

**DRAFT**

**SOURCES  
OF  
ATMOSPHERIC CADMIUM**

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

**DRAFT**

# **SOURCES OF ATMOSPHERIC CADMIUM**

by

**Energy and Environmental Analysis, Inc.  
1111 North 19th Street, 6th Floor  
Arlington, Virginia 22209**

**Contract No. 68-02-2836**

**EPA Project Officer: Richard Johnson**

**Strategies and Air Pollutant Standards Division  
Environmental Protection Agency  
Research Triangle Park, North Carolina 27711**

**Prepared for**

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

**February 27, 1978**

## TABLE OF CONTENTS

<u>TITLE</u>	<u>PAGE</u>
EXECUTIVE SUMMARY.....	1
SECTION I: INTRODUCTION.....	9
SECTION II: CADMIUM IN THE ENVIRONMENT.....	11
A. Introduction.....	11
B. Physical and Chemical Characteristics of Cadmium.....	11
C. Multi-Media Nature of Cadmium Exposures.....	12
SECTION III: METHODOLOGY.....	17
A. Introduction.....	17
B. Determination of Potential Cadmium Emission Sources.....	17
C. Emission Factor Determination.....	18
D. Computation of Emission Levels.....	20
E. Source Screening.....	20
SECTION IV: USES OF CADMIUM.....	22
A. Introduction.....	22
B. Electroplating.....	22
C. Paint Pigments.....	24
D. Plastic Stabilizers.....	24
E. Nickel-Cadmium Batteries.....	25
F. Miscellaneous.....	25

## TABLE OF CONTENTS (Continued)

<u>TITLE</u>	<u>PAGE</u>
SECTION V: SOURCES OF ATMOSPHERIC CADMIUM EMISSIONS.....	27
A. Introduction.....	27
B. Mining.....	28
C. Primary Metal Production.....	29
D. Iron and Steel.....	46
E. Secondary Smelting.....	56
F. Manufacturing.....	62
G. Fossil Fuel Combustion.....	69
H. Miscellaneous.....	76
I. Incineration.....	81
J. Summary.....	85
SECTION VI: SCREENING OF CADMIUM SOURCE TYPES.....	98
A. Introduction.....	98
B. Mining.....	102
C. Primary Metals.....	104
D. Iron and Steel.....	105
E. Secondary Smelting.....	106
F. Manufacturing.....	107
G. Fossil Fuel Combustion.....	107
H. Miscellaneous.....	109
I. Incineration.....	110

## EXECUTIVE SUMMARY

This report is one of a series of reports which will be used by EPA in responding to the Congressional request under section 122 of the Clean Air Act Amendments of 1977 to determine whether atmospheric emissions of cadmium pose any threat to public health. This report surveys the uses of cadmium and potential emission sources to determine which sources are the most significant both in terms of total emissions and potential ambient levels.

The basic methodology used in this report is as follows:

- Determination of potential cadmium emission sources through a literature review;
- Determination of emission factors (lbs. cadmium emitted/unit output) for each source;
- Application of these emission factors to current and projected production levels to obtain estimates of total cadmium emissions;
- Evaluation of control technology for reducing cadmium emissions;
- Screening of all cadmium sources to identify those sources potentially able to cause measurable ambient levels of cadmium.

Consumption of cadmium in the U.S. has averaged about 5,000 megagrams/year over the last several years. United States production is closely tied to zinc production and has not been adequate to meet demand. In 1975 almost 40 percent of the cadmium used in the U.S. was imported. The principal uses of cadmium and their relative share of consumption is shown in Figure E-1.

It is estimated that about 914 tons of cadmium were emitted during 1974. The breakdown of emissions by source category is shown on Table E-2. This table also lists the anticipated change in cadmium emissions due to growth changes in technology or the anticipated imposition of higher efficiency control equipment.

As Table E-1 shows, the largest estimated emitter of cadmium is the production of zinc. This source accounts for approximately 53 percent of total cadmium emissions. Although zinc production is expected to increase significantly, emissions are not expected to increase and very possibly will decrease due to the increased use of electrolytic processes which have almost no emissions.

Emissions from other major sources (incinerators, iron and steel and fossil fuel combustion) are expected to remain relatively constant as the increased production is balanced by the increasing levels of control technology.

Data on Table E-1 is based on the use of "best judgement" emission factors developed through a review of the literature and various stack test results. Table E-2 shows the emission factors developed in this study. Also shown on Table E-2 is the minimum and maximum emission factor reported for any of

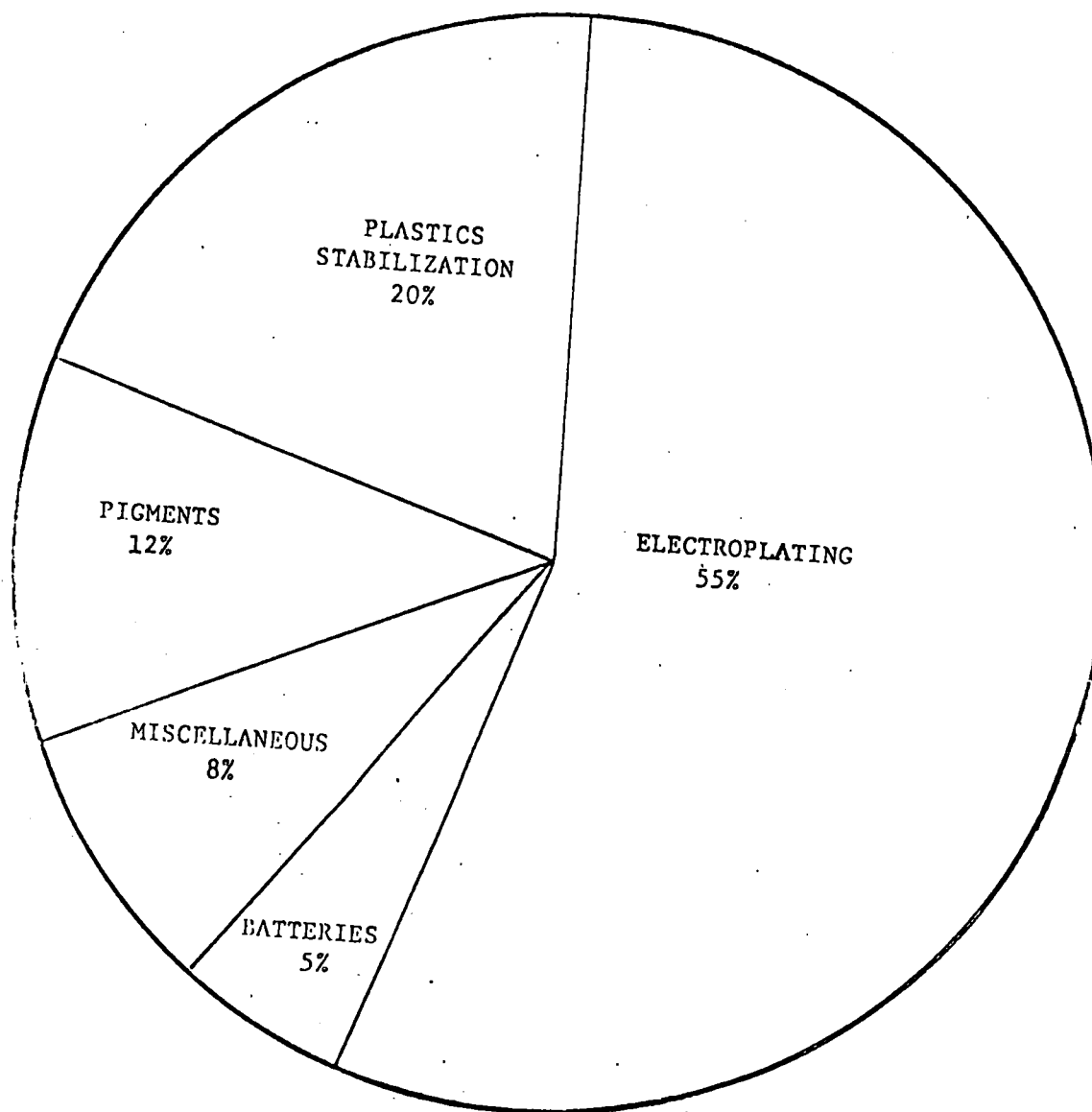


FIGURE E-1

CADMIUM CONSUMPTION IN THE UNITED STATES (1)

