace pass through a cyclone to remove PM and then move through wet ESP's to remove arsenic, mercury, and some of the SO₂. If the mercury concentration in the gold ore is high, the ESP's will not remove all of the mercury, and an activated carbon adsorber bed may be required for additional mercury removal. The gas passes through a lime scrubber to remove SO₂; if the SO₂ concentration is low, a caustic scrubber may be used. From the scrubber, the gas is discharged through the stack to the atmosphere. Essentially, the same emission control measures are used for the exhaust gas from the retort. After the gas passes through the condenser tubes to remove the mercury, a venturi and a cyclone are used to remove PM and water droplets. These controls are followed by the lime scrubber to remove the SO₂ prior to discharging to the atmosphere.

No emission data have been published for facilities producing mercury as a byproduct of gold ore; therefore, no estimate of mercury emissions from gold ore mining can be made at

this time. However, the treatment techniques used to recover mercury after it has been vaporized in a retort or furnace in the gold ore mining process are similar to those that were used in primary mercury production from ore. Likewise, the overall emission sources of mercury are similar for the two processes. The estimated mercury emissions from mercury ore can therefore be used as a benchmark for mercury emissions from gold ore.¹

No specific data on emission factors from potential sources of mercury emissions from mercury ore mining have been published since 1973.¹ The 1973 report gives a total emission factor of 0.171 kg of mercury emitted for each megagram of mercury ore mined (0.342 lb/ton), which was based on stack tests conducted in the early 1970's.¹⁷ However, this emission factor is for mercury emissions from mercury ore mining only and cannot be used for mercury emissions from gold ore mining. Therefore, no mercury emission from gold ore mining were estimated for this report.

Secondary Mercury Production

Secondary mercury production (mercury recycling) involves processing scrapped mercury-containing products, industrial waste and scrap, and scrap mercury from government stocks. Secondary mercury production is estimated to have accounted for approximately 6.7 Mg (7.4 tons) of mercury emissions in 1991. Major sources of recycled mercury include dental amalgams and scrap mercury from instrument and electrical manufacturers (lamps

and switches), wastes and sludges from research laboratories and electrolytic refining plants, and mercury batteries.¹ Table 3-9 lists the five major companies that were involved in secondary mercury production in 1989.

TABLE 3-9. 1989 U.S. MERCURY RECYCLERS⁴⁵

Adrow Chemical Company	Wanaque, NJ
Bethlehem Apparatus Company, Inc.	Hellertown, PA
D. F. Goldsmith Chemical and Metals Corp.	Evanston, IL
Mercury Refining Company, Inc.	Latham, NY
Wood Ridge Chemical Company	Newark, NJ

Secondary mercury production (recycling) can be accomplished by one of two general methods: chemical treatment or thermal treatment.¹ The most common method of recycling metallic mercury is through thermal treatment. Generally, the mercury-containing scrap is reduced in size and is heated in retorts or furnaces at about 538°C (1000°F) to vaporize the mercury. The mercury vapors are condensed by water-cooled condensers and collected under water.^{39, 43}

Vapors from the condenser, which may contain PM, organic compounds and possibly other volatile materials from the scrap, are combined with vapors from the mercury collector line. This combined vapor stream is passed through an aqueous scrubber to remove PM and acid gases (e.g., hydrogen chloride [HCl], SO₂). From the aqueous scrubber, the vapor stream passes through a charcoal filter to remove organic components prior to discharging into the atmosphere.³⁹

The collected mercury is further purified by distillation and then transferred to the filling area. In the filling area, special filling devices are used to bottle small quantities, usually 0.464 kg (1 lb) or 2.3 kg (5 lb) of distilled mercury. With these filling devices, the mercury flows by gravity through tubing from a holding tank into the flask until the flask overflows into an overflow bottle. The desired amount of mercury is dispensed into the shipping bottle by opening a valve at the bottom of the flask. The shipping bottle is then immediately capped after the filling and sent to the storage area.⁴³

Chemical treatment can encompass several methods for aqueous mercury-containing waste streams. To precipitate metallic mercury, the waste stream can be treated with sodium borohydride or the stream can be passed through a zinc-dust bed. Mercuric sulfide can be precipitated from the waste streams by treatment with a water-soluble sulfide, such as sodium sulfide. Ion-exchange systems can be used to recover ionic mercury for reuse, while mercuric ions can be trapped by treatment with chemically modified cellulose.⁴⁶

During secondary mercury production, emissions may potentially occur from the retort or furnace operations, the distillation percent, and the discharge to the atmosphere process.^{39,43} The major mercury emission sources are the condenser exhaust and fugitive vapor emissions that occur during unloading of the retort chamber. Mercury emissions can also occur in the

filling area when the flask overflows and during the bottling process.

Information on specific emission control measures is limited and site-specific. If a scrubber is used, mercury vapor or droplets in the exhaust gas may be removed by condensation in the spray. No information was found for other control measures that are being used in secondary mercury production processes. Concentrations in the workroom air due to mercury vapor emissions from the hot retort may be reduced by the following methods: containment, local exhaust ventilation, dilution ventilation, isolation, and/or personal protective equipment. No information was provided to indicate that these methods are followed by any type of emission control device.⁴³ Vapor emissions due to mercury transfer during the distillation or filling stages may be reduced by containment, ventilation (local exhaust or ventilation), or temperature control.

Because the secondary mercury production process has not undergone any recent emission tests, virtually no data are available for this process. In 1973, emission factors were estimated to be 20 kg of mercury emitted per megagram of mercury processed (40 lb/ton) due to uncontrolled emissions over the entire process.¹⁷ These data are not considered to be reliable because (1) they are 20 years old, and processes may have changed substantially since they were generated; and (2) no information is available on their bases.

In 1991, 122 Mg (134 tons) of mercury were recycled from industrial scrap and 215 Mg (237 tons) from government stocks in the United States.¹⁴ This total (337 Mg [371 tons]) does not include in-house mercury reclamation at industrial plants using mercury. Multiplying the total mercury recycled by the emission factor gives a mercury emission estimate of 6.7 Mg (7.4 tons) for 1991. Again, this estimate has a high degree of uncertainty because of the limited reliability of the emission factor.

Mercury Compounds Production

The production of mercury compounds presents a potential source of mercury emissions into the atmosphere. Common mercury compounds include mercuric chloride, mercuric oxide, and phenylmercuric acetate (PMA). Table 3-10 presents a list of several producers of inorganic and organic mercury compounds.

Because numerous mercury compounds are produced in the United States, it is beyond the scope of this study to present process descriptions for each one. Process descriptions of the more common mercury compounds can be found in the mercury L&E document.¹

During the production of mercury compounds, emissions of mercury vapor and particulate mercury compounds may occur at the following sources: reactors, driers, filters, grinders, and transfer operations. No information was found on specific emission control devices to remove or treat the mercury

TABLE 3-10. 1991 U.S. MERCURY COMPOUND PRODUCERS⁴⁰

Producer	Location	1991 TRI emissions, kg (lb) ⁴¹	Compound(s)
Atochem North America, Inc., Chemical Specialties Division	Tulsa, OK	NR	HgF ₂
Atomergic Chemetals Corp.	Farmingdale, NY	NR	Thimerosal (Merthiolate)
Cambrex Corp., CasChem, Inc., Subsidiary (formerly Cosan Chem. Corp.)	Carlstadt, NJ	18 (40)	Phenylmercuric acetate (PMA), Phenylmercuric oleate
W.A. Cleary Corp.	Somerset, NJ	NR	Phenylmercuric acetate (PMA)
Deepwater, Inc.	Carson, CA	NR	HgI ₂
GFS Chemicals, Inc.	Columbus, OH	NR	HgBr ₂ , HgI ₂ , Hg(NO ₃) ₂ , HgSO ₄
Hüls America, Inc.	Elizabeth, NJ	0 (0)	Phenylmercuric acetate (PMA)
Insera Group, Inc., Mallinkrodt Inc., Subsidiary, Mallinkrodt Specialty Chem. Co.,	Erie, PA	227 (500)	HgCl ₂ on carbon support (catalyst for vinyl chloride manufacture)
Morton International, Inc., Specialty Chemicals Group, Advanced Materials, CVD Inc. Subsidiary	Woburn, MA	NR	Highly purified dimethylmercury, (CH ₃) ₂ Hg, for chemical vapor deposition (CVD) of thin films
Polychemical Laboratories, Inc.	Melville, NY	NR	Thimerosal (Merthiolate)
R.S.A Corporation	Ardsley, NY	NR	Hg(SCN) ₂
Troy Chemical Corp.	Newark, NJ	0 (0)	Phenylmercuric acetate (PMA)

NR = Not reported; company did not appear in 1991 TRI.

emissions, but the literature did contain information on methods designed to reduce the workplace concentrations without subsequent treatment.⁴³ Typically, these procedures included some combination of enclosure or containment, process modifications, exhaust ventilation, dilution ventilation, and personal protective equipment.⁴³ In some cases, ventilation systems are reported to be ducted to cyclone dust collectors to reduce dust emissions, but no information was located on mercury vapor controls.¹ No information was available from the literature on mercury emissions or emission factors from the production of mercury compounds; therefore, no mercury emission estimate could be developed. As shown in Table 3-10, the only company that reported significant emissions (227 kg [500 lb]) in the 1991 TRI was Mallinkrodt, Inc.

Carbon Black Production

The majority of U.S. manufactured carbon black (over 98 percent) is produced using a highly aromatic petrochemical or carbochemical heavy oil feedstock containing mercury. In 1991, mercury emissions from carbon black production were estimated to be 0.23 Mg (0.25 ton). This estimate is expected to be an overestimate because it is based on production capacity and not on actual production. Table 3-11 lists the names, locations, and annual capacities of U.S. producers of carbon black in 1991.

TABLE 3-11. 1992 U.S. CARBON BLACK PRODUCTION FACILITIES⁴⁷

Company	Location	Type of process ^a	Annual capacity ^b	
			10 ³ Mg	10 ³ tons
Cabot Corporation North American Rubber Black Division	Franklin, Louisiana	F	141	155
	Pampa, Texas	F	32	35
	Villa Platte, Louisiana	F	127	140
	Waverly, West Virginia	F	82	90
Chevron Corporation Chevron Chemical Company, subsidiary Olefin and Derivatives Division	Cedar Bayou, Texas	A	9	10
Degussa Corporation	Aransas Pass, Texas	F	59	65
	Belpre, Ohio	F	64	70
	New Iberia, Louisiana	F	109	120
Ebonex Corporation	Melvindale, Michigan	C	4	4
General Carbon Company	Los Angeles, California	C	0.5	0.5
Hoover Color Corporation	Hiwassee, Virginia	C	0.5	0.5
J.M. Huber Corporation	Baytown, Texas	F	102	112
	Borger, Texas	F and T	79	87.5
	Orange, Texas	F	61	67.5
Phelps Dodge Corporation Colombian Chemical Company, subsidiary	El Dorado, Arkansas	F	50	55
	Moundsville, West Virginia	F	77	85
	North Bend, Louisiana	F	109	120
	Ulysses, Kansas	F	36	40
Sir Richardson Carbon & Gasoline Company	Addis, Louisiana	F	66	72.5
	Big Spring, Texas	F	52	57.5
	Borger, Texas	F	98	107
Witco Corporation Continental Carbon Company, subsidiary	Phenix City, Alabama	F	27	30
	Ponca City, Oklahoma	F	114	125
	Sunray, Texas	F	45	50
	TOTAL		1,546	1,700

^aA = acetylene decomposition

C = combustion

F = furnace

T = thermal

^bCapacities are variable and based on SRI estimates as of January 1, 1992.

Three primary raw materials used in the production of carbon black are preheated feedstock (either the petrochemical oil or carbochemical oil), which is preheated to a temperature between 150° and 250°C (300° and 480°F), preheated air, and an auxiliary fuel such as natural gas. A turbulent, high-temperature zone is created in the reactor by combusting the auxiliary fuel, and the preheated oil feedstock is introduced in this zone as an atomized spray. In this zone of the reactor, most of the oxygen is used to burn the auxiliary fuel, resulting in insufficient oxygen to combust the oil feedstock. Thus, pyrolysis of the feedstock is achieved, and carbon black is produced. Most of the mercury present in the feedstock is emitted in the hot exhaust gas from the reactor.^{48,49}

The product stream from the reactor is quenched with water, and any residual heat in the product stream is used to preheat the oil feedstock and combustion air before the carbon is recovered in a fabric filter. Carbon recovered in the fabric filter is in a fluffy form. The fluffy carbon black may be ground in a grinder, if desired. Depending on the end use, carbon black may be shipped in fluffy form or in the form of pellets. Pelletizing is done by a wet process in which carbon black is mixed with water along with a binder and fed into a pelletizer. The pellets are subsequently dried and bagged prior to shipping.^{48,49}

High-performance fabric filters are reported to be used to control PM emissions from main process streams during the

manufacture of carbon black. The fabric filters can reduce PM emissions to levels as low as 6 milligrams per normal cubic meter (mg/Nm^3) ($0.003 \text{ gr}/\text{dscf}$). Mercury emissions from the reactor are primarily in the vapor phase, and these emissions will proceed through the main process streams to the fabric filters as a vapor. If the mercury remains in the vapor phase, the mercury control efficiency of the fabric filters is expected to be low. If the product gas stream is cooled to below 170°C (325°F), the fabric filter may capture a significant fraction of the condensed mercury, thus providing a high degree of emission control.⁴⁸

Mercury, which is present in the oil feedstock, can be emitted during the pyrolysis step. However, no data are available on the performance of the fabric filter control systems for mercury emissions. The only available data are for emissions from the oil-furnace process. These data show mercury emission to be $1.5 \times 10^{-4} \text{ kg}/\text{Mg}$ ($3 \times 10^{-4} \text{ lb}/\text{ton}$) from the main process vent.⁵⁰ The source of these data could not be obtained in order to validate of the emission factors. Because the factors are not verified, they are considered to be of limited reliability.

In 1991, the total capacity for carbon black production was $1.55 \times 10^6 \text{ Mg}$ ($1.7 \times 10^6 \text{ tons}$).⁴⁷ Multiplying the total capacity by the emission factor above gives a mercury emission estimate of 0.23 Mg (0.25 tons). This estimate may be greater than the actual emissions because it is based on production capacity and not on actual production. On the other hand, this estimate may understate the actual mercury emissions because the data are from

the oil-furnace process only and not the main process streams. Therefore, it is difficult to determine if this estimate overstates or understates the actual mercury emissions.

Byproduct Coke Production

Byproduct coke, also called metallurgical coke, is a primary feedstock for the integrated iron and steel industry. Because no information concerning mercury emissions from the production of byproduct coke could be found in the literature, no nationwide mercury emission estimates were generated. Table 3-12 contains a list of U.S. byproduct coke oven facilities in 1991.

Coke is currently produced in two types of coke oven batteries: the slot oven byproduct battery and the nonrecovery battery. The slot oven byproduct type is by far the most commonly used battery; over 99 percent of coke produced in 1990 was produced in this type of battery.^{52,53}

The byproduct coke oven battery consists of a series (ranging from 10 to 100) of narrow ovens, 0.4 to 0.6 m (1.3 to 2 ft) wide, and 12 to 18 m (40 to 60 ft) long. The height of the ovens may range between 3 and 6 m (10 and 20 ft). Depending on the dimensions, the production capacity may range between 6.8 and 35 Mg (7.5 and 39 tons) of coke per batch. A heating flue is located between each oven pair.^{52,53}

Pulverized coal, which is the feedstock, is fed through ports located on the top of each oven by a car that travels on

TABLE 3-12. 1991 U.S. BYPRODUCT COKE PRODUCERS⁵¹

Facility	No. of batteries	Total No. of ovens	Total capacity, Mg/d (ton/d)
Acme Steel, Chicago, IL	2	100	1,450 (1,600)
Armco, Inc., Ashland, KY	2	146	2,450 (2,700)
Armco, Inc., Middletown, OH	3	203	4,130 (4,540)
Bethlehem Steel, Bethlehem, PA	3	284	3,580 (3,940)
Bethlehem Steel, Burns Harbor, IN	2	164	3,980 (4,380)
Bethlehem Steel, Lackawanna, NY	2	152	1,700 (1,870)
Bethlehem Steel, Sparrows Point, MD	3	210	3,700 (4,070)
Genava Steel, Orem, UT	1	208	2,050 (2,250)
Gulf States Steel, Gadsden, AL	2	130	2,550 (2,800)
Inland Steel, East Chicago, IN	6	446	5,250 (5,780)
LTV Steel, Pittsburgh, PA	5	315	4,910 (5,400)
LTV Steel, Chicago, IL	1	60	1,450 (1,600)
LTV Steel, Cleveland, OH	2	126	2,910 (3,200)
LTV Steel, Warren, OH	1	85	1,360 (1,500)
National Steel, Granite City, IL	2	90	1,380 (1,520)
National Steel, Ecorse, MI	1	78	840 (925)
USS, Div. of USX Corp., Clairton, PA	12	816	11,490 (12,640)
USS, Div. of USX Corp., Gary, IN	6	422	6,490 (7,140)
Wheeling-Pittsburgh Steel, East Steubenville, WV	4	224	3,450 (3,800)
Total	58	4,259	65,120 (71,660)

tracks along the top of each battery. The ports are sealed upon charging, and gaseous fuel is combusted in the flues located between the ovens to provide the energy for the pyrolysis. The coking process takes place for between 12 and 20 hours, at the end of which almost all the volatile matter from the coal is driven off, thus forming coke. The coke is then unloaded from the ovens through vertical doors on each end of the oven into a rail car, where it is cooled by being sprayed with several thousand gallons of water. The rail car then unloads the coke in a separate area, where the coke is allowed to cool further.^{52,53}

Mercury is present in coal in appreciable quantities. Depending on the type of coal used, the mercury content can be as high as 8 parts per million by weight (ppmwt). Consequently, the volatile gases that evolve from the coking operation are likely to contain mercury.^{52,53}

Emissions at byproduct coke plants are generated during coal preparation, oven charging operations, and pushing operations. Emissions are also generated from door leaks and from the battery stack. The battery stack emissions are primarily a result of leakage from the oven into the flue. Mercury emissions can be generated in small quantities during coal preparation and handling as fugitive PM because mercury is present as a trace contaminant in coal. Mercury also may be volatilized and released during charging and pushing operations as well as from the battery stacks and door and topside leaks. Emission levels are expected to be minimal, but no data are available.

Primary Lead Smelting

Primary lead smelters recover lead from a sulfide ore, which contains mercury, and emitted an estimated 8.2 Mg (9 tons) of mercury into the atmosphere in 1990. Table 3-13 gives the locations and 1990 production rates of the three primary lead smelters that are currently operating in the United States.

TABLE 3-13. 1990 U.S. PRIMARY LEAD SMELTERS AND REFINERIES⁵⁴

Smelter	Refinery	1990 Production, Mg (tons)
ASARCO, East Helena, MT	ASARCO, Omaha, NE	65,800 (72,500)
ASARCO, Glover, MO	ASARCO, Glover	112,000 (123,200)
Doe Run (formerly St. Joe), Herculancum, MO	Doe Run, Herculancum, MO	231,000 (254,100)

Recovery of lead from the lead ore in primary lead smelters consists of three main steps: sintering, reduction, and refining. The sintering machine, which converts lead sulfide in the ore to lead and lead oxide, is a continuous steel pallet conveyor belt. Each pallet consists of perforated grates, beneath which are wind boxes connected to fans to provide a draft through the moving sinter charge. The sintering reactions on the grate take place at about 1000°C (1832°F). Because mercury evaporates at approximately 350°C (660°F), most of the mercury present in the ore is assumed to be emitted as a vapor in the sintering machine exhaust gas either as elemental mercury or as mercuric oxide.⁵³

Reduction of the sintered lead is carried out in a blast furnace at a temperature of 1600°C (2920°F). The furnace is charged with a mixture of sinter (80 to 90 percent of charge), metallurgical coke (8 to 14 percent of charge), and other materials, such as limestone, silica, litharge, and unspecified slag-forming constituents. In the blast furnace, the lead sulfate and lead oxide in sinter is reduced to lead. The heat for the reaction is supplied by the combustion of coke. Impurities are removed from the furnace as slag, which is either processed at the smelter for its metal content or shipped to treatment facilities. The impurities include arsenic, antimony, copper sulfide and other metal sulfides, and silicates. Lead bullion, which is the primary product, undergoes a preliminary treatment to remove impurities, such as copper, sulfur, arsenic, antimony, and nickel, before carrying out further refining. Any residual mercury left in the ore after sintering will be emitted during the reduction step.⁵³

The lead bullion is refined in cast iron kettles. Refined lead, which is 99.99 to 99.999 percent pure is cast into pigs for shipment.⁵³ Mercury emissions from refining operations are expected to be negligible.

Primary lead smelters use high-efficiency emission control systems to reduce the levels of PM and SO₂ from the blast furnace and sintering machines. Centrifugal collectors (cyclones) are used in conjunction with baghouses or ESP's for PM control. Control of SO₂ emissions is achieved by absorption to form

sulfuric acid in the sulfuric acid plants, which are commonly part of lead smelting plants. Because mercury is emitted from these as a vapor and these PM control systems often operate at temperatures at which mercury has a significant vapor pressure, these PM control devices are expected to have little effect on mercury emissions from the sintering machine and blast furnace. However, no data are available on performance of these systems with respect to mercury emissions.⁵³

Mercury, which may be present in the ore, may be emitted during the sintering and blast furnace steps and in the dressing area because these processes take place at high temperatures.

The most recent emission factor data available for mercury emissions from primary lead smelting are presented in Table 3-14.⁵⁵ These data represent emission factors for a custom smelter operated by ASARCO in El Paso, Texas; this facility ceased operating in 1985. No recent mercury emission factors are available for the three current primary lead smelters. The custom smelter in El Paso obtained lead ore from several sources both within and outside the United States. These ores had a variable mercury content depending upon the source of the ore. Two of the three current smelters are not custom smelters; they typically process ore from the vicinity of the smelter. The two smelters in Missouri use ore only from southeast Missouri; these ores have a very low mercury content. The ASARCO-East Helena plant, although a custom smelter, processes low mercury concentrates. None of the three primary lead smelters reported

TABLE 3-14. MERCURY EMISSION FACTORS FOR PRIMARY LEAD SMELTING

Process	Emission factor		Notes
	g/Mg	lb/ton	
Materials Handling: Ore crushing	1.2 ^a	0.0024 ^a	Uncontrolled
Materials Handling: Sinter charge mixing	6.5 ^a	0.013 ^a	Uncontrolled
Sintering Machine leakage	0.7 ^b	0.0014	Uncontrolled
Blast furnace	1.9 ^c	0.0038 ^c	Baghouse sampling data
Slag fuming furnace	1.7 ^d	0.0034 ^d	Baghouse sampling data
Slag pouring	0.45 ^d	0.0009 ^d	Uncontrolled
Dross reverberatory furnace	0.08 ^c	0.00016 ^c	Uncontrolled sampling data

Source: Reference 55

^aPer ton (or Mg) of raw materials.^bPer ton (or Mg) of sinter.^cPer ton (or Mg) of concentrated ore.^dPer ton (or Mg) of lead product.

mercury emission data in the 1990 TRI, indicating that emissions from the sources are estimated to be below the TRI reporting threshold.

Because the data in Table 3-14 were based on ores with a variable mercury content and the current sources of lead ore have a low mercury content, the emission factors in Table 3-14 probably would lead to an overestimation of current emissions.

The estimated lead ore utilization quantity in 1990 was 3.74×10^6 Mg (4.11×10^6 tons).¹ Based on background information developed for the new source performance standards (NSPS) for lead smelters, 100 units of ore yields 10 units of ore concentrate, 9 units of sinter, and 4.5 units of refined lead.⁵⁶ Multiplying the product yield information in the NSPS by the appropriate emission factor, as shown in Table 3-14, gives a total mercury emission estimate of 8.2 Mg (9 tons) for primary lead smelters in 1990. Because substantial assumptions were used to convert the emission factors to a lead production basis, this emission estimate has a high degree of uncertainty.

Primary Copper Smelting

Copper is recovered from a sulfide ore principally by pyrometallurgical smelting methods. The ore contains significant quantities of arsenic, cadmium, lead, antimony, and mercury. Table 3-15 gives the locations and 1992 production capacities of primary copper smelters currently operating in the United States.

Data pertaining to mercury contents of the ore are not available.¹

TABLE 3-15. 1992 U.S. PRIMARY COPPER SMELTERS AND REFINERIES⁵⁸

Smelter	Location	1992 Capacity, Mg (tons)
ASARCO Inc.	Hayden, AZ	170,000 (187,000)
Cyprus Miami Mining Co.	Globe, AZ	180,000 (198,000)
MAGMA Copper Co.	San Manuel, AZ	290,000 (319,000)
Copper Range Co.	White Pine, MI	60,000 (66,000)
Phelps Dodge	Hidalgo, NM	190,000 (209,000)
Chino Mines Co.	Hurley, NM	170,000 (187,000)
ASARCO Inc.	El Paso, TX	104,000 (114,400)
Kennecott	Garfield, UT	210,000 (231,000)

A conventional copper smelting process sequentially involves roasting ore concentrates to produce calcine, smelting of roasted or unroasted ore concentrates to produce matte, converting matte to produce blister copper, and fire refining the blister copper in an anode furnace. After fire refining, the 99.5 percent pure copper is cast into "anodes" and sent to an electrolytic refinery for further impurity removal.²⁵

Roasting involves heating a copper concentrate mixed with a siliceous flux to about 650°C (1200°F) to eliminate 20 to 50 percent of the sulfur impurities.²⁵ Portions of antimony, arsenic, and lead impurities are driven off, and some iron is converted to oxide. Because mercury has a boiling point of 350°C (660°F) it will be volatilized and emitted as a vapor in the roaster exhaust gas.

Smelting produces a copper matte by melting hot calcine from the roaster, or raw unroasted concentrate, with siliceous flux in a furnace. The mattes produced by domestic smelters range from 35 to 65 percent copper. Smelting furnace technologies operate at temperatures well above the boiling point of mercury, with operating ranges as high as 2500°C (4530°F). Hence, any residual mercury remaining in the calcine will likely be emitted as an air pollutant during smelting, and any mercury contained in the raw, unroasted concentrate will likely emit during this process step.²⁵

The final step in the production of molten "blister" copper is converting. Converting eliminates remaining iron and sulfur impurities, leaving 98.5 to 99.5 percent pure copper. Converting involves molten matte, siliceous flux, and scrap copper being charged in a rotating cylindrical shell, where air or oxygen rich air is blown through the molten matte. Blowing and slag skimming are repeated until relatively pure Cu_2S , called "white metal" accumulates in the bottom of the converter. A renewed air blast then oxidizes the copper sulfide to SO_2 , leaving blister copper. Blister copper is then removed and transferred to refining facilities. Further purification may involve fire refining and electrolytic refining.²⁵

Copper smelters use high efficiency air pollution control options to control PM and SO_2 emissions from roasters, smelting furnaces, and converters. Electrostatic precipitators are the most common PM control device at copper smelters. Control of SO_2

emissions is achieved by absorption to sulfuric acid in the sulfuric acid plants, which are common to all copper smelters.

Mercury emission data for primary copper smelting facilities are very limited. One emission test report for the Copper Range Company located in White Pine, Michigan, containing metals analysis results was reviewed during this study.⁵⁸ This facility operates a reverberatory furnace with an ESP to control PM. The exhaust stream from the convertor (which is uncontrolled) is mixed with the exhaust from the ESP outlet and is routed through the main stack and discharged into the atmosphere. Testing for metals was performed at a location in the main stack downstream from the point where the two exhaust streams (from the ESP outlet and the convertor) are combined. Mercury emissions were measured for three modes of convertor operation: slag-blow, copper-blow, and convertor idle (no blow) cycles. The mercury level during the convertor idle cycle was measured to be the highest, corresponding to a mercury emission rate of 0.0753 kg/hr (0.166 lb/hr). During the slag-flow and copper-flow periods, the emission rates were 0.0494 kg/hr (0.109 lb/hr) and 0.0635 kg/hr (0.140 lb/hr), respectively. Additionally, the plant capacity was reported to be approximately 38 Mg/hr (42 tons/hr) of feed, which consists of mill concentrate, limestone, iron pyrites, and recycled material. The actual process rate during the test is not known, so an emission factor cannot be calculated from this test.

Because the feed mix varies from facility to facility and because the Copper Range Company is the only facility in the United States that operates a reverberatory, the emission data from the Copper Range Company may not be representative of industry practice. As a result, a mercury emissions estimate of 0.6 Mg/yr (0.7 tons/yr) from this one facility was calculated using an emission rate of 0.068 kg/hr (0.15 lb/hr), and an operating schedule of 8,760 hr/yr. Nationwide mercury emissions from this source category as a whole are expected to be higher than this estimate.