TABLE E-1

## AIRBORNE CADMIUM EMISSIONS--1974, 1985

<u>Source</u>	<u>Production 1974*</u>	<u>Emissions Estimate</u>	<u>Reference</u>	<u>Production 1985 (e)</u>	<u>Emissions Estimate</u>	<u>Reference</u>
<b>MINING</b>						
Zinc	478,850	< 1	12	845,377	< 1	41
Copper	1,414,246.8	< 1	12	2,563,122	< 1	41
Lead	603,024	< 1	12	1,169,524	< 1	41
<b>PRIMARY METALS</b>						
Zinc						
Pyrometallurgic	423,000	529	40	1,000,000	529	9
Electrolytic	121,945	0	40	-	-	-
Lead	866,095	2	40	790,000	2	9
Copper	1,435,662.4	5	40	3,849,844	13.4	9
Cadmium	3,088.2	2	12	1,139	< 1	9
<b>SECONDARY METAL PROCESSING</b>						
<b>Iron and Steel</b>						
Sinter Windbox Uncontrolled	21.94x10 <sup>6</sup>	22	13	-	-	
Sinter Windbox w/Rotoclone and ESP	11.35x10 <sup>6</sup>	5.4	13	40x10 <sup>6</sup>	19	13
Basic Oxygen Furnace Uncontrolled	1.2x10 <sup>6</sup>	< 1	13	-	-	
BOF w/Venturi or ESP	78.8x10 <sup>6</sup>	< 1	13	1.73x10 <sup>6</sup>	< 1	13
Open Hearth Uncontrolled	7.64x10 <sup>6</sup>	22	13	-	-	
Open Hearth w/ESP	29.06x10 <sup>6</sup>	2	13	21.1x10 <sup>6</sup>	< 1	13
Electric Arc Uncontrolled	27.3x10 <sup>6</sup>	46	13	-	-	
Electric Arc Controlled	-	4.6	13	38.8x10 <sup>6</sup>	3.3	13
Blast Furnace Controlled	95.2x10	0	13	113.6x10 <sup>6</sup>	0	13
Overall Uncontrolled	12.84x10 <sup>6</sup>	95	13	-	-	
Zinc	182,665	< 1	12	223,000	< 1	19
Lead	698,698	< 1	12	860,000	< 1	9
Copper	513,308	38	12	800,000	60	20
<b>MANUFACTURING</b>						
Pigments	1,212.1	9	6	1,560	11.3	6
Stabilizers	991.8	3	6	1,179	3.5	6
Batteries	628.14	< 1	6	2,200	2.2	6
<b>FOSSIL FUEL COMBUSTION</b>						
Coal-Fired Power Plants	3.913x10 <sup>8</sup> (Btu's)	7.04	42	530.750x10 <sup>6</sup>	15.9	24
Oil-Fired Power Plants	500x10 <sup>6</sup> (barrels)	9	42	732.2x10 <sup>6</sup> (barrels)	19.9	46
Heating Oil	935.1x10 <sup>6</sup> (barrels)	29.2 (1975)	45	980.9x10 <sup>6</sup> (barrels)	30.5	46
Diesel Oil	11x10 <sup>9</sup> (gallons)	< 1	39	15.12x10 <sup>9</sup> (gallons)	5.25	38
Gasoline	1,330,074x10 <sup>6</sup> (VMT)	13	43	1,707,152x10 <sup>6</sup> (VMT)	17.1	44
<b>MISCELLANEOUS</b>						
Motor Oil	1,028,121x10 <sup>6</sup> (VMT)	< 1	43	1,707,152x10 <sup>6</sup> (VMT)	1.7	44
Rubber Tire Wear	1,330,024x10 <sup>6</sup> (VMT)	5	43	1,707,152x10 <sup>6</sup> (VMT)	6.8	44
Fungicides	59,800	< 1	9	92,769	< 1	9
Fertilizers	8,535x10 <sup>3</sup>	< 1	9	13,240x10 <sup>3</sup>	1.3	9
Cement	81,210x10 <sup>3</sup>	< 1	9	94,537x10 <sup>3</sup>	< 1	32
<b>INCINERATION</b>						
Sewage Sludge Incinerators	1,460,000	< 1	36	1,551,250	< 1	35,36
Municipal Incinerators	20,143,620	131	34	20,143,620	131	34
		991.24			882.3	

\* tons per year unless otherwise stated.

e = estimated

VMT = vehicle miles traveled



TABLE E-2  
CADMIUM EMISSION FACTORS

SOURCE	MINIMUM	MAXIMUM	BEST JUDGEMENT
<u>PRIMARY METALS PROCESSING</u>			
<u>ZINC</u>			
Coking	$9.04 \times 10^{-1} / \text{TZnThru (STK,AA)}$	$3.78^{1b} / \text{TZnThru (STK,AA)}$	$2.34^{1b} / \text{TZnThru}$
Sintering w/Cyclone	$4.06^{1b} / \text{TZnThru (STK,AA)}$	$8.58^{1b} / \text{TZnThru (STK,AA)}$	$6.32^{1b} / \text{TZnThru (STK,AA)}$
Sintering w/Cyclone & ESP	$1.52^{1b} / \text{TZnThru (STK,AA)}$	$2.80^{1b} / \text{TZnThru (STK,AA)}$	$2.16^{1b} / \text{TZnThru (STK,AA)}$
Roasting			~0 (EST)
Horizontal Retort			$6 \times 10^{-31b} / \text{TZnProd (EST)}$
Vertical Retort	$1.2 \times 10^{-21b} / \text{TZnThru (EST)}$	$8.76 \times 10^{-21b} / \text{TZnThru (STK,AA)}$	$6.5 \times 10^{-21b} / \text{TZnThru (STK,AA)}$
Electrothermic			$1.2 \times 10^{-21b} / \text{TZnProd (EST)}$
Overall (Not Electrolytic)	$1.43^{1b} / \text{TZnProd (EST)}$	$2.96^{1b} / \text{TZnProd (STK,AA)}$	$2.5^{1b} / \text{TZnProd}^{1/}$
Electrolytic			~0
<u>LEAD</u>			
Overall Smelter	$5.2 \times 10^{-21b} / \text{TPbProd (EST,MB)}$	$2.6 \times 10^{-11b} / \text{TPbProd (EST,MAX CONC)}^{2/}$	$1.1 \times 10^{-11b} / \text{TPbProd (EST, AVE CONC)}^{3/}$
Blast Furnace w/Baghouse			$5.25 \times 10^{-31b} / \text{TZn (STK,ES)}$
<u>COPPER</u>			
Uncontrolled Smelter	$7 \times 10^{-21b} / \text{TCu (EST,MB)}$	$2.9 \times 10^{-11b} / \text{TCu (EST,MB)}$	$1.5 \times 10^{-11b} / \text{TCu}^{4/}$
Smelter w/Baghouse (~95%)			$7 \times 10^{-31b} / \text{TCu (EST)}$
<u>CADMIUM</u>			
	$25^{1b} / \text{TCdProd (EST,SURV,MB)}$	$30.5^{1b} / \text{TCdProd (EST,MB)}$	$28^{1b} / \text{TCd}^{5/}$
<u>SECONDARY METALS PROCESSING</u>			
<u>IRON &amp; STEEL</u>			
Sinter Windbox-Uncontrolled	$1.35 \times 10^{-31b} / \text{TFeed (STK,ES)}$	$2.63 \times 10^{-31b} / \text{TFeed (STK,ES)}$	$2 \times 10^{-31b} / \text{TFeed}$
Sinter Windbox w/Rotocyclone & ESP	$9.33 \times 10^{-41b} / \text{TFeed (STK,ES)}$	$9.76 \times 10^{-41b} / \text{TFeed (STK,ES)}$	$9.5 \times 10^{-41b} / \text{TFeed}$
Blast Furnace-Controlled			~0 (EST) <sup>6/</sup>
Open Hearth-Uncontrolled	$4.0 \times 10^{-31b} / \text{TSteel (STK,AA)}$	$7.49 \times 10^{-31b} / \text{TSteel (STK,AA)}$	$5.78 \times 10^{-31b} / \text{TSteel (STK,AA)}$
Open Hearth w/ESP	$2.08 \times 10^{-51b} / \text{TSteel (EST,CONC)}$	$1.33 \times 10^{-41b} / \text{TSteel (STK,AA)}$	$1.1 \times 10^{-41b} / \text{TSteel (STK,AA)}$
Basic Oxygen Furnace			
Uncontrolled			$4.1 \times 10^{-51b} / \text{TSteel (CONC)}^{7/}$
w/Venturi or ESP	$3.45 \times 10^{-61b} / \text{TSteel (STK,ES)}$	$2.79 \times 10^{-51b} / \text{TSteel (STK,ES)}$	$1.2 \times 10^{-51b} / \text{TSteel}^{8/}$
Electric Arc Furnace	$2.7 \times 10^{-31b} / \text{TSteel (EST,CONC)}^{9/}$	$5 \times 10^{-31b} / \text{TSteel (EST,STK,CONC)}^{10/}$	$3.4 \times 10^{-31b} / \text{TSteel (EST,STK,CONC)}^{11/}$
Overall-Uncontrolled	$2.2 \times 10^{-61b} / \text{TSteel (EST,MB)}$	$3.5 \times 10^{-31b} / \text{TSteel (EST,MB)}$	$1.7 \times 10^{-51b} / \text{TSteel}^{12/}$
SECONDARY ZINC-UNCONTROLLED	$8 \times 10^{-31b} / \text{TZn (SURV,MB)}$	$1.4 \times 10^{-21b} / \text{TZn Prod (MB)}$	$1 \times 10^{-21b} / \text{TZn Prod}^{13/}$
<u>SECONDARY LEAD</u>			
Blast Furnace w/3 Cyclones & Baghouse	$5.9 \times 10^{-71b} / \text{TPb (STK,ES)}$	$3.5 \times 10^{-51b} / \text{TPb (STK,ES)}$	$2 \times 10^{-61b} / \text{TPb}^{14/}$
Reverberatory Furnace w/Cyclone & Baghouse	$5.9 \times 10^{-71b} / \text{TPb (STK,ES)}$	$4 \times 10^{-41b} / \text{TPb (STK,ES)}$	$1.6 \times 10^{-61b} / \text{TPb}^{15/}$
Reverberatory Furnace w/3 Cyclones & Baghouse	$6.5 \times 10^{-91b} / \text{TPb (STK,ES)}$	$2 \times 10^{-41b} / \text{TPb (STK,ES)}$	$5 \times 10^{-71b} / \text{TPb}^{16/}$
SECONDARY COPPER-UNCONTROLLED	$2.6^{1b} / \text{TCu Scrap (EST,MB)}$	$4^{1b} / \text{TCu Scrap (EST,MB)}$	$3^{1b} / \text{TCu Scrap}^{17/}$
<u>MINING OF ZINC-BEARING ORES</u>			
Zinc Ore			$2 \times 10^{-11b} / \text{TCd in Ore (EST,MB)}$
Lead Ore			$1 \times 10^{-31b} / \text{TZn in Ore (EST,MB)}$
Copper Ore			$1 \times 10^{-41b} / \text{TPb in Ore (EST,MB)}$
			$3.2 \times 10^{-51b} / \text{TCu in Ore (EST,MB)}$
<u>MANUFACTURING</u>			
Alloys & Solders-Controlled			$10^{1b} / \text{TCd Charged (EST,MB)}$
Pigments w/Baghouse			$15^{1b} / \text{TCd Charged (EST,MB)}$
Stabilizers (for Plastics) w/Baghouse			$6^{1b} / \text{TCd Charged (EST,SITE)}$
Batteries (Ni-Cd)			$2^{1b} / \text{TCd Charged (SURV)}$
Miscellaneous (X-Ray Screens, Cathode Ray Tubes, Nuclear Reactor Components, etc.)			$2^{1b} / \text{TCd Charged (EST)}$