Petroleum Refining

Petroleum refining involves converting crude petroleum oil into refined products, including liquified petroleum gas, gasoline, kerosene, aviation fuel, diesel fuel, fuel oils, lubricating oils, and feedstocks for the petroleum industry. Mercury is reported to be present in petroleum crude, with its content ranging from 0.023 to 30 ppmwt.¹²

As of January 1992, there were 32 oil companies in the United States with operable atmospheric crude oil distillation capacities in excess of 100,000 barrels per calendar day. These oil companies operated refineries at a total of 110 different locations. In addition, there are 72 companies with distillation capacities of less than 100,000 barrels per calendar day.⁵⁹

The operations at refineries are classified into five general categories: separation processes, petroleum conversion processes, petroleum treating processes, feedstock and product handling, and auxiliary facilities. In the separation process, crude oil is separated into its constituents (including paraffinic, naphthionic, and aromatic hydrocarbon compounds) by either atmospheric distillation, vacuum distillation, or gas processing (recovery of light ends). Conversion processes include cracking, coking, and visbreaking, which breaks large molecules into smaller molecules; isomerization and reforming processes to rearrange the structures of molecules; and polymerization and alkylation to combine small molecules into larger ones.¹

Petroleum treatment processes include hydrodesulfurization, hydrotreating, chemical sweetening, acid gas removal, and deasphalting. These treatment methods are used to stabilize and upgrade petroleum products. Feedstock and product handling includes storage, blending, loading, and unloading of petroleum crude and petroleum products. Auxiliary facilities include boilers, gas turbines, wastewater treatment facilities, hydrogen plants, cooling towers, and sulfur recovery units.¹

Control of VOC emissions from distillation, catalytic cracking, coking, blowdown system, sweetening, and asphalt blowing is achieved by flares. In some cases, the VOC-laden gas stream is also used as fuel in process heaters. Cyclones in conjunction with ESP's emissions from catalytic cracking.¹ These

control measures are expected to have little effect on mercury emissions.

The primary source of mercury emissions in petroleum refining is the separation process, although mercury emissions can also be expected in the petroleum conversion and petroleum treating processes.¹ A mercury emission factor for the fluid coking unit in the conversion step was obtained from SPECIATE but the original references could not be obtained to confirm the emission data. Therefore, the data from SPECIATE were judged to be unacceptable for use. Mercury emission data were obtained from the CARB Air Toxics Emission Inventory Report for selected processes in petroleum refining using refinery gas as the fuel. No data could be located for the nationwide volume of refining gas used for these selected processes. Therefore, no mercury emissions could be calculated for the petroleum refining industry.

Lime Manufacturing

Lime is produced in various forms, with the bulk of production yielding either hydrated lime or quicklime. In 1992, producers sold or used 16.4×10^6 Mg (18×10^6 tons) of lime produced at 113 plants in 32 States and Puerto Rico. The 1992 production represented a 4 percent increase over 1991 production. The leading domestic uses for lime include steelmaking, flue gas

The leading domestic uses for lime include steelmaking, flue gas desulfurization, pulp and paper manufacturing, water purification, and soil stabilization.⁶⁰

Table 3-16 identifies the top 10 lime-producing plants in the United States, in order of total output for 1991.⁶¹ Lime production is geographically concentrated as demonstrated by 1989 production data, when 63 percent of the U.S. total was produced in seven States (in order of decreasing production; Missouri, Ohio, Pennsylvania, Alabama, Kentucky, Texas, and Illinois).⁶²

Commercial production of the various forms of lime involves the following basic steps.

1. Quarrying raw limestone (or limestone and dolomite);
2. Stone processing or crushing and sizing in preparation for calculation;
3. Calcining the crushed stone in high temperature kilns (producing quicklime);
4. Hydrating the processed lime (to produce hydrated lime from quicklime); and
5. Miscellaneous transfer, storage, and handling processes.

Emissions from quarrying or stone extraction are largely restricted to fugitive dust, as are the emissions from stone processing, crushing, and sizing. Mercury emissions are expected to be negligible from these initial steps in lime production.

Calcining, which uses high temperature kilns to convert carbonate to oxide (removing CO₂), is the lime production step from which most mercury emissions are expected. Rotary kilns are

TABLE 3-16. LEADING 1991 U.S. LIME PRODUCING PLANTS⁶¹

Plant	Company	Location
Ste. Genevieve	Mississippi Lime Company	Ste. Genevieve County, MO
Maysville Division	Dravo Lime Company	Mason County, KY
Black River Division	Dravo Lime Company	Pendleton County, KY
Montavello Plant	Allied Lime Company	Shelby County, AL
Woodville Plant	Martin Marietta Magnesia	Sandusky County, OH
Longview Division	Dravo Lime Company	Shelby County, AL
South Chicago Plant	Marblehead Lime Company	Cook County, IL
Nelson Plant	Chemstar, Inc.	Yavapai County, AZ
Clifton Plant	Chemical Lime, Inc.	Bosque County, TX
Annville Plant	Wimpey Minerals PA, Inc.	Lebanon, PA

primarily used in the calcining step in the United States, accounting for 90 percent of domestic lime kilns. Other types of lime kilns include vertical kilns, rotary hearths, and fluidized bed kilns. During calcination, kiln temperature may reach as high as 1820°C (3300°F).¹ Because mercury has a boiling point of 350°C (660°F), most of the mercury that exists as impurities in the processed stone will likely emit as an air pollutant during calcination.

Fuels, including primarily coal, oil, petroleum coke, or natural gas, are used to provide the energy for calcination. Petroleum coke is usually used in combination with coal. Auxiliary fuels may include shredded municipal garbage, chipped rubber, or waste solvent. Mercury is expected to be present in the coal, oil, and possibly in appreciable quantities in any waste-derived fuels. Any mercury emitted from fuel combustion

will occur during the calcination step and will be discharged as vapor kiln exhausts.

The quicklime that is produced by calcination may then be hydrated gases. The hydration step may be immediately preceded by some crushing, pulverizing, and separation of dolomitic quicklime from high calcium and dolomitic quicklime. The hydration; the preliminary process steps; and handling, storage, and transfer are not likely sources for mercury emissions during lime production.

Air pollution control devices for lime kilns are primarily used to recover product or control fugitive dust and PM emissions. Calcination kiln exhaust is typically routed to a cyclone for product recovery, and then routed through a fabric filter or ESP's to collect fine particulate emissions. Other emission controls found at lime kilns include wet scrubbers (typically venturi scrubbers). How well these various air pollution control devices perform relative to vapor phase mercury emissions in lime production is not well documented. The control efficiencies are expected to be similar to those observed in the production of portland cement, however, because of the similarities in the process and control devices.

Representative estimates of mercury emissions from lime manufacturing are not possible based on the available data from lime kilns around the country. An ongoing EPA study to update AP-42, Section 8.15, on lime manufacturing emission factors has reviewed and summarized test data for lime calcining at

93 kilns.⁶³ Pollutants identified and noted in a summary of the test data did not indicate any mercury emissions and gave little or no indication that emissions tests at lime kilns have sampled and analyzed for trace metals. However, two very limited estimation efforts for mercury emissions are offered in the following discussion: one using 1983 mercury emission test data from only five Wisconsin lime plants; and, the other from a draft report on 1983 mercury emission data from a pulp and paper lime kiln, which is referenced in SPECIATE.

Emission estimates based on mass balances generated from information for mercury content in limestone from the five operating lime kilns in Wisconsin in 1983, revealed mercury emission estimates of 18 kg/yr (39 lb/yr) for all the kilns combined.⁶⁴ In 1983, these five lime plants produced 0.29×10^6 Mg (0.32×10^6 tons) of lime.⁶⁴ Assuming uniform emissions for each ton of production suggests that 5.53×10^{-5} kg (1.22×10^{-4} lb) of mercury were emitted for each Mg (ton) of lime produced. These data do not account for any differences in fuel used to heat the kilns or any differences in raw materials used. However, natural gas, which is believed to contain negligible amounts of mercury, is used to fire 33 percent of the lime kilns. Therefore, total estimated annual emissions would be reduced by 33 percent to reflect the lack of mercury emissions from natural gas.

If the Wisconsin data is extrapolated to the lime production in the United States in 1992, an annual estimate of mercury

emissions from lime kilns of 0.91 Mg/yr (1.00 ton/yr). Assuming that 33 percent of lime kilns use natural gas as their fuel source and produce no mercury emissions reduces this estimate to 0.61 Mg/yr (0.67 tons/yr). This estimate has a high level of uncertainty because material composition could vary significantly across the country, and the fuel type(s) used in Wisconsin may not be representative of those used nationally.

3.4.3 Miscellaneous Sources

Miscellaneous sources are sources that are not readily classified as combustion or manufacturing sources of mercury or are sources that once emitted mercury but currently do not. These sources account for an estimated 1.3 Mg/yr (1.4 tons/yr) of mercury emissions generated in the United States and include geothermal power plants, pigments, oil shale retorting, mercury catalysts, and explosives.

Geothermal Power Plants

Geothermal power plants are either dry-steam or water-dominated and emitted an estimated 1.3 Mg (1.4 tons) of mercury in 1992. For dry-steam plants, steam is pumped from geothermal reservoirs to turbines at a temperature of about 180°C (360°F) and a pressure of 7.9 bars absolute.¹ For water-dominated plants, water exists in the producing strata at a temperature of

approximately 270°C (520°F) and at a pressure slightly higher than hydrostatic.¹ As the water flows towards the surface, pressure decreases and steam is formed, which is used to operate the turbines. There are currently 18 geothermal power plants operating in the United States.⁶⁵ Table 3-17 lists the names, locations, and capacities of these facilities.

Mercury can be expected to be present in the steam and water because it is recovered from beneath the earth's surface. However, no data on the mercury content of steam or water cycled through geothermal facilities are available. Likewise, no information exists on emission control systems for geothermal power plants.¹

Mercury emissions at geothermal power plants are documented to result from two sources: off-gas ejectors and cooling towers. Table 3-18 contains the mercury emission factors for these two sources, which are based on measurements taken in 1977.⁶⁶ No process data are given in the documentation containing the test results, and the primary draft source of these data could not be obtained in order to verify the validity of the emission factors.¹ If significant process modifications or changes in control strategies have been incorporated since 1977, the emission factors reported in Table 3-18 may no longer be valid.

Multiplying the emission factors in Table 3-18 by the total capacity shown in Table 3-18 (assuming that geothermal power plants operate 24 hr/d, 365 d/yr) gives a mercury emission estimate of 1.3 Mg (1.4 tons) for geothermal power plants in

TABLE 3-17. 1992 U.S. GEOTHERMAL POWER PLANTS⁶²

Facility	Type	Net Capacity (MW)
The Geysers, CA	Dry-steam	1,805.7
Salton Sea, CA	Water-dominated	218.3
Heber, CA	Water-dominated	47.0
East Mesa, CA	Water-dominated	106.0
Coso, CA	Water-dominated	247.5
Casa Diablo, CA	Water-dominated	34.0
Amedee, CA	Water-dominated	2.0
Wendel, CA	Water-dominated	0.7
Dixie Valley, NV	Water-dominated	57.0
Steamboat Hot Springs, NV	Water-dominated	19.3
Beowawe Hot Springs, NV	Water-dominated	16.7
Desert Peak, NV	Water-dominated	9.0
Wabuska Hot Springs, NV	Water-dominated	1.7
Soda Lake, NV	Water-dominated	15.7
Stillwater, NV	Water-dominated	12.5
Empire and San Emidio, NV	Water-dominated	3.2
Roosevelt Hot Springs, UT	Water-dominated	20.0
Cove Fort, UT	Water-dominated	12.1
Total		2,628.4

TABLE 3-18. MERCURY EMISSION FACTORS FOR GEOTHERMAL POWER PLANTS⁶⁶

Source	Emission factor range, g/Mwe/hr	Average emission factor	
		g/Mwe/hr	lb/Mwe/hr
Off-gas ejectors	0.00075 - 0.02	0.00725	0.00002
Cooling tower exhaust	0.026 - 0.072	0.05	0.0001

1992. However, because the emission factors used to generate this estimate have limited reliability, this emission estimate has a high degree of uncertainty.

Turf Products

The U.S. EPA's Office of Pesticides Program (OPP) indicates that mercuric compounds that could be used as turf products are primarily restricted to fungistatics. Turf product registration information for mercury containing fungicides is included in the following discussion.

Potential or past uses of mercury-containing fungistatics, include use on agricultural lands, sod farms, golf courses, and even lawns. However, OPP indicates that golf courses are the primary areas for fungistatic use, which is typically confined to putting greens and tee areas. No information on application rates was available from OPP. Two products are still registered. Both products are produced by the same manufacturer and contain mercuric chloride and mercurous chloride as the active ingredients, though at differing concentrations. Calo-Gran contains 18 percent mercurous chloride and 0.9 percent mercuric chloride. Calo-Clor contains 60 percent mercurous chloride and 30 percent mercuric chloride.

Data from an OPP source indicate total chemical production for products registered as containing mercuric chloride as:⁶⁷

1988	10,283 kg (22,671 lb)
1989	9,497 kg (20,937 lb)
1990	8,189 kg (18,053 lb)

The document also cites OPP as indicating total chemical production for products registered as containing mercurous chloride as:

1988	20,567 kg (45,342 lb)
1989	18,977 kg (41,873 lb)
1990	16,377 kg (36,105 lb)

Combining the two production estimates into "total mercury-containing products registered with OPP," yields the following:

1988	30,850 kg (68,013 lb)
1989	28,490 (62,810 lb)
1990	24,567 (54,158 lb)

Information is insufficient to estimate mercury emissions to the atmosphere from turf products application.

Pigments, Oil Shale Retorting, Mercury Catalysts, and Explosives

Pigments, oil shale retorting, mercury catalysts, and explosives were once sources of mercury emissions but now little or no longer produce emissions. Domestic production of mercury-containing pigments ceased in 1988.¹⁶ There are currently no oil shale retorts in the United States.⁶⁸ It was assumed that very few facilities still use mercury catalysts because no emissions of mercury from mercury catalysts were found.¹ Commercial mercury use in explosives ceased to exist prior to 1970.¹⁶

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SECTION 4.0

EMISSIONS SUMMARY

Mercury emissions in the United States fall into two major categories: natural (or nonanthropogenic) sources and anthropogenic sources. Anthropogenic sources may be further categorized as (1) area sources and (2) point sources. Table 4-1 shows estimated mercury emissions with breakdowns for natural, area, and point sources. Note that for the natural sources, no data are available for United States emission levels, and the estimate represents worldwide emissions.

The annual emission estimates presented in Table 4-1 should be interpreted cautiously. As described in Section 3, an emission factor-based approach was used to generate most of the estimates shown in Table 4-1. With the exception of the emission factors used for some of the combustion sources, the emission factors were generated from limited data. Concerns about both the quality of the data used to generate the estimates and the potential that the paucity of the data could make them nonrepresentative, limits the reliability of the emission factors and the aggregated emission estimates.