TABLE E-2 (Continued)  
CADMIUM EMISSION FACTORS

SOURCE	MINIMUM	MAXIMUM	BEST JUDGMENT
<u>FOSSIL FUEL COMBUSTION</u>			
Coal-Fired Power Plants			
Uncontrolled	$1 \times 10^{-41b}$ /TCoal (STK,AA)	$1 \times 10^{-11b}$ /TCoal (STK,ES)	$1 \times 10^{-31b}$ /TCoal <sup>18/</sup>
Controlled (ESP)	$1 \times 10^{-61b}$ /TCoal (STK,AA)	$7 \times 10^{-41b}$ /TCoal (STK,AA) <sup>19/</sup>	$6 \times 10^{-51b}$ /TCoal <sup>20/</sup>
Oil-Fired Power Plants			
Controlled ( ~ ESP)	$7.1 \times 10^{-71b}$ /gal (STK,ES)	$4.4 \times 10^{-61b}$ /gal (STK,CONC,ES) <sup>21/</sup>	$9 \times 10^{-71b}$ /gal (STK,ES) <sup>22/</sup>
Heating Oil (Residual; #6 Fuel Oil)	$1.5 \times 10^{-61b}$ /gal (EST,CONC) <sup>23/</sup>	$4 \times 10^{-51b}$ /gal (EST,CONC,NA) <sup>24/</sup>	$3 \times 10^{-61b}$ /gal <sup>25/</sup>
Diesel Oil	$6 \times 10^{-71b}$ /gal (EST,CONC,ES) <sup>26/</sup>	$2 \times 10^{-61b}$ /gal (EST) <sup>27/</sup>	$7 \times 10^{-71b}$ /gal (EST,CONC,ES) <sup>28/</sup>
Gasoline (for 15 mpg, all Cd Emitted)	$6.3 \times 10^{-11b}$ /veh-mi (EST,CONC) <sup>29/</sup>	$4.5 \times 10^{-81b}$ /veh-mi (EST,CONC) <sup>30/</sup>	$2 \times 10^{-81b}$ /veh-mi <sup>31/</sup>
<u>SLUDGE INCINERATORS</u>			
Multiple Hearth w/Scrubber	$1 \times 10^{-61b}$ /TSludge (DRY)(STK,ES)	$2 \times 10^{-51b}$ /TSludge (DRY) (STK,ES)	$7 \times 10^{-61b}$ /TSludge (DRY) (STK,ES) <sup>32/</sup>
Fluidized Bed w/Scrubber	$4 \times 10^{-71b}$ /TSludge (DRY) (STK,ES)	$3 \times 10^{-61b}$ /TSludge (DRY)(STK,ES)	$1.3 \times 10^{-61b}$ /TSludge (DRY)(STK,ES) <sup>33/</sup>
<u>MUNICIPAL INCINERATORS</u>			
Uncontrolled	$3 \times 10^{-31b}$ /TRefuse (EST)	$1.8 \times 10^{-21b}$ /TRefuse (STK,ES) <sup>34/</sup>	$6 \times 10^{-31b}$ /TRefuse (STK,ES) <sup>35/</sup>
Controlled (Scrubbers or ESP)	$6 \times 10^{-41b}$ /TRefuse (FLAA)	$1.0 \times 10^{-11b}$ /TRefuse (EST,MB)	$1.3 \times 10^{-21b}$ /TRefuse (STK,AA) <sup>36/</sup>
<u>LUBRICATING OIL INCINERATORS</u>			
Uncontrolled			$2 \times 10^{-61b}$ /gal (UNK)
<u>MISCELLANEOUS</u>			
Motor Oil Consumption (Vehicles)			$2 \times 10^{-91b}$ /veh-mi (UNK)
Rubber Tire Wear	$1 \times 10^{-101b}$ /veh-mi (EST,CONC) <sup>37/</sup>	$5 \times 10^{-81b}$ /veh-mi (EST,CONC) <sup>38/</sup>	$8 \times 10^{-91b}$ /veh-mi <sup>39/</sup>
Fungicides Application	$1.8 \times 10^{-61b}$ /gal (EST,MB) <sup>40/</sup>	$5 \times 10^{-51b}$ /gal (EST)	$1 \times 10^{-51b}$ /gal <sup>41/</sup>
Fertilizers Application	$1.7 \times 10^{-41b}$ /T (EST,MB)	$5 \times 10^{-21b}$ /T (EST,MB)	$6 \times 10^{-31b}$ /T <sup>42/</sup>
Superphosphate Fertilizers Application			$2 \times 10^{-41b}$ /T
<u>CEMENT PLANTS</u>			
<u>DRY PROCESS</u>			
Kiln w/Baghouse or ESP			$3 \times 10^{-41b}$ /TFeed (STK,ES)
Raw Mill Feed w/Baghouse	$3 \times 10^{-71b}$ /TFeed (STK,ES)	$4.1 \times 10^{-71b}$ /TFeed (STK,ES)	$3.6 \times 10^{-71b}$ /TFeed
Raw Mill w/Baghouse	$1 \times 10^{-71b}$ /TFeed (STK,ES)	$4.3 \times 10^{-71b}$ /TFeed (STK,ES)	$2.7 \times 10^{-71b}$ /TFeed
Raw Mill Air Separator w/Baghouse	$7.6 \times 10^{-71b}$ /TFeed (STK,ES)	$9 \times 10^{-71b}$ /TFeed (STK,ES)	$8.5 \times 10^{-71b}$ /TFeed
Finish Mill Feed w/Baghouse	$5 \times 10^{-71b}$ /TFeed (STK,ES)	$1.6 \times 10^{-61b}$ /TFeed (STK,ES)	$1 \times 10^{-61b}$ /TFeed
Finish Mill w/Baghouse		$1.3 \times 10^{-71b}$ /TFeed (STK,ES)	$1 \times 10^{-71b}$ /TFeed
Finish Mill Air Separator w/Baghouse			$2.6 \times 10^{-61b}$ /TFeed (STK,ES) <sup>43/</sup>
<u>WET PROCESS</u>			
Kiln w/ESP	$7.4 \times 10^{-61b}$ /TFeed (STK,ES)	$2 \times 10^{-41b}$ /TFeed (STK,ES)	$2 \times 10^{-51b}$ /TFeed <sup>43/</sup>
Raw Mill w/Baghouse			$2 \times 10^{-51b}$ /TFeed
Clinker Cooler w/ESP or Baghouse	$1.7 \times 10^{-61b}$ /TFeed (STK,ES)	$1 \times 10^{-41b}$ /TFeed (STK,ES)	$1 \times 10^{-51b}$ /TFeed <sup>44/</sup>
<u>PIPE KILN (PULVERIZED COAL)</u>			
Kiln w/Spray, Settle & Baghouse	$4.6 \times 10^{-51b}$ /TFeed (STK,ES)	$6.9 \times 10^{-51b}$ /TFeed (STK,ES)	$5.7 \times 10^{-51b}$ /TFeed

a/ EST = Estimate; MB = Mass Balance; SITE = Site Visits, SURV = Survey of Companies, UNK = Unknown (in literature); STK = Stack Sampling Results; CONC = Concentration of Cd in feed, fuel, or emissions (w/STK); ES = Emission Spectroscopy, AA = Atomic Absorption (FL-Flame), NA =

the sources. It is clear that significant differences can exist among tests on different sources. As such, although the emission factors are probably adequate for the purpose of evaluating differences among source categories, care must be taken in the application of these factors to any particular source.

After emission factors and emission levels were determined for particular source categories, sources were evaluated to determine if an individual source had the potential to cause a measurable level of cadmium (assumed to be  $0.1 \text{ ng/m}^3$  on an annual average). Screening was accomplished by modeling a very large plant in each category under very astringent assumptions of stack height, flow rate, temperature and meteorology. The evaluation procedure was not designed to determine what expected levels of cadmium might be, but to determine if any possibility existed that the source could cause a measurable level. A more detailed modeling effort was undertaken during the cadmium exposure analysis.

Table E-3 lists the source categories which were determined to be potentially able to cause a measurable level of cadmium. These sources were further evaluated in the second phase of this study to evaluate the population potentially exposed.

TABLE E-3

SOURCE CATEGORIES POTENTIALLY ABLE TO  
CAUSE A MEASURABLE LEVEL OF CADMIUM

Primary Zinc Smelters  
Primary Copper Smelters  
Primary Lead Smelters  
Primary Cadmium Smelters  
Secondary Zinc Smelters  
Secondary Copper Smelters  
Municipal Incinerators  
Iron and Steel Mills

---

a/ Assumed to be  $0.1 \text{ ng/m}^3$  on an annual average.

## SECTION I

### INTRODUCTION

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

This report focuses on three of the areas of information required to make this determination--identification of the uses and sources of cadmium, development of emission factors for cadmium from industrial sources, and the screening of cadmium sources to determine which sources are potentially "significant" sources of ambient cadmium. For screening purposes of this report, a "significant" source is one which, by itself, can cause a measurable ambient level of cadmium.

A companion study<sup>1/</sup> takes information from this study to provide an estimate of the population exposed to measurable levels of cadmium. Neither this report, nor the companion report on population exposure, draws any conclusions as to the health consequences of ambient cadmium levels. Rather, the purpose of the two reports is to provide a relative ranking of sources, both by the magnitude of emissions and the population exposed, and to provide information in such a way so as to allow EPA to make informed estimates of any health implications of the reported emissions and exposures.

The report is organized into several sections summarized below:

- Section II provides an overview of the physical and chemical properties of cadmium, as well as the routes through which cadmium exposure could occur.
- Section III provides an overview of the methodology used in preparing this report.
- Section IV discusses the current and expected uses of cadmium.
- Section V discusses the potential emission sources for cadmium. For each source, a brief description of the process, cadmium emission points, and the emission factors are described. Total current and expected cadmium emissions and available control technology are also discussed.
- SECTION VI discusses the screening of the various cadmium sources which was used to determine which cadmium sources can cause a measurable level of cadmium ( $0.1 \text{ ng/m}^3$  on an annual average).

## SECTION II

### CADMIUM IN THE ENVIRONMENT

#### A. Introduction

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

#### B. Physical and Chemical Characteristics of Cadmium

Cadmium is a relatively rare element in the earth's crust. It occurs at a concentration of 0.1 to 0.5 ppm, ranking in abundance between mercury and silver, and thus, not in sufficient quantities to be mined as an ore.<sup>2/</sup> Table III-1 shows the physical properties of cadmium. Cadmium is always associated with zinc and is usually present as a sulfide.<sup>4/</sup>

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

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

Cadmium metal is ductible, easily soldered can and can be readily electroplated and maintains a lustrous finish in air.<sup>5/</sup> These properties lead to the use of cadmium as a protective coating on iron and steel products.

#### C. Multi-Media Nature of Cadmium Exposures

While this report is focused on the atmospheric emissions of cadmium, it is important to recognize the overall cycle of cadmium in the environment. Measurable levels of cadmium occur in all phases of environmental concern (air, water, food, solid waste), and in almost all areas. One author<sup>6/</sup> refers to cadmium as the "dissipated element." EPA in 1975<sup>7/</sup> estimated that about 1,800 Mg/year of cadmium was lost to the environment. Of this, about 18 percent was in atmospheric emissions, 75 percent in solid waste, and the remainder in water-borne emissions.

Measurable cadmium levels have been found in air, water, soil and food. Atmospheric concentrations generally have been measured in the center of urban areas and generally range from  $0.1 \mu\text{g}/\text{m}^3$  down to below the detectable limit. Typical urban concentrations are in the range of  $0.003 \mu\text{g}/\text{m}^3$ . Due to the low solubility of cadmium compounds, levels of cadmium in water supplies are generally low. Main sources of cadmium are discharges from mining operations, leaching from soil disposal of wastes and rain-out from atmospheric emissions.

Cadmium in food results from a wide variety of sources. Listed in order of importance from a recent Battelle Report,<sup>8/</sup> they are:

- (1) Direct contact by plants or uptake from soils by plant roots. Cadmium may occur in soil:
  - a. Naturally as a normal constituent of soils of marine origin.



- b. As an impurity (cadmium oxide) in phosphate-treated soils, especially in those treated with "superphosphate."
  - c. By fertilization with sludge containing cadmium.
  - d. By desposition of cadmium-containing pesticides or as a contaminant of zinc-containing pesticides.
  - e. From run-off of mine tailings or from electroplating washing process.
- (2) Accumulation in animal tissues due to:
- a. Feeding on crops which have absorbed cadmium. (The organs of such animals may have very high cadmium concentrations.)
  - b. Treatment with cadmium-containing helminth kilers, used especially in swine.
- (3) Concentrations of cadmium by molluscs and crustaceans and most other aquatic organisms from ambient waters.
- (4) Use of zinc-galvanized containers, cans, cooking implements or vessels; or utensils used in food preparation, particularly grinders, pressing machines, or galvanized netting used to dry fish and gelatin.
- (5) Adsorption of cadmium contained in wrapping and packaging materials such as paper, plastic bags, and tin cans.

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

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

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

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

TABLE II-2

CADMIUM CONTENT OF SELECTED ADULT FOODS a/

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

---

a/ Source: Reference 8

TABLE II-3

MEDIA CONTRIBUTIONS TO NORMAL RETENTION  
OF CADMIUM<sup>a/</sup>

<u>Medium</u>	<u>Exposure Level</u>	<u>Daily Retention</u> (ug)
Ambient air	0.03 µg/m <sup>3</sup>	0.15
Water	1 ppb	0.09
Cigaretts:		
<u>Packs/Day</u>	<u>ug/day</u> <sup>b/</sup>	
1/2	1.1	0.70 <sup>c/</sup>
1	2.2	1.41 <sup>c/</sup>
2	4.4	2.82 <sup>c/</sup>
3	6.6	4.22 <sup>c/</sup>
Food	50 µg/day	3.0

---

a/ Source: Reference 8.

b/ Based on 0.11 µg per cigarette.

c/ Assumes a 6.4 percent retention rate.