While these emission estimates have limitations, they do provide insight into the relative magnitude of emissions from different groups of sources. Figure 4-1 shows the distribution of estimated emissions among the four major classes of sources of anthropogenic emissions (area sources, combustion point sources, manufacturing point sources, and miscellaneous point sources). Figures 4-2 through 4-4 show the distributions among individual source categories for the first three of these four classes; these three classes represent well over 99 percent of the total anthropogenic emissions.

Of the estimated 309 Mg (341 tons) of mercury emitted annually into the atmosphere by anthropogenic sources, approximately 84 percent is from combustion point sources, 10 percent is from manufacturing point sources, and 5 percent is

TABLE 4-1. ESTIMATED MERCURY EMISSION RATES BY CATEGORY

Source of mercury ^a	Mg/yr ^b	tons/yr ^b
Natural sources (global) ^c	3,000	3,300
Area sources	18	20
Mobile sources	4.5	5.0
Lamp breakage	8.0	8.8
Paint use	4.0	4.4
General lab use	0.4	0.4
Dental prep and use	0.5	0.6
Crematories	0.4	0.4
Point sources	291	321
Combustion sources	259	285
Utility boilers	110	121
Coal	(106)	(117)
Oil	(4)	(4.4)
Commercial/industrial	28	30
Residential	3.2	3.5
MWC's	57.7	63.5
MWI's	58.8	64.7
SSI's	1.7	1.8
Wood ^d	0.3	0.3
Manufacturing sources	32.3	35.6
Chlor-alkali	6.6	7.3
Portland cement	5.9	6.5
Batteries	0.08	0.09
Electrical apparatus	0.2	0.2
Instruments	0.6	0.7
Primary Hg production	Negligible	Negligible
Secondary Hg production	6.7	7.4
Mercury compounds	Negligible	Negligible
Carbon black	0.2	0.2
Byproduct coke	Negligible	Negligible
Primary lead ^e	8.2	9.0
Primary copper	0.6	0.7
Refineries	Negligible	Negligible
Lime manufacturing	0.6	0.7
Miscellaneous sources	1.3	1.4
Geothermal power	1.3	1.4
Turf products	Not available	Not available
Pigments, oil, etc.	Negligible	Negligible

^aMWC = Municipal waste combustor; MWI = medical waste incinerator; SSI = sewage sludge incinerator.

^bNumbers may not add exactly because of rounding.

^cWorldwide emissions, totals unavailable for the United States.

^dIncludes wood boilers only; does not include residential wood combustion (wood stoves).

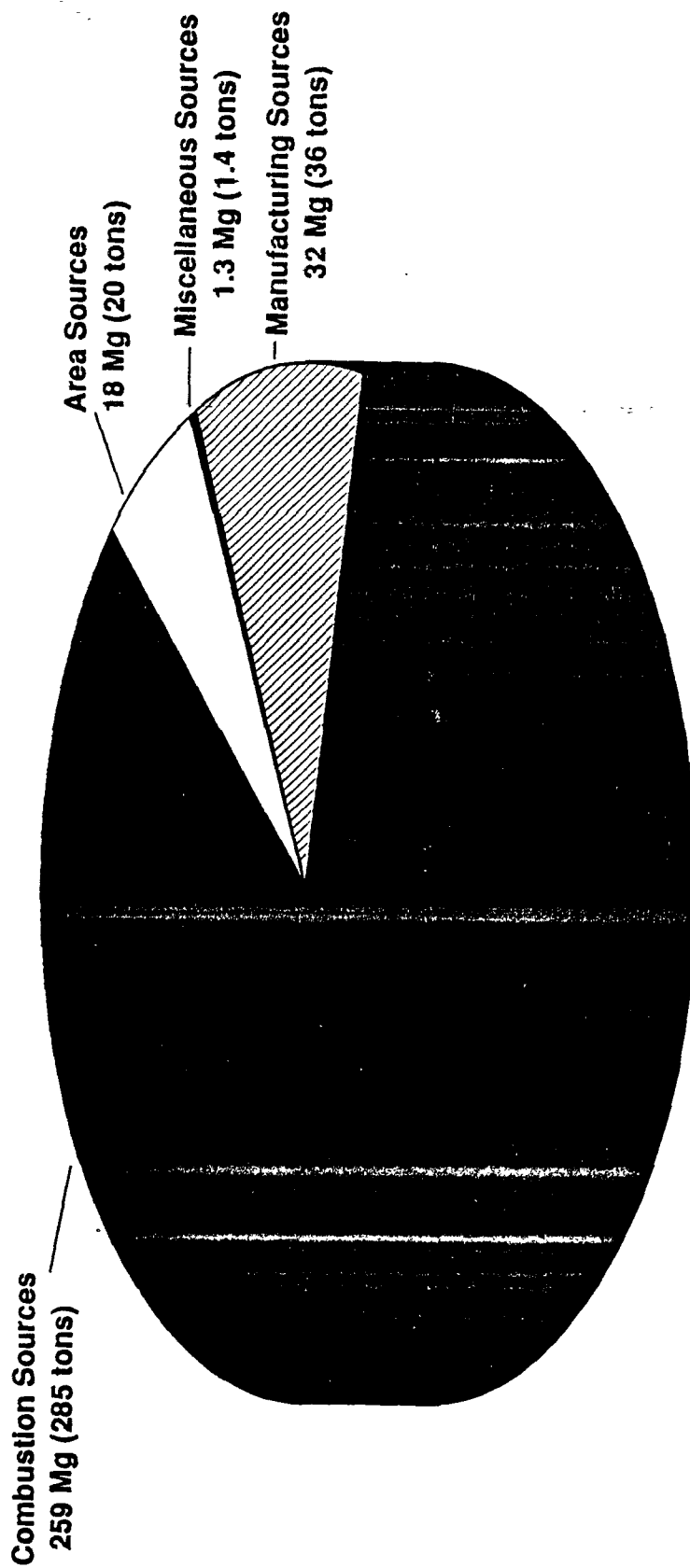


Figure 4-1. Estimated annual mercury emissions.

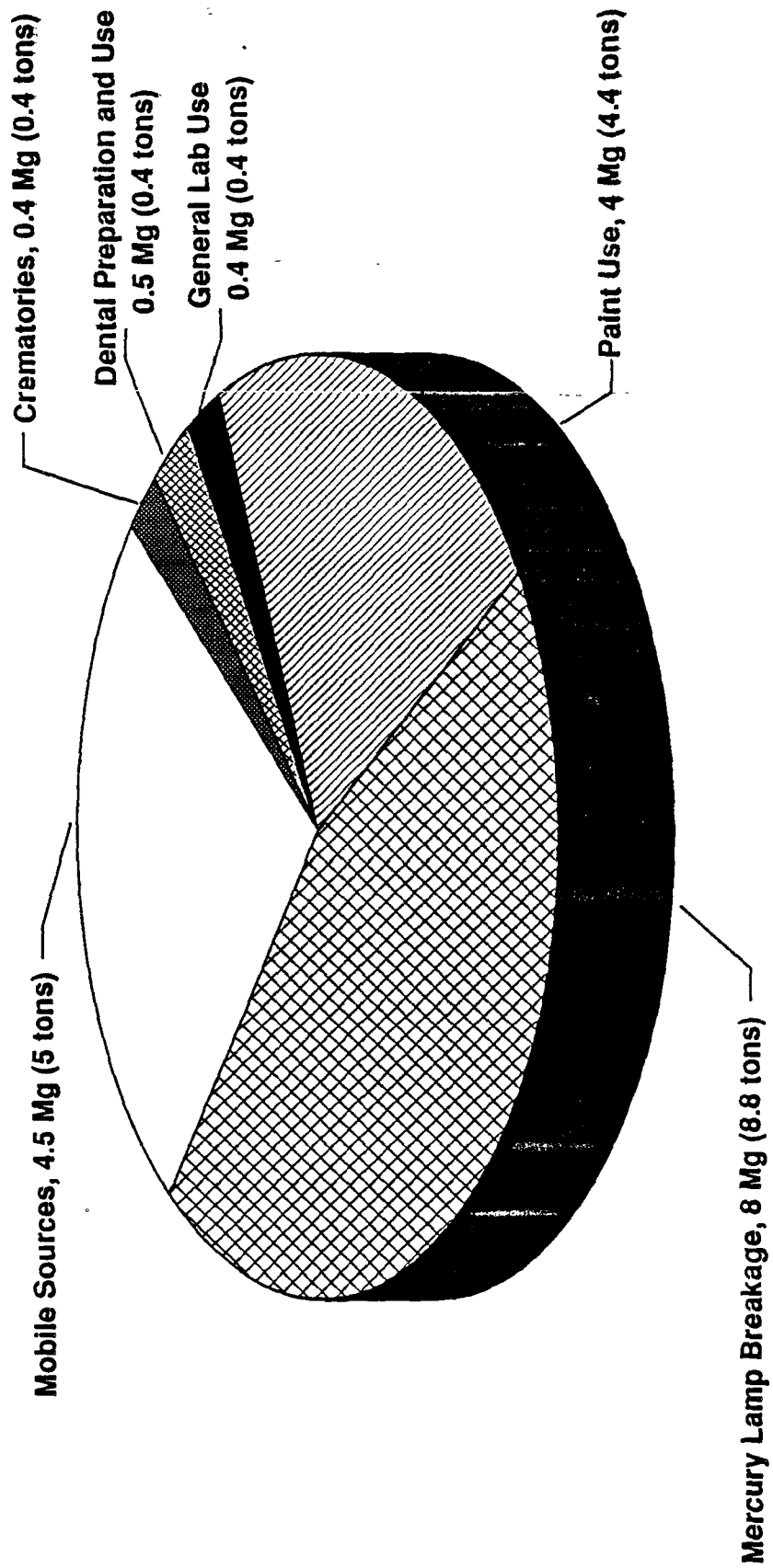
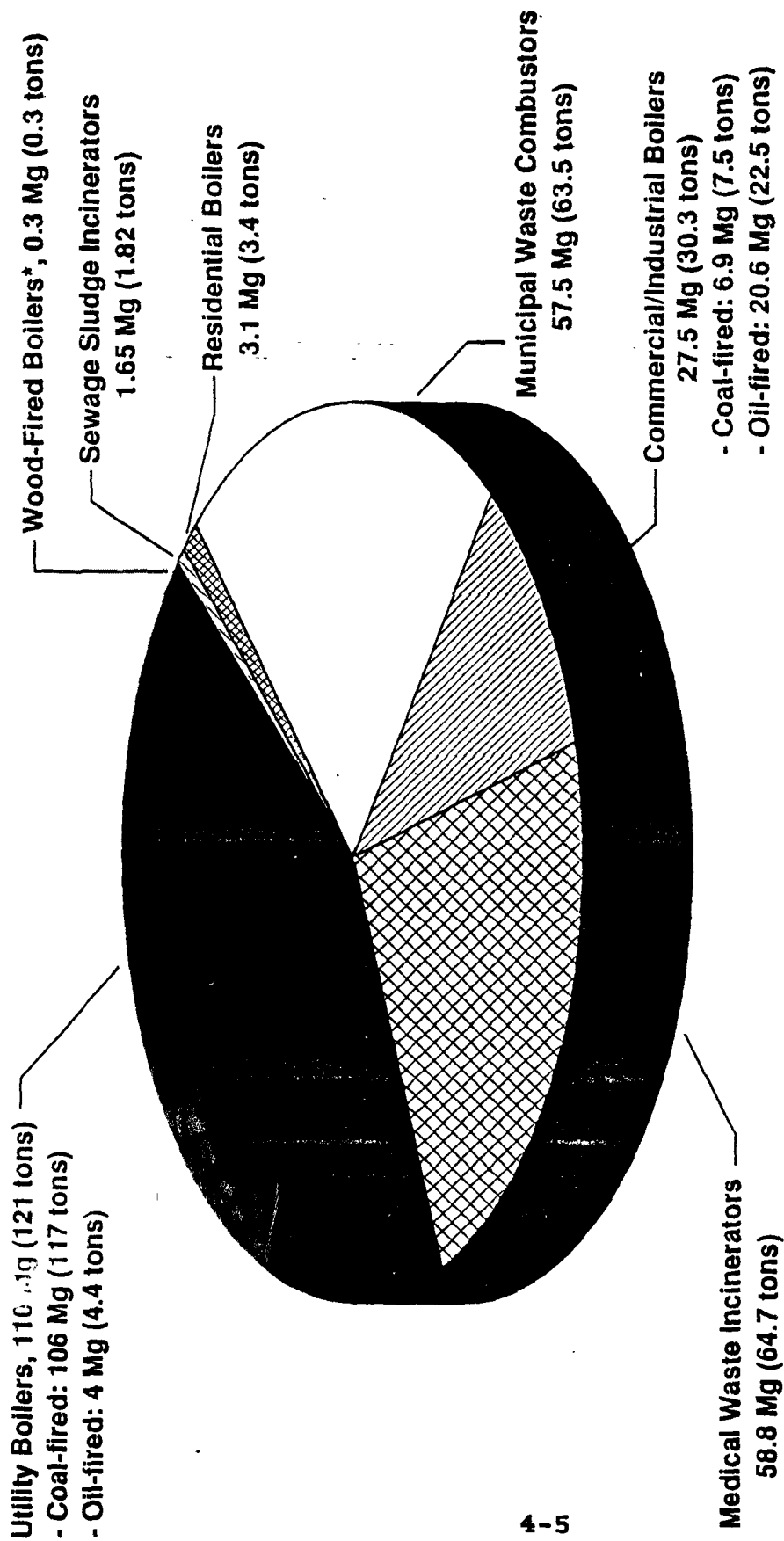
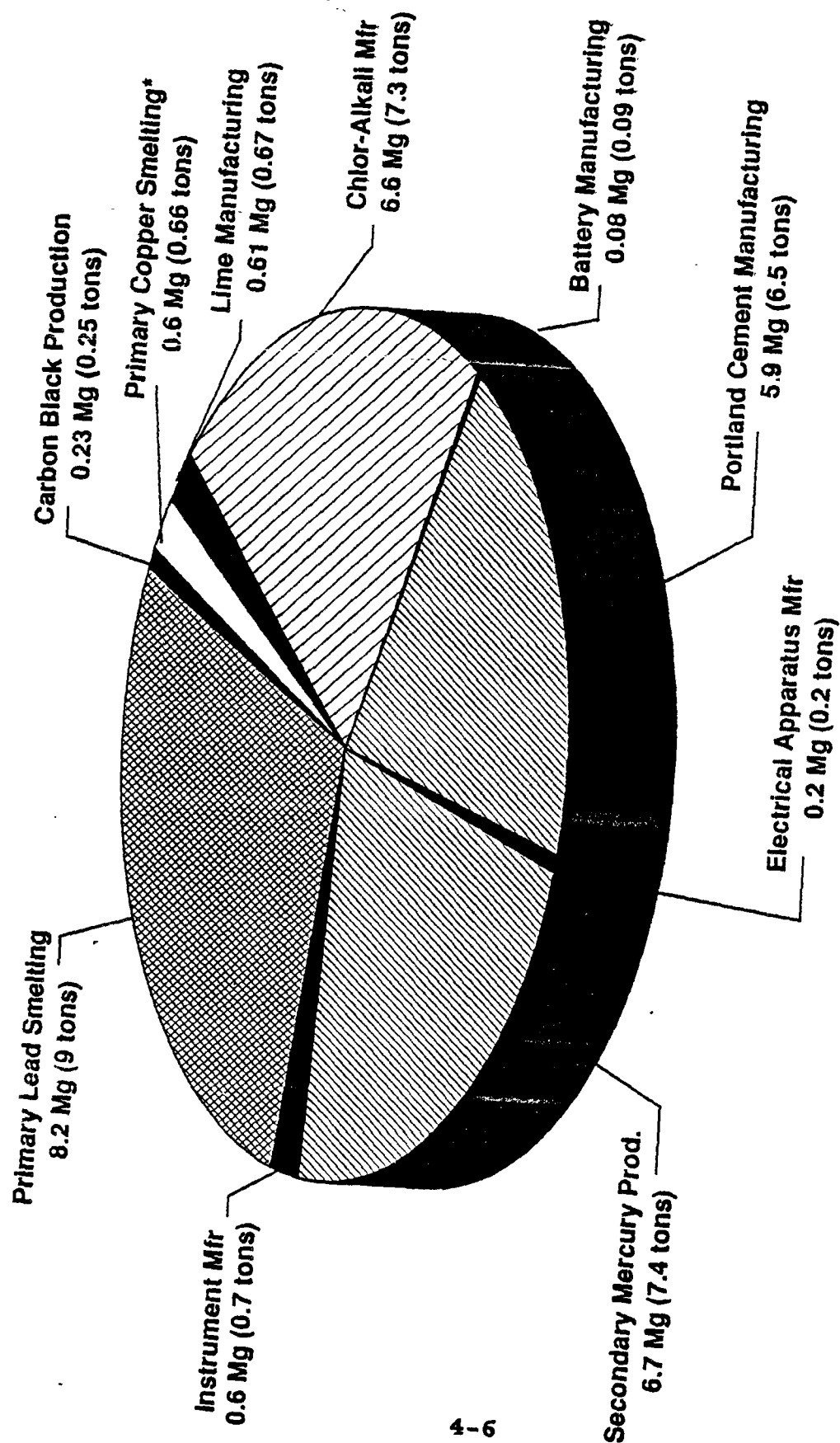