## SECTION III

### METHODOLOGY

#### A. Introduction

This section describes the general methodology used in evaluating sources of cadmium emissions and in determining the magnitude and significance of these sources. In simplest terms, the methodology can be viewed as having five components:

- Determination of potential cadmium emission sources;
- Determination of emission factors for these sources;
- Estimation of current and future emissions of cadmium;
- Evaluation of control technology for reducing cadmium emissions from these sources; and
- Screening of all potential cadmium sources to identify the sources most likely to cause measurable ambient levels.

#### B. Determination of Potential Cadmium Emission Sources

A literature search and a review of previous EPA studies was carried out to determine the sources most likely to emit cadmium. The basic procedure followed in this study, as well as

in previous studies, was to concentrate on the production and uses of cadmium, and then to follow cadmium through to its ultimate disposal.

Once the potential sources were identified, trade literature and other references were used to develop process descriptions, identify potential emission sources, and estimate total current and projected production. Special emphasis was placed on determining changes in production patterns which could lead to changes in emission characteristics. The sub-sections of Section V which discusses each industry identify the data used to develop the above information.

#### C. Emission Factor Determination

For each source identified as potentially emitting cadmium, the literature was surveyed to determine the amount of cadmium emitted per unit of product produced. For most sources, several types of data were available and a ranking system was established in determining the final emission factor. The data were ranked in the following order:

- Actual Stack Tests--Stack tests conducted on several sources, or even one source, and analyzed by a quantitative analytic technique such as atomic absorption (AA). Stack tests conducted using a semi-quantitative technique such as emission spectroscopy (ES) were given a somewhat lower ranking. The primary source of stack tests using ES came from EPA tests in support of particulate new source performance standards.

- Concentration of Cadmium in Feed--For fuel burning sources, data on incoming cadmium levels can be used to determine cadmium emissions relatively accurately if 100 percent loss of cadmium is assumed. This assumption is reasonable because of the high volatility of cadmium.
- Mass Balances--For several sources, the only data available came from an estimate of the losses of cadmium during processing. Data comes from site visits carried out by EPA during earlier emission factor development and engineering judgement on process operations.

For each source type, several emission factors were developed:

- Minimum Emission--Lowest emission factor reported by any study.
- Maximum Emission--The highest emission factor reported by any study.
- Best Judgement--The best estimate of emissions when the quality of all the data is considered and the ranking system described above is used.

As with any substance, cadmium emissions can vary greatly from source to source, and the accuracy of any specific emission factor for a specific plant is questionable. The emission factors developed here are probably sufficiently accurate for the purposes intended (relative evaluation among source categories),

but care should be taken in applying the factors to any specific plant.

#### D. Computation of Emission Levels

The production levels for each source category and the emission factors previously developed were combined to provide an estimate of total current cadmium emissions. The emission factors were modified (where necessary) to reflect the application of typical control technology.

#### E. Source Screening

To determine which source types are capable of causing a measurable level of cadmium (assumed to be an annual average of  $0.1 \text{ ng/m}^3$ ), a screening procedure was developed. While the detailed procedure for screening varied from source type to source type (each is discussed in Section VI), the general procedure is as follows:

- For each source type, an expected largest or very large source in each type was determined from the literature.
- A very conservative combination of stack conditions was then determined. These conditions (stack height, temperature, flow, etc.) were based on engineering judgement, coupled with limited data available in the literature. Every assumption was made such that ground level concentrations would be maximized.



- Emissions were based on maximum emission factors and plants were assumed to produce their rated capacity in only eight hours of operation.
- Ambient concentrations (for point sources) were determined using the EPA "PTMAX" model. If these concentrations exceeded the detectable limit  $C.lng/m^3$ ), further analysis was required. This criterion is extremely conservative because the PTMAX estimates one-hour concentrations, which are typically at least ten times higher than annual averages.

It is recognized that the above approach is extremely conservative and the results are much higher than would normally be estimated. However, the purpose of the screening is to determine what sources have almost no potential for causing measurable levels of cadmium. Further analysis of the sources which passed this screening was carried out using the EPA CRSTER model and more reasonable stack assumptions. The results of this analysis are discussed in the companion study to this report.

## SECTION IV

### USES OF CADMIUM

#### A. Introduction

Consumption of cadmium in the United States has averaged approximately 5,000 metric tons a year over the past several years. In 1975, almost 40 percent of the cadmium used in the U.S. was imported.

There are four major uses of cadmium, all of which are dissipative (Figure 1). In 1974, approximately 46 percent (2,700 metric tons) of the cadmium consumed in the U.S. was used by the electroplating industry. Paint pigment manufacturing required close to 1,000 metric tons of cadmium in 1974, and 900 metric tons were used to produce plastic stabilizers.<sup>1/</sup> The fourth major use of cadmium in 1974 was the nickel-cadmium battery, for which 550 metric tons of the metal were used.<sup>1/</sup> Cadmium is also used in nuclear reactor controls, fluorescent phosphors, and in alloys.<sup>1/</sup>

#### B. Electroplating

Electroplating a metal with cadmium inhibits corrosion and enhances solderability. Products made of iron and steel are most frequently coated with cadmium, including motor vehicle parts, industrial machinery parts, aircraft parts, marine equipment, and hardware.

There are several reasons why cadmium is preferred as a coating material. Only a thin coating is necessary to provide

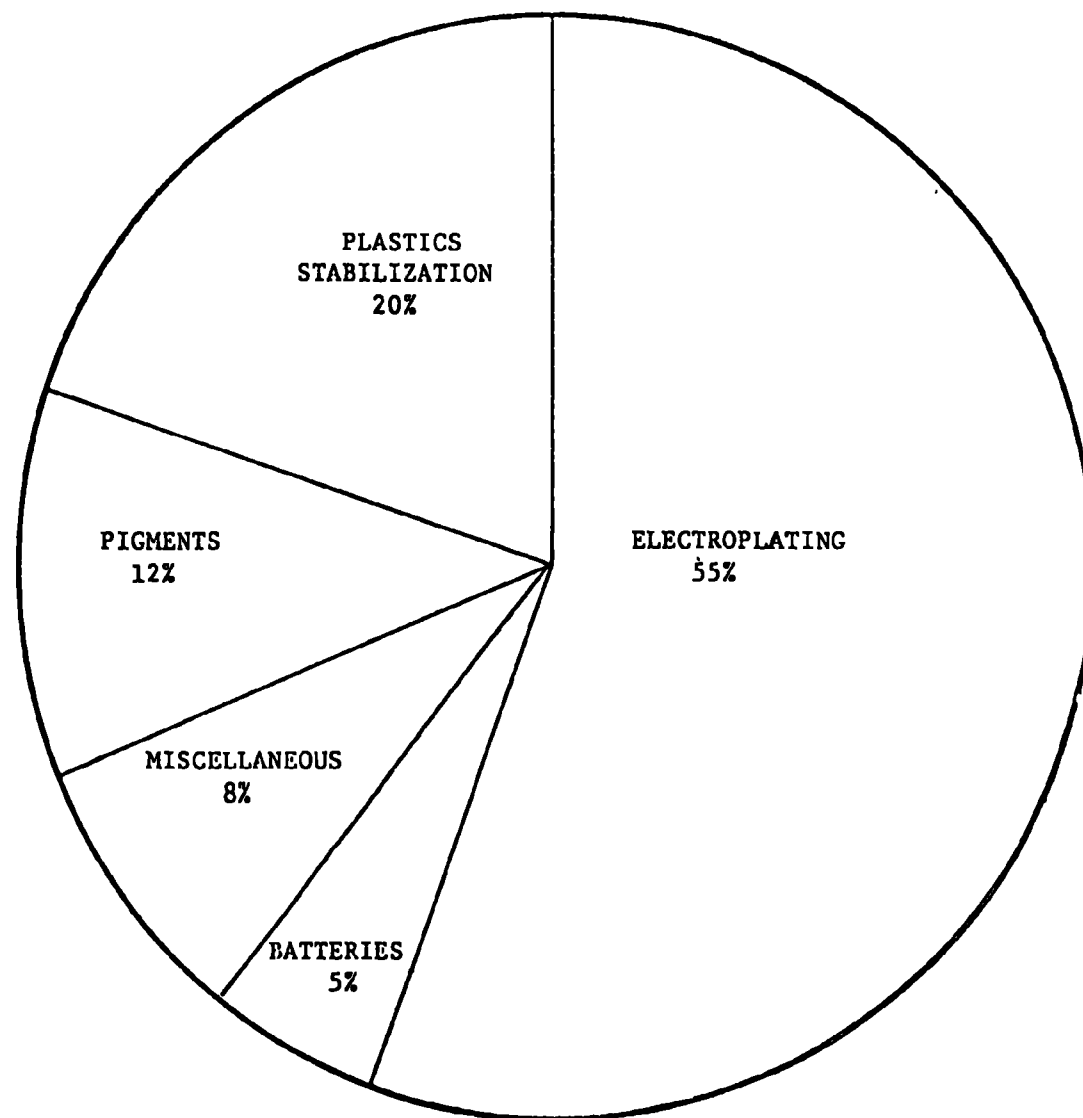


FIGURE 1

CADMIUM CONSUMPTION IN THE UNITED STATES (1)

adequate protection from corrosive elements, especially salt water and alkalies. It is possible to obtain a uniform deposition on objects of intricate design, and luster is maintained for a long period of time. Although several substitutes exist, cadmium is believed to be superior.

#### C. Paint Pigments

Paint pigment production accounts for approximately 20 percent of the U.S. consumption of cadmium. The cadmium-sulfide compounds are used to obtain colors ranging from yellow to orange, while the cadmium-sulfoselenide compounds produce colors ranging from orange to light red and deep maroon.

It has been estimated that approximately 75 percent of the pigments are used to color plastic. Other uses for cadmium pigments include water-base paints, rubber, artists' colors, printing inks, glass, textiles, enamels, and ceramic glazes.

Cadmium pigments have certain properties which render them difficult to replace. Because they are totally non-bleeding and alkali-resistant, they are particularly suitable for plastic automobile interior parts. The pigments provide very bright colors and a high degree of opacity. Their high temperature properties contribute to the unique character of the pigment.

#### D. Plastic Stabilizers

The third major consumer of cadmium is the plastic stabilizer industry. Heat stabilizers containing cadmium have been found to halt or slow discoloration caused by the breakdown of polyvinyl chloride resin during molding. The stabilizers are found in almost every plastic material with the exception of food packaging, where use is prohibited by FDA regulations.

Substitutes for the cadmium plastic stabilizers may be forthcoming in light of FDA regulations. Stabilizers of calcium-zinc composition have been found to be competitive in both performance and cost, and are expected to replace the cadmium stabilizer in some items sometime in the future.

E. Nickel-Cadmium Batteries

The nickel-cadmium battery is the fourth major product composed of cadmium. Demand for cadmium in this segment of the industry tripled between 1968 and 1973. Batteries range in size from small button cells (614 mm in diameter) to large rectangular cells (113 mm high by 91 mm long by 38 mm wide).

The nickel-cadmium battery is used in a variety of systems and products including alarm systems, pacemakers, and portable appliances and tools. Calculators presently are the largest market for the battery. The nickel-cadmium battery is preferable to others if long-life is important.

F. Miscellaneous

Cadmium is also used to produce alloys, primarily low temperature solders, silver bronzes, and a copper alloy used in automobile radiators. Nuclear reactor rods are often made of silver-cadmium. Cadmium phosphates are used for television and fluorescent tubes; silver-cadmium oxide is used in motor starting switches, relays, and circuit breakers.

## REFERENCES

1. \_\_\_\_\_, Determination and Evaluation of Environmental Levels of Cadmium, EPA 68-01-1983, Battelle-Columbus Laboratories, Columbus, Ohio, 1977.
2. Sargent, D.J. and Metz, J.R., Technical and Microeconomic Analysis of Cadmium and Its Compounds, Environmental Protection Agency, 560/3-75-005, June 1975.

## SECTION V

### SOURCES OF ATMOSPHERIC CADMIUM EMISSIONS

#### A. Introduction

Cadmium, a relatively rare element in the earth's crust, does not occur alone naturally. It is a metal found only in conjunction with other metallic ores, principally zinc, lead, and copper. Released into the environment, cadmium can be absorbed, ingested or inhaled by biological systems, causing subsequent damage to these systems. This study focuses upon one form of environmental release--emission to the atmosphere.

Airborne cadmium emissions result from the production of cadmium, its use (primarily dissipative), and the use of other substances which are contaminated with cadmium. Cadmium is produced commercially as a by-product of the primary production of zinc, and is found in the ores of lead and copper also. As a result, the mining and primary smelting of these three metal ores produce approximately 56 percent of the cadmium emitted to the air. Cadmium is a major constituent in the production of paint pigments, metal alloys, plastic stabilizers, and nickel-cadmium batteries. Metals are often electroplated with cadmium. Substances which contain cadmium as a contaminant include phosphatic fertilizers, sewage sludge, fossil fuels, cement, and fungicides. All of these materials contribute to the emission of cadmium into the environment.

Each process which contributes to the amount of cadmium in the air is described in the following sections, together with

control devices used, and national production trends for the near future.

## B. Mining

The mining of zinc, lead, and copper is a source of airborne cadmium emissions, though the quantities emitted are small--less than one ton a year.

### 1. Process

The process of preparing each metal ore for shipment to a primary smelter involves two steps, mining and beneficiation. First, the large chunks of ore are removed from the ground, crushed, and ground to fine, sand-sized particles. The concentration process which follows is most often done using a combination of gravity and flotation mechanisms or using flotation alone; however, some plants use only gravity settling. At this point, any cadmium in the ore is present in the zinc concentrate. Ore beneficiation is usually conducted in close proximity to the mine, particularly in the western states.

### 2. Emissions Source and Control

The major emissions from this phase of the metal production are a result of the dust which escapes during mining and crushing. Because beneficiation is a wet process, air emissions from this phase are minimal. Control methods are rarely needed or used during the ore-crushing procedures due to the effective design of the equipment; however, in any raw material handling, a hood and a cyclone, baghouse, or the electrostatic precipitator (ESP) is used.<sup>1/</sup>



### 3. Emission Estimate

Emission factors used in this estimate were  $1 \times 10^{-3}$  pounds/ton of zinc in the ore,<sup>2,3/</sup>  $1 \times 10^{-4}$  pounds/ton of lead in the ore,<sup>2,3/</sup> and  $3.2 \times 10^{-5}$  pounds/ton<sup>2,3/</sup> of copper in the ore.\* From these emission factors and production figures, the emissions estimate of less than one ton of cadmium per year was developed. Estimates from other organizations are in agreement with EEA's, as similar emission factors were used (GCA-- $<1 \text{ ton}^2/$ ; Mitre-- $<1 \text{ ton}^{11/}$ ; Davis-- $<1 \text{ ton}^7/$ ; EPA-- $<1 \text{ ton}^6/$ ).

### 4. Future Trends

It is believed that the mining of the various metal ores will increase by 7.5 percent (compounded annually) each year through 1985.<sup>41/</sup> Even with this increase, cadmium emissions from mining and ore beneficiation are predicted to remain below one ton/year.

## C. Primary Metal Production

Primary metal production involves conversion of an ore concentrate to a relatively pure metal. Three primary metal production processes--zinc, lead, and copper--are responsible for over 50 percent of all airborne cadmium emissions.

### 1. Primary Zinc

#### (a) Process

The primary smelting of zinc produces both zinc and cadmium metal and thus produces airborne cadmium emissions. There

---

\* Production of ore at various mines in 1974 equaled 478,850 tons of zinc ore,<sup>12/</sup> 603,024 tons of lead ore,<sup>12/</sup> and 1,414,246.8 tons of copper ore.<sup>12/</sup>

are two basic methods used to obtain the desired output--pyrometallurgical and electrolytic extraction. The first step in each process is the roasting of the zinc concentrate, during which zinc sulfide is converted to zinc oxide. The sulfur which escapes from this process is often converted to sulfuric acid in a contact process acid plant.

In the pyrolytic reduction of the ore, the next step is sintering, which renders the material better to handle and use as feed. Smelting of the zinc oxide follows the sintering. Smelting is conducted in batches in horizontal retorts or continuously in vertical retorts, electrothermic furnaces, or blast furnaces. Addition of carbon to the zinc oxide at this point indirectly aids reduction of the oxide to the zinc metal, as it reacts more readily with oxygen than does the zinc. The metal is then vaporized, transferred from smelter to condensers, converted to molten zinc, and cast into slab zinc. Slab zinc is frequently purified further by redistillation.

Electrolytic zinc recovery was developed chiefly for the processing of low-grade or mixed ore concentrates. As high grade zinc deposits are depleted, this process will assume an increasingly important role in the processing of zinc (and other metals).

Any likeness of the electrolytic process to the pyrometallurgical processes ends with roasting. In electrolytic recovery, the roasted zinc ore is leached with sulfuric acid to produce soluble zinc sulfates. Filtration to remove insoluble impurities (including cadmium) is followed by treatment of the solution with zinc dust. This treatment is done twice--the first time to remove copper impurities, and the second to produce a zinc-cadmium residue. It is possible to continue further processing of these residues to recover the copper and cadmium contained in them.