Figure 4-2. Estimated annual mercury emissions from area sources.



* Wood boilers only; does not include residential woodstoves.

Figure 4-3. Estimated annual mercury emissions from combustion point sources.



* Estimate includes one smelter only.

Figure 4-4. Estimated annual mercury emissions from manufacturing point sources.

from area sources. Further examination shows that four specific source categories account for approximately 83 percent of the total anthropogenic emissions--utility boilers (36 percent), municipal and medical waste incineration (19 percent each), and commercial/industrial boilers (9 percent).

APPENDIX A.

INFORMATION ON LOCATIONS OF AND EMISSIONS FROM COMBUSTION SOURCES

**TABLE A-1. ESTIMATES OF COAL, NATURAL GAS, AND OIL CONSUMPTION
IN THE COMMERCIAL/INDUSTRIAL SECTOR PER STATE
(Trillion Btu)**

State	Coal			Natural gas	Petroleum
	Bituminous coal and lignite	Anthracite	Total		Distillate fuel
Alabama	144.6	0.4	145	185.0	45.6
Alaska	5.1	0.0	5.1	277.2	16.0
Arizona	13.3	0.0	13.3	48.3	21.1
Arkansas	5.8	0.0	5.8	153.6	23.4
California	65.1	0.0	65.1	900.6	138.2
Colorado	16.2	0.0	16.2	133.4	18.1
Connecticut	0.0	0.1	0.1	56.7	23
Delaware	5.8	0.0	5.8	21.4	4.5
Dist. of Col.	1.1	0.0	1.1	13.6	2.9
Florida	30.1	0.1	30.2	133.7	39.2
Georgia	56.5	*	56.5	217.2	31.1
Hawaii	0.7	0.0	0.7	2.4	7.7
Idaho	9.6	0.0	9.6	32.8	17.9
Illinois	154.5	0.1	154.6	486.5	53.4
Indiana	350.6	0.1	350.7	300.8	32.7
Iowa	56.2	0.7	56.9	135.2	27.0
Kansas	3.8	0.0	3.8	213.8	24.4
Kentucky	89	0.5	89.5	107.8	34.2
Louisiana	16	0.0	16	1242.4	84.8
Maine	6.0	0.1	6.1	3.7	13.9
Maryland	58.1	*	58.1	88.2	22.3
Massachusetts	2.3	0.4	2.7	98.1	49.0
Michigan	122.2	*	122.2	468.3	29.9
Minnesota	25.9	0.0	25.9	167.0	33.0
Mississippi	6.3	0.0	6.3	129.8	36.4

State	Coal			Natural gas	Petroleum
	Bituminous coal and lignite	Anthracite	Total		Distillate fuel
Missouri	34.5	0.0	34.5	115.1	23.6
Montana	4.7	0.0	4.7	24.5	16.9
Nebraska	4.6	*	4.6	61.3	25.5
Nevada	3.9	*	3.9	23.2	21.0
New Hampshire	0.5	0.3	0.8	8.4	9.4
New Jersey	6.8	0.3	7.1	211.2	57.2
New Mexico	1.0	0.0	1	115.0	16.4
New York	84.0	2.1	86.1	305.7	95.6
North Carolina	77.1	0.0	77.1	121.2	28.3
North Dakota	87.5	0.0	87.5	22.3	16.0
Ohio	258.0	0.3	258.3	444.7	39.5
Oklahoma	12.7	0.0	12.7	350.7	21.1
Oregon	1.4	0.0	1.4	71.0	24.4
Pennsylvania	382.3	15.1	397.4	393.5	69.3
Rhode Island	0.0	0.1	0.1	8.3	5.3
South Carolina	57.9	0.2	58.1	105.1	14.9
South Dakota	3.9	0.0	3.9	14.7	13.1
Tennessee	100.0	0.3	100.3	158.7	20.7
Texas	61.7	*	61.7	2373.3	169.9
Utah	52.7	0.0	52.7	77.8	10.9
Vermont	0.0	0.1	0.1	3.9	6
Virginia	121.4	0.3	121.7	121.1	31.6
Washington	6.1	0.0	6.1	120.7	38.2
West Virginia	127.0	0.1	127.1	84.6	18.2
Wisconsin	47.2	0.1	47.3	189.4	31.6
Wyoming	42.9	0.0	42.9	83.1	14.5
United States	2824.6	21.8	2842.5	11226.0	1668.8

*Number less than 0.05

Source: U.S. Department of Energy. State Energy Data Report. Report No. DOE/EIA-0214(40). May 1992.

**TABLE A-2. ESTIMATES OF MERCURY EMISSIONS FROM COAL-FIRED
COMMERCIAL/INDUSTRIAL BOILERS ON A PER-STATE BASIS FOR 1991**

State	Coal consumption, trillion Btu			Mercury emissions ^a	
	Bituminous coal and lignite	Anthracite	Total	Ton/Yr ^c	Mg/Yr
Alabama	144.6	0.4	145	1.2	1.1
Alaska	5.1	0.0	5.1	0.0	0.0
Arizona	13.3	0.0	13.3	0.1	0.1
Arkansas	5.8	0.0	5.8	0.0	0.0
California	65.1	0.0	65.1	0.5	0.5
Colorado	16.2	0.0	16.2	0.1	0.1
Connecticut	0.0	0.1	0.1	0.0	0.0
Delaware	5.8	0.0	5.8	0.0	0.0
Dist. of Col.	1.1	0.0	1.1	0.0	0.0
Florida	30.1	0.1	30.2	0.2	0.2
Georgia	56.5	b	56.5	0.5	0.4
Hawaii	0.7	0.0	0.7	0.0	0.0
Idaho	9.6	0.0	9.6	0.1	0.1
Illinois	154.5	0.1	154.6	1.2	1.1
Indiana	350.6	0.1	350.7	2.8	2.6
Iowa	56.2	0.7	56.9	0.5	0.4
Kansas	3.8	0.0	3.8	0.0	0.0
Kentucky	89	0.5	89.5	0.7	0.7
Louisiana	16	0.0	16	0.1	0.1
Maine	6.0	0.1	6.1	0.0	0.0
Maryland	58.1	b	58.1	0.5	0.4
Massachusetts	2.3	0.4	2.7	0.0	0.0
Michigan	122.2	b	122.2	1.0	0.9
Minnesota	25.9	0.0	25.9	0.2	0.2
Mississippi	6.3	0.0	6.3	0.1	0.0
Missouri	34.5	0.0	34.5	0.3	0.3
Montana	4.7	0.0	4.7	0.0	0.0
Nebraska	4.6	b	4.6	0.0	0.0
Nevada	3.9	b	3.9	0.0	0.0
New Hampshire	0.5	0.3	0.8	0.0	0.0
New Jersey	6.8	0.3	7.1	0.1	0.1
New Mexico	1.0	0.0	1	0.0	0.0
New York	84.0	2.1	86.1	0.7	0.6
North Carolina	77.1	0.0	77.1	0.6	0.6
North Dakota	87.5	0.0	87.5	0.7	0.6
Ohio	258.0	0.3	258.3	2.1	1.9
Oklahoma	12.7	0.0	12.7	0.1	0.1
Oregon	1.4	0.0	1.4	0.0	0.0
Pennsylvania	382.3	15.1	397.4	3.2	2.9
Rhode Island	0.0	0.1	0.1	0.0	0.0
South Carolina	57.9	0.2	58.1	0.5	0.4
South Dakota	3.9	0.0	3.9	0.0	0.0
Tennessee	100.0	0.3	100.3	0.8	0.7
Texas	61.7	b	61.7	0.5	0.4
Utah	52.7	0.0	52.7	0.4	0.4
Vermont	0.0	0.1	0.1	0.0	0.0
Virginia	121.4	0.3	121.7	1.0	0.9
Washington	6.1	0.0	6.1	0.0	0.0
West Virginia	127.0	0.1	127.1	1.0	0.9
Wisconsin	47.2	0.1	47.3	0.4	0.3
Wyoming	42.9	0.0	42.9	0.3	0.3
United States	2824.6	21.8	2842.5	22.8	20.7

^aMercury emission factors of 16 lb Hg/trillion Btu and 18 lb Hg/trillion Btu were used for bituminous and anthracite coal, respectively. No control of emissions from commercial/industrial boilers was assumed.

^bNumber less than 0.05.

^cEmissions less than 100 pounds/year for an entire State are reported as zero.

**TABLE A-3. ESTIMATES OF MERCURY EMISSIONS FROM OIL-FIRED
COMMERCIAL/INDUSTRIAL BOILERS ON A PER-STATE BASIS FOR 1991**

State	Petroleum consumption, trillion Btu	Mercury emissions*	
	Distillate fuel	Ton/Yr	Mg/Yr
Alabama	45.6	0.16	0.15
Alaska	16.0	0.06	0.05
Arizona	21.1	0.08	0.07
Arkansas	23.4	0.08	0.08
California	138.2	0.50	0.45
Colorado	18.1	0.07	0.06
Connecticut	23	0.08	0.08
Delaware	4.5	0.02	0.01
Dist. of Col.	2.9	0.01	0.01
Florida	39.2	0.14	0.13
Georgia	31.1	0.11	0.10
Hawaii	7.7	0.03	0.03
Idaho	17.9	0.06	0.06
Illinois	53.4	0.19	0.17
Indiana	32.7	0.12	0.11
Iowa	27.0	0.10	0.09
Kansas	24.4	0.09	0.08
Kentucky	34.2	0.12	0.11
Louisiana	84.8	0.31	0.28
Maine	13.9	0.05	0.05
Maryland	22.3	0.08	0.07
Massachusetts	49.0	0.18	0.16
Michigan	29.9	0.11	0.10
Minnesota	33.0	0.12	0.11
Mississippi	36.4	0.13	0.12
Missouri	23.6	0.08	0.08
Montana	16.9	0.06	0.06
Nebraska	25.5	0.09	0.08
Nevada	21.0	0.08	0.07
New Hampshire	9.4	0.03	0.03
New Jersey	57.2	0.21	0.19
New Mexico	16.4	0.06	0.05
New York	95.6	0.34	0.31
North Carolina	28.3	0.10	0.09
North Dakota	16.0	0.06	0.05
Ohio	39.5	0.14	0.13
Oklahoma	21.1	0.08	0.07
Oregon	24.4	0.09	0.08
Pennsylvania	69.3	0.25	0.23
Rhode Island	5.3	0.02	0.02
South Carolina	14.9	0.05	0.05
South Dakota	13.1	0.05	0.04
Tennessee	20.7	0.07	0.07
Texas	169.9	0.61	0.56
Utah	10.9	0.04	0.04
Vermont	6	0.02	0.02
Virginia	31.6	0.11	0.10
Washington	38.2	0.14	0.13
West Virginia	18.2	0.07	0.06
Wisconsin	31.6	0.11	0.10
Wyoming	14.5	0.05	0.05
United States	1,668.8	6.01	5.46

*Mercury emission factor for distillate oil is 7.2 lb Hg/trillion Btu. Calculation was performed assuming that all pollution control devices provide no mercury reduction.

*Number less than 0.05.