In the next step, zinc metal is produced by processing of the zinc sulfate solution in electrolytic cells. The zinc is then electrodeposited onto aluminum cathodes. At regular intervals, the cathodes are removed from the electrolytic cells, the zinc is stripped from the aluminum, and then melted to produce slab zinc. Slab zinc produced in this manner does not usually require any additional refining, as it is of very high purity. It is not possible to process scrap in this manner as it contains too many impurities.

Figure 1 illustrates the primary zinc smelting process.

#### (b) Emission Sources

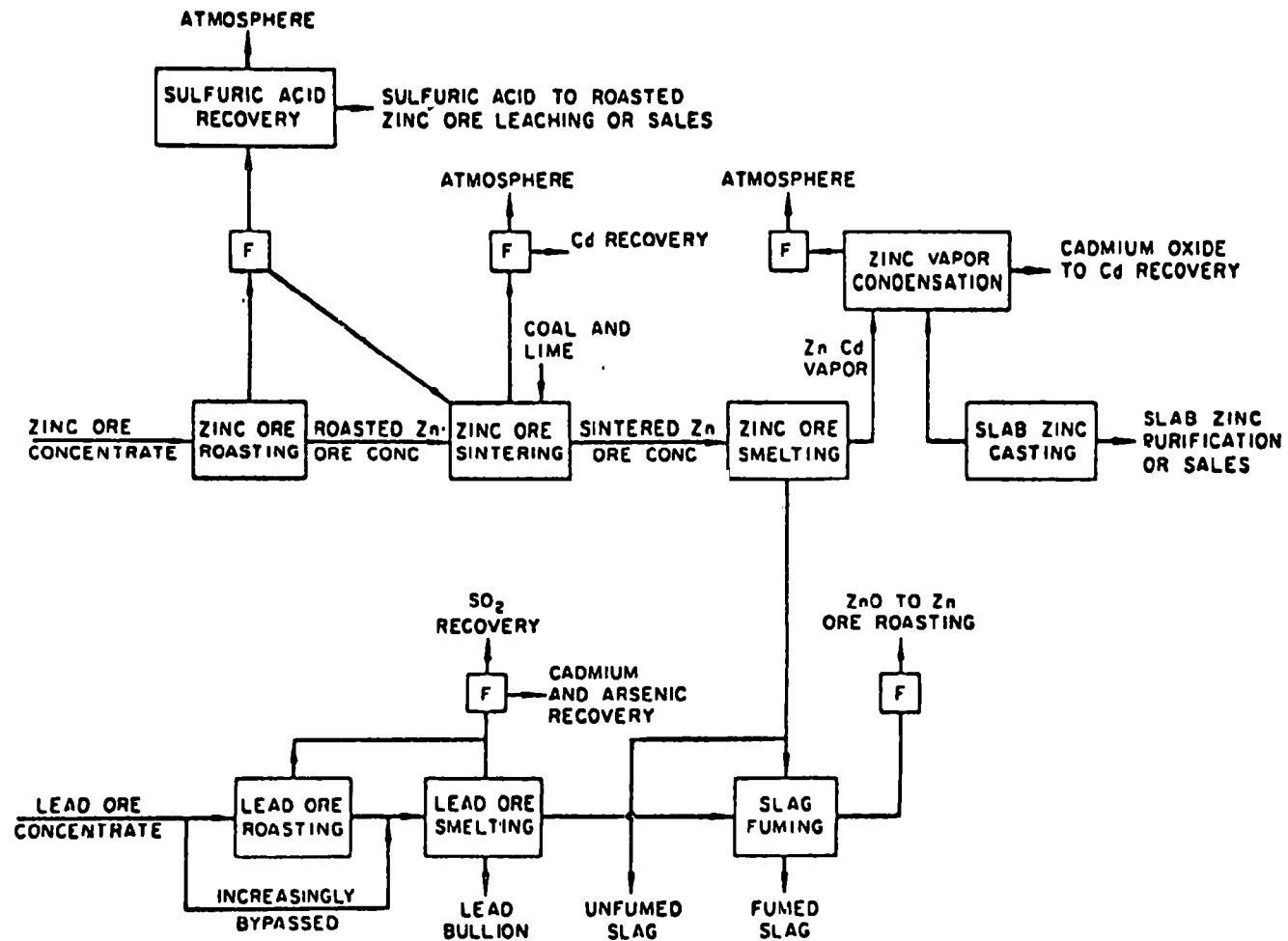
The processes which contribute most to the release of airborne cadmium emissions are thermal processes, as cadmium has very low melting and boiling points ( $321^{\circ}\text{C}$  and  $767^{\circ}\text{C}$ , respectively). Therefore, roasting, sintering, and reduction in the pyrometallurgical process would warrant the closest attention, as they probably would be responsible for most of the airborne cadmium emissions.

The roasting procedure, part of both the pyrometallurgic and electrolytic processes, is not considered a source of large cadmium emissions. Control technology used at roasting facilities is highly effective and allows almost no emission of cadmium into the air.<sup>6/</sup>

Sintering is considered the major potential source of cadmium, and is done at all pyrometallurgical plants. Reduction of the sintered ore is considered a source of airborne cadmium only if the externally-fired horizontal retort is used, as this configuration is not conducive to particulate control. Only one

FIGURE 1

PRIMARY SMELTING PROCESS OF ZINC AND LEAD<sup>2/</sup>



domestic plant (National Zinc) employs the horizontal retort, and it is expected that in the near future this retort will be replaced.

Electrolytic processing is considered to be relatively free of airborne emissions. A minor potential source of airborne cadmium emissions does exist in the filtration which follows leaching.

#### (c) Control

High efficiency control devices are employed at all zinc smelters. Roaster facilities at all smelters use fabric filters or electrostatic precipitators (ESP). Sintering emissions are also controlled with fabric filters or ESPs.<sup>1/</sup>

#### (d) Emissions Estimates

Estimates of the cadmium released into the air through primary zinc production made by EEA have been compared with estimates from other sources. EEA's emission factors, with assumed control technologies, were derived from several sources and expressed in pounds per ton of zinc produced. Yost (1974), and Jacko and Nuendorf (1977) measured coking emissions of 2.34 pounds/ton of zinc throughput using stack sampling<sup>4,5/</sup> and atomic absorption (AA) analysis. Sintering with a cyclone produces emissions at a rate of 6.32 pounds/ton of zinc produced, while sintering with controls of a cyclone and an ESP releases 2.16 pounds/ton of zinc throughput.<sup>5/</sup> The vertical retort, at the particular plant where the stack tests were conducted, emitted  $6.50 \times 10^{-2}$  pounds/ton of zinc throughput. It should be noted that these particular test results, though highly accurate in both sampling and analysis, may not be typical. Vertical retorts, which produce high emissions, are uncommon in the U.S.;

in addition, high zinc losses were a problem at the plant, largely due to the high temperatures in the coking operation which was volatilizing zinc and thus, cadmium also. The Sargent (1975) study concluded that roasting emits negligible amounts of cadmium into the air. Sargent's other estimated emissions factors which EEA used include:  $6 \times 10^{-3}$  pounds/ton of zinc produced in a horizontal retort;  $1.2 \times 10^{-2}$  pounds/ton of zinc produced by the electrothermic process; and negligible emissions from electrolytic processes.<sup>6/</sup> Overall emissions rates varied between 1.43 pounds/ton of zinc and 2.96 pounds/ton of zinc.<sup>3,7,8/</sup> To calculate an emissions estimate, a factor of 2.5 pounds/ton of zinc produced for nonelectrolytic processes was estimated by weighting the atomic absorption stack sampling results more heavily than previous mass balances.

Production figures (1974) of 423,000 tons of zinc processed pyrometallurgically and 121,945 tons of zinc processed electrolytically were combined with the overall emissions factor to obtain EEA's emissions estimate of 529 tons yearly.

The above estimate compared favorably with others made previously and was very close to the GCA estimate of 500 tons/year.<sup>2/</sup> Mitre found that 619 tons of cadmium were released in primary zinc smelting,<sup>11/</sup> EPA estimates 644 tons of cadmium,<sup>18/</sup> and Sargent estimates 112 tons.<sup>16/</sup> The Sargent estimate is lower than others made because it assumes 95 percent or better cadmium collection efficiencies which are presently attainable.

The production at primary zinc smelters increased in 1976 for the first time since 1972.<sup>9/</sup> In the years between 1972 and 1976, production had steadily decreased. This may account for the variety of emissions estimates obtained. Both the Mitre and EPA estimates were made before the decline in production

occurred. GCA's was made during a low point and EEA's, based on 1974 data, illustrates the effect of more recent emission factors.