**TABLE A-4. ESTIMATES OF COAL, NATURAL GAS, AND OIL CONSUMPTION
IN THE RESIDENTIAL SECTOR PER STATE (Trillion Btu)**

State	Coal			Natural gas	Petroleum distillate fuel
	Bituminous coal and lignite	Anthracite	Total		
Alabama	0.9	0.0	0.9	46.7	0.1
Alaska	2.7	0.0	2.7	13.4	10.2
Arizona	a	0.0	0	29.3	0.1
Arkansas	a	0.0	0	39.5	a
California	0.2	0.0	0.2	530.8	1.3
Colorado	0.4	0.0	0.4	92.4	0.2
Connecticut	0.0	0.2	0.2	38.7	66.6
Delaware	0.2	0.0	0.2	7.4	5.6
Dist. of Col.	0.6	0.0	0.6	15.3	0.9
Florida	a	0.0	0	14.1	1.4
Georgia	0.2	0.0	0.2	92.7	1.5
Hawaii	0.0	0.0	0	0.6	a
Idaho	0.5	0.0	0.5	8.8	3.1
Illinois	2.1	a	2.1	451.9	7.0
Indiana	4.3	a	4.3	143.1	10.0
Iowa	2.0	a	2	71.9	4.6
Kansas	a	0.0	0	71.3	0.1
Kentucky	1.3	0.0	1.3	58.5	3.8
Louisiana	0	0.0	0	55.6	0.1
Maine	0.3	0.2	0.5	0.7	29.3
Maryland	0.4	0.1	0.5	68.2	25.0
Massachusetts	0.3	0.4	0.7	110.5	100.7
Michigan	2.3	0.0	2.3	342.2	24.3
Minnesota	1.1	0.0	1.1	107.4	18.8
Mississippi	0.0	0.0	0	25.9	a
Missouri	2.2	0.0	2.2	117.2	2.1
Montana	0.4	0.0	0.4	17.3	1.7
Nebraska	a	0.0	0	40.8	1.0
Nevada	a	a	a	17.7	1.4
New Hampshire	0.0	0.2	0.2	6.0	19.8
New Jersey	0.0	0.2	0.2	176.0	67.0
New Mexico	a	0.0	0	29.7	0.1
New York	1.2	2.0	3.2	347.8	154.5
North Carolina	1.4	0.0	1.4	36.1	20.7
North Dakota	0.7	0.0	0.7	9.5	4.9
Ohio	5.5	a	5.5	321.0	23.8
Oklahoma	0.0*	0.0	0	66.9	a
Oregon	a	0.0	0	23.9	10.4
Pennsylvania	2.9	14.7	17.6	248.9	99.1
Rhode Island	0.0	0.1	0.1	18.2	14.9
South Carolina	0.1	0.0	0.1	18.9	5.9
South Dakota	a	0.0	0	10.4	4.7
Tennessee	1.8	0.1	1.9	48.0	1.4
Texas	0.1	0.0	0.1	220.8	a
Utah	2.2	0.0	2.2	47.3	0.8
Vermont	0.0	0.1	0.1	2.1	11.2
Virginia	2.1	a	2.1	53.6	29.8
Washington	0.5	0.0	0.5	41.6	17.5
West Virginia	1.6	0.0	1.6	34.9	3.3
Wisconsin	a	a	0	114.7	27.0
Wyoming	0.9	0.0	0.9	12.6	0.1
United States	43.4	18.3	61.7	4,518.8	837.8

*Number less than 0.05.

Source: U.S. Department of Energy. State Energy Data Report. Report No. DOE/EIA-0214(40). May 1992.

**TABLE A-5. ESTIMATES OF MERCURY EMISSIONS FROM
COAL-FIRED RESIDENTIAL BOILERS ON A PER-STATE BASIS FOR 1991**

State	Coal consumption, trillion Btu			Mercury emissions ^a	
	Bituminous coal and lignite	Anthracite	Total	Ton/Yr	Mg/Yr
Alabama	0.9	0.0	0.9	0.007	0.007
Alaska	2.7	0.0	2.7	0.022	0.020
Arizona	b	0.0	0	0.000	0.000
Arkansas	b	0.0	0	0.000	0.000
California	0.2	0.0	0.2	0.002	0.001
Colorado	0.4	0.0	0.4	0.003	0.003
Connecticut	0.0	0.2	0.2	0.002	0.002
Delaware	0.2	0.0	0.2	0.002	0.001
Dist. of Col.	0.6	0.0	0.6	0.005	0.004
Florida	b	0.0	0	0.000	0.000
Georgia	0.2	0.0	0.2	0.002	0.001
Hawaii	0.0	0.0	0	0.000	0.000
Idaho	0.5	0.0	0.5	0.004	0.004
Illinois	2.1	b	2.1	0.017	0.015
Indiana	4.3	b	4.3	0.034	0.031
Iowa	2.0	b	2	0.016	0.015
Kansas	b	0.0	0	0.000	0.000
Kentucky	1.3	0.0	1.3	0.010	0.009
Louisiana	0	0.0	0	0.000	0.000
Maine	0.3	0.2	0.5	0.004	0.004
Maryland	0.4	0.1	0.5	0.004	0.004
Massachusetts	0.3	0.4	0.7	0.006	0.005
Michigan	2.3	0.0	2.3	0.018	0.017
Minnesota	1.1	0.0	1.1	0.009	0.008
Mississippi	0.0	0.0	0	0.000	0.000
Missouri	2.2	0.0	2.2	0.018	0.016
Montana	0.4	0.0	0.4	0.003	0.003
Nebraska	b	0.0	0	0.000	0.000
Nevada	b	b	b	0.000	0.000
New Hampshire	0.0	0.2	0.2	0.002	0.002
New Jersey	0.0	0.2	0.2	0.002	0.002
New Mexico	b	0.0	0	0.000	0.000
New York	1.2	2.0	3.2	0.028	0.025
North Carolina	1.4	0.0	1.4	0.011	0.010
North Dakota	0.7	0.0	0.7	0.006	0.005
Ohio	5.5	b	5.5	0.044	0.040
Oklahoma	0.0	0.0	0	0.000	0.000
Oregon	b	0.0	0	0.000	0.000
Pennsylvania	2.9	14.7	17.6	0.156	0.141
Rhode Island	0.0	0.1	0.1	0.001	0.001
South Carolina	0.1	0.0	0.1	0.001	0.001
South Dakota	b	0.0	0	0.000	0.000
Tennessee	1.8	0.1	1.9	0.015	0.014
Texas	0.1	0.0	0.1	0.001	0.001
Utah	2.2	0.0	2.2	0.018	0.016
Vermont	0.0	0.1	0.1	0.001	0.001
Virginia	2.1	b	2.1	0.017	0.015
Washington	0.5	0.0	0.5	0.004	0.004
West Virginia	1.6	0.0	1.6	0.013	0.012
Wisconsin	b	b	0	0.000	0.000
Wyoming	0.9	0.0	0.9	0.007	0.007
United States	43.4	18.3	61.7	0.512	0.465

^aMercury emission factors of 16 lb Hg/trillion Btu and 18 lb Hg/trillion Btu were used for bituminous and anthracite coal, respectively. No control of emissions from residential boilers was assumed.

^bNumber less than 0.05.

**TABLE A-6. ESTIMATE OF MERCURY EMISSIONS FROM OIL-FIRED
RESIDENTIAL BOILERS ON A PER-STATE BASIS FOR 1991**

State	Petroleum consumption, trillion Btu	Mercury emissions*	
	Distillate fuel	Ton/Yr	Mg/Yr
Alabama	0.1	0.0004	0.0003
Alaska	10.2	0.0367	0.0334
Arizona	0.1	0.0004	0.0003
Arkansas	*	0.0000	0.0000
California	1.3	0.0047	0.0043
Colorado	0.2	0.0007	0.0007
Connecticut	66.6	0.2398	0.2180
Delaware	5.6	0.0202	0.0183
Dist. of Col.	0.9	0.0032	0.0029
Florida	1.4	0.0050	0.0046
Georgia	1.5	0.0054	0.0049
Hawaii	*	0.0000	0.0000
Idaho	3.1	0.0112	0.0101
Illinois	7.0	0.0252	0.0229
Indiana	10.0	0.0360	0.0327
Iowa	4.6	0.0166	0.0151
Kansas	0.1	0.0004	0.0003
Kentucky	3.8	0.0137	0.0124
Louisiana	0.1	0.0004	0.0003
Maine	29.3	0.1055	0.0959
Maryland	25.0	0.0900	0.0818
Massachusetts	100.7	0.3625	0.3296
Michigan	24.3	0.0875	0.0795
Minnesota	18.8	0.0677	0.0615
Mississippi	*	0.0000	0.0000
Missouri	2.1	0.0076	0.0069
Montana	1.7	0.0061	0.0056
Nebraska	1.0	0.0036	0.0033
Nevada	1.4	0.0050	0.0046
New Hampshire	19.8	0.0713	0.0648
New Jersey	67.0	0.2412	0.2193
New Mexico	0.1	0.0004	0.0003
New York	154.5	0.5562	0.5056
North Carolina	20.7	0.0745	0.0677
North Dakota	4.9	0.0176	0.0160
Ohio	23.8	0.0857	0.0779
Oklahoma	*	0.0000	0.0000
Oregon	10.4	0.0374	0.0340
Pennsylvania	99.1	0.3568	0.3243
Rhode Island	14.9	0.0536	0.0488
South Carolina	5.9	0.0212	0.0193
South Dakota	4.7	0.0169	0.0154
Tennessee	1.4	0.0050	0.0046
Texas	*	0.0000	0.0000
Utah	0.8	0.0029	0.0026
Vermont	11.2	0.0403	0.0367
Virginia	29.8	0.1073	0.0975
Washington	17.5	0.0630	0.0573
West Virginia	3.3	0.0119	0.0108
Wisconsin	27.0	0.0972	0.0884
Wyoming	0.1	0.0004	0.0003
United States	837.8	3.02	2.74

*Mercury emission factor for distillate oil is 7.2 lb Hg/trillion Btu. Calculations performed under the assumption that air pollution control devices provide no mercury reduction.

*Number less than 0.05.

TABLE A-7. EXISTING MWC FACILITIES (As of December, 1991)

Facility	City	State	Capacity	
			tons/yr	Mg/yr
Parsons (SOHIO)	Endicott	AK	4,380	3,982
Juneau	Juneau	AK	25,550	23,227
Kypanuk (ARCO)	Kyparuk	AK	4,380	3,982
Prudhoe Bay	Prudhoe Bay	AK	36,500	33,182
Shemya (Air Force Base)	Shemya	AK	7,300	6,636
Sitka (Sheldon Jackson College)	Sitka	AK	9,125	8,295
Huntsville	Huntsville	AL	251,850	228,955
Tuscaloosa	Tuscaloosa	AL	109,500	99,545
Augusta	Augusta	AR	7,300	6,636
Batesville	Batesville	AR	36,500	33,182
Blytheville	Blytheville	AR	25,550	23,227
Kensett	Kensett	AR	5,475	4,977
North Little Rock	North Little Rock	AR	36,500	33,182
Osceola	Osceola	AR	18,250	16,591
Stuttgart	Stuttgart	AR	21,900	19,909
Los Angeles County	Commerce	CA	138,700	126,091
Long Beach (SERRF)	Long Beach	CA	503,700	457,909
Stanislaus County	Modesto	CA	292,000	265,455
Bridgeport	Bridgeport	CT	821,250	746,591
Bristol	Bristol	CT	237,250	215,682
MID-Connecticut	Hartford	CT	730,000	663,636
New Cannan	New Cannan	CT	45,625	41,477
Southeastern	Preston	CT	219,000	199,091
Stamford II	Stamford	CT	131,400	119,455
Stamford I	Stamford	CT	54,750	49,773
Wellingford	Wallingford	CT	153,300	139,364
Windham	Windham	CT	39,420	35,836
Washington	Washington	DC	365,000	331,818

TABLE A-7. (continued)

Facility	City	State	Capacity	
			tons/yr	Mg/yr
Wilmington (Newcastle)	Wilmington	DE	219,000	199,091
Hillsborough County	Brandon	FL	438,000	398,182
Fort Mead	Fort Meade	FL	9,490	8,627
Broward County (South)	Ft. Lauderdale	FL	821,250	746,591
Pasco County	Hudson	FL	383,250	348,409
Monroe County	Key West	FL	54,750	49,773
Lakeland	Lakeland	FL	109,500	99,545
Mayport NAS	Mayport	FL	17,520	15,927
Dade County	Miami	FL	1,095,000	995,455
Miami (Airport)	Miami	FL	21,900	19,909
Lake County	Okahumpka	FL	192,720	175,200
Bay County	Panama City	FL	186,150	169,227
Broward County (North)	Pompano Beach	FL	821,250	746,591
Pinellas County	St. Petersburg	FL	1,095,000	995,455
McKay Bay	Tampa	FL	365,000	331,818
Palm Beach County	West Palm Beach	FL	730,000	663,636
Savannah	Savannah	GA	182,500	165,909
Honolulu	Honolulu	HI	788,400	716,727
Honolulu	Honolulu	HI	219,000	199,091
Ames	Ames	IA	73,000	66,364
Burley (Cassia County)	Burley	ID	18,250	16,591
Chicago NW	Chicago	IL	584,000	530,909
Indianapolis	Indianapolis	IN	862,130	783,755
Louisville	Louisville	KY	365,000	331,818
Agawan	Agawam	MA	131,400	119,455
Fall River	Fall River	MA	219,000	199,091
Framingham	Framingham	MA	182,500	165,909
Haverhill	Haverhill	MA	602,250	547,500

TABLE A-7. (continued)

Facility	City	State	Capacity	
			tons/yr	Mg/yr
Lawrence	Lawrence	MA	259,150	235,591
Millbury	Millbury	MA	547,500	497,727
North Andover	North Andover	MA	547,500	497,727
Pittsfield	Pittsfield	MA	131,400	119,455
Rochester (SEMASS)	Rochester	MA	657,000	597,273
Saugus	Saugus	MA	547,500	497,727
Springfield	Springfield	MA	131,400	119,455
Hartford County	Aberdeen	MD	131,400	119,455
Baltimore (Pulaski)	Baltimore	MD	438,000	398,182
Baltimore (RESCO)	Baltimore	MD	821,250	746,591
Biddeford	Biddeford	ME	219,000	199,091
Aroostook County	Frenchville	ME	18,250	16,591
Harpwell	Harpwell	ME	5,110	4,645
Penobscot (Orrington)	Orrington	ME	262,800	238,909
Portland	Portland	ME	182,500	165,909
Clinton Township	Clinton Township	MI	219,000	199,091
Detroit	Detroit	MI	1,204,500	1,095,000
Fisher Guide Division	Detroit	MI	36,500	33,182
Grand Rapids	Grand Rapids	MI	228,125	207,386
Jackson County	Jackson	MI	73,000	66,364
SE Oakland County	Madison Heights	MI	219,000	199,091
Alexandria	Alexandria	MN	26,280	23,891
Duluth	Duluth	MN	146,000	132,727
Anoka County (Elk River)	Elk River	MN	547,500	497,727
Fergus Falls	Fergus Falls	MN	34,310	31,191
Polk County	Fosston	MN	29,200	26,545
Mankato	Mankato	MN	262,800	238,909
Hennepin County	Minneapolis	MN	438,000	398,182

TABLE A-7. (continued)

Facility	City	State	Capacity	
			tons/yr	Mg/yr
Perham	Perham	MN	41,610	37,827
Red Wing	Red Wing	MN	262,800	238,909
Red Wing	Red Wing	MN	26,280	23,891
Olmstead County	Rochester	MN	73,000	66,364
Savage	Savage	MN	21,900	19,909
Thief River Falls (Hospital)	Thief River Falls	MN	1,825	1,659
Thief River Falls (Hospital)	Thief River Falls	MN	36,500	33,182
Ft. Leonard Wood	Ft. Leonard Wood	MO	28,470	25,882
Pascagoula	Moss Point	MS	54,750	49,773
Livingston (Park County)	Livingston	MT	26,280	23,891
Mecklenburg Co.	Charlotte	NC	85,775	77,977
Cherry Point Marine St.	Cherry Point	NC	365	332
RTP/NIEHS	RTP	NC	14,600	13,273
New Hanover County	Wilmington	NC	73,000	66,364
New Hanover County	Wilmington	NC	91,250	82,955
Wrightsville Beach	Wrightsville Beach	NC	18,250	16,591
Auburn	Auburn	NH	1,825	1,659
Candia	Candia	NH	5,475	4,977
Canterbury	Canterbury	NH	3,650	3,318
Claremont	Claremont	NH	73,000	66,364
Concord	Concord	NH	182,500	165,909
Durham	Durham	NH	39,420	35,836
Lincoln	Lincoln	NH	8,760	7,964
Litchfield	Litchfield	NH	8,030	7,300
Nottingham	Nottingham	NH	2,920	2,655
Pelham	Pelham	NH	8,760	7,964
Pittsfield	Pittsfield	NH	17,520	15,927
Plymouth	Plymouth	NH	5,840	5,309

TABLE A-7. (continued)

Facility	City	State	Capacity	
			tons/yr	Mg/yr
Wilton	Wilton	NH	10,950	9,955
Wolfeboro	Wolfeboro	NH	5,840	5,309
Atlantic County Jail	Atlantic County Jail	NJ	5,110	4,645
Camden County	Camden	NJ	383,250	348,409
Fort Dix	Fort Dix	NJ	29,200	26,545
Essex County	Newark	NJ	831,105	755,550
Warren County	Oxford Township	NJ	146,000	132,727
Union County	Rahway	NJ	525,600	477,818
Gloucester County	West Deptford	NJ	209,875	190,795
Albany	Albany	NY	219,000	199,091
Babylon	Babylon	NY	273,750	248,864
SW Brooklyn	Brooklyn	NY	350,400	318,545
Cattaraugus	Cuba	NY	40,880	37,164
Ellis Island	Ellis Island	NY	4,380	3,982
Fire Island	Fire Island	NY	4,380	3,982
Glen Cove	Glen Cove	NY	91,250	82,955
Hempstead	Hempstead	NY	846,435	769,486
Huntington	Huntington	NY	273,750	248,862
Islip	Islip	NY	189,070	171,884
Liberty Island	Liberty Island	NY	4,380	3,982
Long Beach	Long Beach	NY	73,000	66,364
Betts Ave (NY City)	New York	NY	365,000	331,818
Niagara Falls-Occidental	Niagara Falls	NY	730,000	663,636
Oswego County	Oswego County	NY	73,000	66,364
Westchester County	Peekskill	NY	821,250	746,591
Dutchess County	Poughkeepsie	NY	146,000	132,727
Oneida County	Rome	NY	73,000	66,364
Akron	Akron	OH	365,000	331,818

TABLE A-7. (continued)

Facility	City	State	Capacity	
			tons/yr	Mg/yr
Columbus	Columbus	OH	730,000	663,636
South Montgomery County	Dayton	OH	328,500	298,636
North Montgomery County	Dayton	OH	328,500	298,636
Euclid	Euclid	OH	73,000	66,364
Miami	Miami	OK	38,325	34,841
Poteau	Poteau	OK	9,125	8,295
Tulsa	Tulsa	OK	273,750	248,864
Wilburton	Wilburton	OK	6,570	5,973
Bendon	Benton	OR	9,490	8,627
Marion County	Brooks	OR	200,750	182,500
Coos Bay	Coos Bay	OR	36,500	33,182
Courthouse-Coquille	Coquille	OR	54,750	49,773
Courthouse-Coquille	Coquille	OR	4,745	4,314
Delaware County (Chester)	Chester	PA	981,120	891,927
Lancaster County	Conoy Township	PA	438,000	398,182
Westmoreland County	Greensburg	PA	18,250	16,591
Harrisburg	Harrisburg	PA	262,800	238,909
York County	Manchester Township	PA	490,560	445,964
Philadelphia EC	Philadelphia	PA	273,750	248,864
Philadelphia NW	Philadelphia	PA	273,750	248,864
Montgomery County	Plymouth Township	PA	438,000	398,182
Charleston County	Charleston	SC	219,000	199,091
Hampton	Hampton	SC	87,600	79,636
Davidson County	Davidson County	TN	67,525	61,386
Dyersburg	Dyersburg	TN	36,500	33,182
Galletin	Galletin	TN	73,000	66,364
Lewisburg	Lewisburg	TN	21,900	19,909
Nashville	Nashville	TN	408,800	371,636

TABLE A-7. (continued)

Facility	City	State	Capacity	
			tons/yr	Mg/yr
Carthage City	Carthage	TX	14,600	13,273
Center	Center	TX	14,600	13,273
Cleburne	Cleburne	TX	41,610	37,827
Gatesville (Prison)	Gatesville	TX	7,300	6,636
Walker County	Huntsville	TX	9,125	8,295
Walker County (Prison)	Huntsville	TX	9,125	8,295
Grimes County	Navasota	TX	9,125	8,295
Anderson County	Palestine	TX	9,125	8,295
Quitman	Quitman	TX	7,300	6,636
Waxahachie	Waxahachie	TX	18,250	16,591
Davis County	Layton	UT	146,000	132,727
Alexandria	Alexandria	VA	355,875	323,523
Arlington (Pentagon)	Arlington	VA	18,250	16,591
Galax	Galax	VA	20,440	18,582
Hampton	Hampton	VA	73,000	66,364
Harrisonburg	Harrisonburg	VA	36,500	33,182
Fairfax County	Lorton	VA	1,095,000	995,455
Norfolk Navy Yard	Norfolk	VA	730,000	663,636
Norfolk Naval Station	Norfolk	VA	131,400	119,455
Salem	Salem	VA	36,500	33,182
Readsboro	Readsboro	VT	4,745	4,314
Rutland	Rutland	VT	87,600	79,636
Stamford	Stamford	VT	3,650	3,318
Bellingham	Ferndale	WA	36,500	33,182
Fort Lewis	Fort Lewis	WA	43,800	39,818
Friday Harbor	Friday Harbor	WA	4,380	3,982
Skagit County	Mt. Vernon	WA	64,970	59,064
Spokane	Spokane	WA	292,000	265,455

TABLE A-7. (continued)

Facility	City	State	Capacity	
			tons/yr	Mg/yr
Tacoma	Tacoma	WA	109,500	99,545
Barron Co.	Almena	WI	29,200	26,545
La Crosse County	La Crosse	WI	146,000	132,727
Madison (Oscar Meyer)	Madison	WI	21,900	19,909
Madison (Power Plant)	Madison	WI	43,800	39,818
Muscoda	Muscoda	WI	43,800	39,818
St. Croix Co.	New Richmond	WI	41,975	38,159
Port Washington	Port Washington	WI	27,375	24,886
Sheboygan	Sheboygan	WI	78,840	71,673
Waukesha	Waukesha	WI	64,240	58,400
Total			41,899,810	38,090,736

Source: Memorandum from Fenn, D., and K. Nebel, Radian Corporation, to Stevenson, W.,
U. S. Environmental Protection Agency. March 9, 1992.

**TABLE A-8. MERCURY EMISSIONS FROM MWC's BY COMBUSTOR TYPE
FOR 1991**

Combustor type	Control status	Process rate, 10 ⁶ Mg/yr	Uncontrolled emission factor, g/Mg	Control efficiency, %	Annual Emissions	
					Mg/yr	Ton/yr
Mass burn	U	0.517	2.82	0	1.46	1.60
Mass burn	SD	7.190	2.82	50	10.14	11.15
Mass burn	DSI	1.077	2.82	50	1.52	1.67
Mass burn	ESP	13.806	2.82	0	38.93	42.83
RDF	SD	2.809	2.77	50	3.89	4.28
Modular	ESP	0.630	2.82	0	1.78	1.95
Total					57.72	63.48

Key:

- SD = Spray dryer with either ESP or fabric filter
- ESP = Electrostatic precipitator
- DSI = Duct sorbent injection with either ESP or fabric filter
- U = Uncontrolled

Basis of Input Data

- Under the assumption that ESP's provide essentially no control, the facility-average concentrations at 7 percent oxygen for uncontrolled and ESP-controlled mass burn (including modular) and RDF systems were averaged to obtain the following "typical" concentrations:

 Mass Burn - 696 µg/dscm
 RDF - 561 µg/dscm
- The F-factor for municipal waste combustors was assumed to be 0.257×10^{-6} dscm/J at 0 percent oxygen and the heating values were assumed to be 10,500 kJ/kg for MSW and 12,800 kJ/kg for RDF. The F-factor was converted from 0 percent oxygen to 7 percent oxygen (at which concentrations are based) using a factor of 1.5.
- Based on a meeting with the EPA MWC project team, all modular MWC's are assumed to be controlled with ESP's.
- Spray dryer or dry sorbent injection systems combined with fabric filters or ESP's and wet scrubber systems achieve 50 percent removal. No other control measures achieve appreciable mercury control.
- The 1990 MWC processing rates are assumed to be equal to those presented in Waste Age, November 1991.

Calculations

Uncontrolled Emission Factors

- Mass burn/modular - $696 \mu\text{g/dscm} \times 0.257 \times 10^{-6} \text{ dscm/J} \times 10,500 \text{ kJ/kg} \times 1.5 = 2.82 \text{ g/Mg}$
- RDF - $561 \mu\text{g/dscm} \times 0.257 \times 10^{-6} \text{ dscm/J} \times 12,800 \text{ kJ/kg} \times 1.5 = 2.77 \text{ g/Mg}$

Controlled Emissions

Annual Emissions

$$= \text{Process rate} \times \text{emission factor} \times \frac{(100 - \text{efficiency})}{100}$$

Source: Locating and Estimating air Emissions from Sources of Mercury and Mercury Compounds.
U. S. Environmental Protection Agency. July 1993.

TABLE A-9. MWI POPULATION BY STATE

State	Commercial units		Onsite units		
	No.	Capacity range, lb/hr	No.	Capacity range, lb/hr	Facilities included
Alabama	2	Up to 60,000 lb/wk	250	ND	H,N
Alaska	1	ND	10 to 12	ND	H
Arizona	1	ND	97	ND	All
Arkansas	1	ND	150	ND	ND
California	10	ND	157	ND	H,N,O
Colorado	2	225	46	13-1,000	H
Connecticut	1	1,200	44	20-1,500	All
Delaware	0	NA	20	ND	H,V
Florida	12	300-3,750	273	ND	H,F,V,A,L,O
Georgia	1	ND	ND	ND	
Hawaii	0	NA	6 or 7	100-1,000	H
Idaho	ND	ND	20-25 permitted	ND	H
Illinois	2	ND	259	2-1,500	H,F,V,A,L,O
Indiana	4	ND	91	Most <7 tons/d	H
Iowa	0	NA	ND	≤125	H
Kansas	Some	ND	ND	ND	
Kentucky	1	1,500	ND	ND	
Louisiana	1	1,500	100-125	<500 to >1,000 (most <500)	H
Maine	1	150	22	20-1,000	H,N,L
Maryland	ND	ND	121	ND	All
Massachusetts	3	350-1,200	200	3-1,875	All
Michigan	1	720	160	ND	H,N
Minnesota	0	NA	145	50-1,250	H
Mississippi	0	NA	125-175	ND	All
Missouri	2	ND	100	Most <500	H
Montana	ND	ND	<50	ND	ND
Nebraska	0	NA	80	ND	H
Nevada	0	NA	17	40-360	H
New Hampshire	1	ND	27	Most 75-150	H
New Jersey	1	5,000	154	20-1,560	All
New Mexico	3	75-1,000	31	25-360	H,F,V,A,L
New York	2	1,950	599	3-3,000	All
North Carolina	7	150-3,250	29	60-2,100	H,L
North Dakota	0	NA	50	Most <500	H
Ohio	15	500-1,700	125	25-2,500	H,F,V,A,L,O
Oklahoma	1	ND	93	ND	H,N,L
Oregon	2	200-1,000	31	25-750	H
Pennsylvania	8	ND	186	ND	H
Rhode Island	1	975	11	50-1,500	H
South Carolina	3	6,250	70	<500 to 1,000	H
South Dakota	0	NA	30	ND	H
Tennessee	≥1	ND	126	ND	H
Texas	2	ND	ND	ND	
Utah	0	NA	20	<500	H
Vermont	0	ND	9	ND	H

TABLE A-9. (continued)

State	Commercial units		Onsite units		
	No.	Capacity range, lb/hr	No.	Capacity range, lb/hr	Facilities included
Virginia	1 or 2	ND	ND	ND	
Washington	6	1,600-7,500	137	40-825	All
West Virginia	ND	ND	50	ND	H
Wisconsin	4	ND	ND	ND	H
Wyoming	0	NA	30	ND	

KEY:

General

ND = no data

NA = not applicable

Facility types

H = hospital/medical centers

F = funeral homes

V = veterinaries

A = animal shelters

L = laboratories, clinical and research

N = nursing homes

O = other/unidentified facilities

All = all MWI facilities (using current broad working definition)

Source: U.S. EPA. Medical Waste Incinerators—Background Paper for New and Existing Facilities. Draft Report. June 1992.

TABLE A-10. U.S. SEWAGE SLUDGE INCINERATORS

Facility	Location	State	Capacity	
			Ton/yr	Mg/yr
Anchorage	Anchorage	AK	401.5	365
Petersburg	Petersburg	AK	N/A	N/A
Wrangell	Wrangell	AK	73	66.4
Barstow	Barstow	CA	912.5	829.5
Lake Arrowhead	Lake Arrowhead	CA	1,752	1,592.7
Martinez	Martinez	CA	N/A	N/A
Palo Alto	Palo Alto	CA	2,190	1,990.9
Redwood City	Redwood City	CA	N/A	N/A
Sacramento	Sacramento	CA	2,628	2,389.1
San Mateo	San Mateo	CA	1,788.5	1,625.9
South Lake Tahoe	South Lake Tahoe	CA	292	265.5
Tahoe Truckee	Truckee	CA	N/A	N/A
Central Contra Costa	Walnut Creek	CA	16,060	14,600
Yosemite	Yosemite National Park	CA	1,241	1,128.2
Mattabassett	Cromwell	CT	4,562.5	4,147.7
Mattabassett	Cromwell	CT	N/A	N/A
Hartford WPCF	Hartford	CT	122,640	111,490.9
New Canaan	New Canaan	CT	14,198.5	12,907.7
East Shore WPCF	New Haven	CT	10,658	9,689.1
New London WPCF	New London	CT	18,907	17,188.2
Norwalk	Norwalk	CT	13,140	11,945.5
Stamford	Stamford	CT	34,565.5	31,423.2
Waterbury WPCF	Waterbury	CT	2,372.5	2,156.8
West Haven	West Haven	CT	N/A	N/A
Willimantic WPCF	Willimantic	CT	N/A	N/A
Jacksonville	Jacksonville	FL	10,366	9,423.6
Pensacola WWTP	Pensacola	FL	N/A	N/A
R.M. Clayton WWTP	Atlanta	GA	N/A	N/A
Atlanta (Utoy)	Atlanta	GA	2,956.5	2,687.7
Atlanta (Bolton Rd)	Atlanta	GA	47,304	43,003.6
Decatur	Decatur	GA	16,352	14,865.5

TABLE A-10. (continued)

Facility	Location	State	Capacity	
			Ton/yr	Mg/yr
Gainesville	Gainesville	GA	2,007.5	1,825
Cobb County	Marietta	GA	7,227	6,570
Savannah	Savannah	GA	4,380	3,981.8
San Island WWTF	Honolulu	HI	9,453.5	8,594.1
Honouliuli WWTP	Honouliuli	HI	N/A	N/A
Oahu	Oahu	HI	N/A	N/A
Cedar Rapids WPCF	Cedar Rapids	IA	8,869.5	8,063.2
Davenport	Davenport	IA	12,994	11,812.7
Dubuque	Dubuque	IA	20,440	18,581.8
Decatur STP	Decatur	IL	N/A	N/A
Indianapolis-Belmont	Indianapolis	IN	132,458.5	120,416.8
Kansas City	Kansas City	KS	6,570	5,972.7
Kaw Point	Kansas City	KS	14,600	13,272.7
Mission Township STP	Mission	KS	N/A	N/A
Turkey Creek MSD #1	Shawnee Mission	KS	6,497	5,906.4
Cynthiana	Cynthiana	KY	N/A	N/A
Kenton County	Kenton	KY	N/A	N/A
New Orleans West Bank STP	Algiers	LA	N/A	N/A
Lake Charles	Lake Charles	LA	2,190	1,990.9
Lake Charles-Plant B	Lake Charles	LA	N/A	N/A
Lake Charles-Plant C	Lake Charles	LA	N/A	N/A
East Bank STP #2	Lake Charles	LA	14,965	13,604.5
Natchitoches	Natchitoches	LA	N/A	N/A
East Bank STP #1	New Orleans	LA	10,950	9,954.5
Attleboro Advanced WTF	Attleboro	MA	N/A	N/A
Chicopee	Chicopee	MA	2,628	2,389.1
Chicopee	Chicopee	MA	2,628	2,389.1
Fall River	Fall River	MA	N/A	N/A
Fitchburg East WWTP	Fitchburg	MA	14,198.5	12,907.7

TABLE A-10. (continued)

Facility	Location	State	Capacity	
			Ton/yr	Mg/yr
Lynn	Lynn	MA	N/A	N/A
Upper Blackstone WWTP	Millbury	MA	12,811.5	11,646.8
New Bedford WWTP	New Bedford	MA	5,913	5,375.5
Greater Lawrence SD WWTP	North Andover	MA	33,142	30,129.1
Annapolis City SIP	Annapolis	MD	N/A	N/A
Patapsco	Baltimore	MD	35,916	32,650.9
Ocean City	Ocean City	MD	2,920	2,654.5
Cox Creek WWTP	Riviera Beach	MD	N/A	N/A
Ann Arbor	Ann Arbor	MI	19,710	17,918.2
Battle Creek	Battle Creek	MI	N/A	N/A
Bay City STP	Bay City	MI	1,168	1,061.8
Bay County STP	Bay County	MI	N/A	N/A
Detroit (1)	Detroit	MI	148,920	135,381.8
Detroit (2)	Detroit	MI	245,937	223,579.1
East Lansing	East Lansing	MI	11,826	10,750.9
Grand Rapids	Grand Rapids	MI	11,826	10,750.9
Kalamazoo WWTP	Kalamazoo	MI	17,520	15,927.3
Lansing WWTP	Lansing	MI	N/A	N/A
Niles WWTP	Niles	MI	N/A	N/A
Owosso WWTP	Owosso	MI	N/A	N/A
Pontiac STP	Pontiac	MI	23,652	21,501.8
Port Huron	Port Huron	MI	2,774	2,521.8
Trenton WWTP	Trenton	MI	N/A	N/A
Warren	Warren	MI	9,453.5	8,594.1
Wyandotte STP	Wyandotte	MI	88,768	80,698.2
Ypsilanti Community WWTP	Ypsilanti	MI	19,710	17,918.2
Duluth	Duluth	MN	12,410	11,281.8
Metropolitan TP	St. Paul	MN	283,824	258,021.8

TABLE A-10. (continued)

Facility	Location	State	Capacity	
			Ton/yr	Mg/yr
Seneca TP	St. Paul	MN	7,081	6,437.3
Independence	Independence	MO	3,540.5	3,218.6
Kansas City	Kansas City	MO	16,571	15,064.5
Little Blue Valley	Little Blue	MO	N/A	N/A
St. Louis (Lenay STP)	St. Louis	MO	53,217	48,379.1
St. Louis (Bissel Point STP)	St. Louis	MO	118,260	107,509.1
Greensboro	Greensboro	NC	16,571	15,064.5
Manchester WWTP	Manchester	NC	N/A	N/A
Rocky Mount	Rocky Mount	NC	2,737.5	2,488.6
Shelby	Shelby	NC	5,913	5,375.5
Lebanon WWTP	Lebanon	NH	2,628	2,389.1
Merrimack WWTP	Merrimack	NH	N/A	N/A
Atlantic City	Atlantic City	NJ	9,453.5	8,594.1
Gloucester Township	Blackwood	NJ	3,504	3,185.5
Somerset Raritan Valley Authority	Bridgewater	NJ	5,110	4,645.5
West Side STP	Jersey City	NJ	5,037	4,579.1
Two Bridges	Lincoln Park	NJ	24,090	21,900
Parsippany	Parsippany	NJ	28,397	25,815.5
Rockaway Valley	Parsippany-Troy Hills	NJ	N/A	N/A
Stony Brook RSA STP #1	Princeton	NJ	14,417.5	13,106.8
Bayshore Regional Sewer Authority	Union Beach	NJ	10950	9,954.5
NW Bergen County Utilities	Waldwick	NJ	6,570	5,972.7
Wayne	Wayne	NJ	35,040	31,854.5
Mountain View Sewer Authority	Wayne Township	NJ	N/A	N/A
Round Hill	Round Hill Village	NV	3,285	2,986.4
Douglas County SID #1 WWTF	Zephyr Cove-Round Hill Village	NV	1,825	1,659.1

TABLE A-10. (continued)

Facility	Location	State	Capacity	
			Ton/yr	Mg/yr
Albany (North)	Albany	NY	47,304	43,003.6
Albany (South)	Albany	NY	33,507	30,460.9
Amherst	Amherst	NY	N/A	N/A
Arlington	Arlington	NY	3,066	2,787.3
Auburn	Auburn	NY	14,782.5	13,438.6
Bath	Bath	NY	N/A	N/A
Beacon WPCP	Beacon	NY	3,540.5	3,218.6
Birds Island STP	Buffalo	NY	67,014	60,921.8
Southtowns Advanced WWTF	Buffalo	NY	15,768	14,334.5
Dunkirk STP	Dunkirk	NY	N/A	N/A
Numburg	Erie County	NY	105,120	95,563.6
Glen Cove	Glen Cove	NY	9,125	8,295.5
Glens Falls	Glens Falls	NY	N/A	N/A
NW Quadrant TP	Greece	NY	N/A	N/A
Little Falls	Little Falls	NY	1,423.5	1,294.1
Mamaroneck	Mamaroneck	NY	N/A	N/A
New Rochelle SD STP	New Rochelle	NY	N/A	N/A
Niagra County	Niagara County	NY	N/A	N/A
Utica	Oneida County	NY	21,900	19,909.1
Orangetown DPW	Orangetown	NY	6,132	5,574.5
East STP	Oswego	NY	N/A	N/A
West STP	Oswego	NY	N/A	N/A
Port Chester SDSTP	Port Chester	NY	N/A	N/A
Port Washington	Port Washington	NY	N/A	N/A
Gates Chile Ogden STP	Rochester	NY	13,140	11,945.5
Rochester (NW Quad)	Rochester	NY	17,520	15,927.3
Frank E. Van Lare WWTP	Rochester	NY	26,280	23,890.9
Saratoga	Saratoga	NY	N/A	N/A
Schenectady STP	Schenectady	NY	51,100	46,454.5

TABLE A-10. (continued)

Facility	Location	State	Capacity	
			Ton/yr	Mg/yr
Disposal District No. 15	Southampton	NY	N/A	N/A
Two Mile Creek STP	Tonawanda	NY	N/A	N/A
Watertown	Watertown	NY	N/A	N/A
Watertown	Watertown	NY	7,665	6,968.2
Akron WWTP	Akron	OH	14,162	12,874.5
Canton WWTP	Canton	OH	18,250	16,590.9
Little Miami WWTP	Cincinnati	OH	N/A	N/A
Cincinnati (Millcreek)	Cincinnati	OH	61,466	55,878.2
Cleveland (Southerly WWTP)	Cleveland	OH	94,608	86,007.3
Cleveland (Westerly STP)	Cleveland	OH	70,956	64,505.5
Columbus (South)	Columbus	OH	16,571	15,064.5
Columbus (Jackson Pike WWTP)	Columbus	OH	14,198.5	12,907.7
Euclid WWTP	Euclid	OH	7,884	7,167.3
Warren County	Franklin	OH	N/A	N/A
Lorain	Lorain	OH	N/A	N/A
Willoughby-Eastlake WWTP	Willoughby	OH	7,665	6,968.2
Youngstown WWTP	Youngstown	OH	14,782.5	13,438.6
Tigard	Tigard	OR	5,475	4,977.3
Ambridge STP	Ambridge	PA	N/A	N/A
Kiski Valley WPCA	Appollo	PA	49,676.5	45,160.5
Bridgeport SIP	Bridgeport	PA	N/A	N/A
Delcora-Chester STP	Chester	PA	7,081	6,437.3
Hatfield Township STP	Colmer	PA	2,080.5	1,891.4
Duryea	Duryea	PA	9,453.5	8,594.1
Erie	Erie	PA	49,275	44,795.5
Hershey	Hershey	PA	14,782.5	13,438.6
City of Johnstown	Johnstown	PA	2,956.5	2,687.7
Cumberland City	Lemoine	PA	N/A	N/A

TABLE A-10. (continued)

Facility	Location	State	Capacity	
			Ton/yr	Mg/yr
E. Morristown Plymouth TP	Norristown	PA	N/A	N/A
Upper Gwynedd	North Wales	PA	401.5	365
Lower Lackawanna STP	Old Forge	PA	N/A	N/A
Alcosan WWTP	Pittsburgh	PA	N/A	N/A
Tyrone	Tyrone	PA	1,861.5	1,692.3
Trout Run WPCC	Upper Merion Township	PA	N/A	N/A
Hazeltown	West Hazeltown	PA	1,642.5	1,493.2
Wyoming Valley Sanitation Authority	Wilkes-Barre	PA	11,826	10,750.9
Upper Moreland-Hatboro TP	Willow Grove	PA	N/A	N/A
York	York	PA	14,162	12,874.5
Cranston	Cranston	RI	7,446	6,769.1
Harrisburg	Harrisburg	RI	49,421	44,928.2
Providence	Providence	RI	N/A	N/A
Charleston	Charleston	SC	11,826	10,750.9
Columbia	Columbia	SC	2,993	2,720.9
North Charleston	North Charleston	SC	N/A	N/A
Bristol	Bristol	TN	5,913	5,375.5
Maryville Regional STP	Maryville	TN	4,745	4,313.6
Central WWTP	Nashville	TN	33,580	30,527.3
Newport	Newport	TN	2,847	2,588.2
Alexandria STP	Alexandria	VA	N/A	N/A
Arlington COWPCP	Arlington	VA	12,702	11,547.3
Fairfax	Fairfax	VA	23,652	21,501.8
Fairfax (Lower Potomac STP)	Fairfax	VA	33,142	30,129.1
Hopewell	Hopewell	VA	2,956.5	2,687.7
Boat Harbor	Newport News	VA	12,300.5	11,182.3
Lamberta Point WPCF	Norfolk	VA	21,133.5	19,212.3

TABLE A-10. (continued)

Facility	Location	State	Capacity	
			Ton/yr	Mg/yr
Army Base WWTP (Hampton Rds.)	Norfolk	VA	9,307.5	8,461.4
Chesapeake-Elizabeth WPCF	Virginia Beach	VA	8,322	7,565.5
Williamsburg WPCF	Williamsburg	VA	20,330.5	18,482.3
Potomac River STP	Woodbridge	VA	N/A	N/A
Edmonds	Edmonds	WA	584	530.9
Lynnwood	Lynnwood	WA	255.5	232.3
Vancouver	Vancouver	WA	12,410	11,281.8
Brookfield STP	Brookfield	WI	1,423.5	1,294.1
Green Bay WWTP	Green Bay	WI	31,937.5	29,034.1
Milwaukee	Milwaukee	WI	2,591.5	2,355.9
Clarksburg	Clarksburg	WV	N/A	N/A
Huntington	Huntington	WV	N/A	N/A
Total			3,208,240.5	2,916,582.3

Source: Locating and Estimating Air Toxic Emissions from Sewage Sludge Incinerators. U.S. EPA.
EPA-450/2-90-009. May 1990.

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

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7. AUTHOR(S) Thomas F. Campbell				8. PERFORMING ORGANIZATION REPORT NO.	
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16. ABSTRACT Under section 112(n)(1)(B) of the Clean Air Act Amendments of 1990, the EPA is to submit a study of mercury emissions to Congress. The mercury study is to evaluate the rate and mass of mercury emissions, to determine the health and environmental effects of these emissions, the technologies that are available to control such emissions, and the costs of such technologies. The Mercury Study Report to Congress will be submitted in November 1994. This document represents the emissions inventory portion of the Mercury Study Report to Congress. It is being released early, and as an interim final report to make publicly available EPA's current data on sources of mercury emissions. Prior to final publication, as part of the Mercury Report to Congress, the document will peer-reviewed by experts in the field. The information contained in the document may or may not change prior to final publication.					
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