(e) Future Trends

Future emissions are expected to decrease over the next eight years in spite of an anticipated substantial increase in capacity. Between 1967 and 1975, the zinc industry lost nearly 50 percent of its capacity due to environmental problems, rising costs, and scarce capital.<sup>9/</sup> In 1976, however, there was a small increase in zinc production (4.6 percent) over 1975 and projections for 1977 indicate a 9.6 percent increase in production over 1976.<sup>9/</sup>

The zinc market is expected to remain stable. No large decrease in use is anticipated. There is a possibility of increased use of zinc by the steel industry, as the use of thinner gauge steel will create the need for increased corrosion protection (zinc-coated steel).

Domestic smelter capacity is expected to increase steadily through 1985. For example, ASARCO has planned to open 180,000 ton/year electrolytic plant in Kentucky during 1979.<sup>9/</sup> If present industry expansion plans continue, 1,000,000 tons of zinc would be produced in the United States in 1985.<sup>9/</sup>

Increased construction of electrolytic zinc-processing plants has led EEA to conclude that cadmium emissions from this source is estimated to remain constant at 529 tons/year. This is a high estimate, as the nonelectrolytic plants now in operation will probably be phased out and replaced by electrolytic plants.

## 2. Primary Lead

Primary lead is a source of cadmium emissions, but does not contribute greatly to the production of commercial cadmium metal. Lead is produced in much the same way as zinc, therefore, only a brief discussion of the process follows.

### (a) Process

Roasting is usually the first step which the ore concentrate undergoes in the process of purification and metal production. However, this is not always done with the lead concentrate. More often, the sintering machine or electric furnace receives the lead sulfide ore concentrate directly. During the sintering process, the concentrates are combined with coal, lime and silica flux, then reduced to the lead metal. At a blast furnace, the ore is initially reduced to molten metallic lead and then removed as lead bullion at specific intervals.

Slag processing is more common in primary lead smelting than in zinc smelting. The slags are placed in a fuming furnace, brought to the proper temperature and mixed with powdered coal which burns and volatilizes most of the zinc remaining in the slag. Any residual lead is also collected.

Figure 1 illustrates the processing of primary lead.

### (b) Emission Sources

As in zinc smelting, thermal processes are the cause of most emissions from lead smelting.

Roasting is not considered a pollution source, as it is often deleted, and when used, employs as good control technology. Sintering operations create most of the airborne cadmium emissions



in lead ore concentrate processing. With the exception of one plant, all use updraft sintering which is considered superior to other types. Reduction blast furnaces are also a source of cadmium emissions; however, all plants use extremely efficient particulate collection apparatus on the sinters and blast furnaces.

#### (c) Control Technology

In attempting to control the emission of cadmium to the atmosphere, several collection devices are employed in primary lead processing. Emissions from sintering and blast furnaces are usually controlled with a cyclone plus a baghouse or an ESP. A waste heat boiler plus baghouse or ESP is used with the reverberatory furnace. In handling material from any of the steps of the processes, a hood and a settling chamber, cyclone, ESP, or baghouse is used to control emissions.<sup>1/</sup>

#### (d) Emissions Estimate

The emissions of cadmium from lead processing are estimated to equal two tons/year. Using data from several sources,<sup>2,7,8,10,11/</sup> an emissions factor of  $1.1 \times 10^{-1}$  pounds/ton of lead produced was obtained, assuming 3.0 percent cadmium in the particulate emissions. With a 95 percent control efficiency, the factor was used with a production figure of 866,095 tons (1974)<sup>9/</sup> to arrive at the above figure. The estimate is lower than those previously made (Mitre--55;<sup>11/</sup> EPA--163;<sup>2/</sup> GCA--65<sup>2/</sup>), as the previous estimates were based on mass balances of the amount of cadmium in the feed material, assuming no control or, at most, a 50 percent control efficiency.

#### (e) Future Trends

At present, the primary lead industry is slowly recovering from the depressed level of 1975 with a growth rate of approximately 1.6 percent (compounded annually) expected through 1985.<sup>9/</sup>

The major uses of lead include storage batteries, gasoline anti-knock additives, and pigments. The battery market is considered strong. A substantial increase in demand is due to the desire on the part of the consumer for a longer-lasting battery, which requires 20-30 percent more lead for each unit. There is a possibility that batteries with longer lives may lead to a depressed market by 1985.<sup>9/</sup>

The demand for lead by the gasoline industry is expected to drop sharply. This market, which usually accounts for 17-18 percent of the lead consumed, faces a reduction potential of 70 percent in demand over the next few years.<sup>9/</sup>

Modifications of the catalytic converter and internal combustion engines which would allow use of leaded gasoline are still under study. This could bring about increased demand for lead, but the feasibility still remains unclear. Lead in paint pigments accounts for approximately six percent of total lead production, an increase over the last several years.

At present, producers are hesitant to increase capacity because of environmental regulation uncertainty and, at this point, production equals only 87 percent capacity.<sup>9/</sup> Therefore, growth is expected in a steady, slow manner. NSPS regulations are not likely to affect the lead industry, as no new construction is being considered for the near future. EEA projects that a total of two tons/year of cadmium will be released into the air as a result of primary lead processing by 1985.

### 3. Primary Copper

Copper production constitutes a source of cadmium emissions into the atmosphere, but the concentration of the cadmium in the

ore is too low for an economical recovery. Emissions from this source are generated in much the same manner as those from lead and zinc.

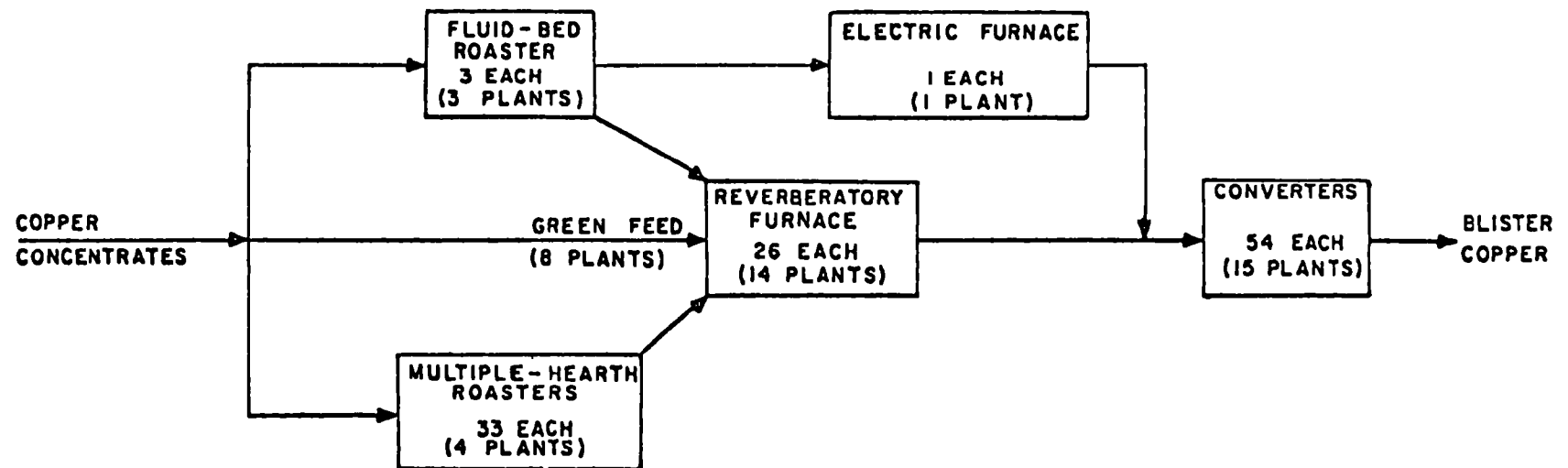
#### (a) Process

Ores which contain low percentages of copper are first subjected to a grinding and flotation process to produce a high percentage copper concentrate. The concentrate is then roasted to remove excess sulfur, and is placed in the reverberatory furnace. Here, a slag is formed through a combination of iron oxide and siliceous flux; a matte of copper, iron, and some sulfur is left. The convertor then reduces the matte to copper metal. To accomplish this, a stream of blowing air first eliminates sulfur. Then, a second stream of air reduces the copper sulfide to metal. At this point, the blister copper is refined further by fire-refining to reduce sulfur and oxygen, and the refined metal is then cast. (Figure 2.)

#### (b) Emission Sources and Control

The thermal processes are again responsible for cadmium emissions. Roasting is considered a source of emissions in the copper production, and is usually controlled with a settling chamber, water spray, and some use of the ESP. Reverberatory furnace emissions are controlled with the ESP; converter emissions are controlled with settling chamber plus cyclones, and, at times, with an ESP. The settling chamber with cyclone is only good for larger particulates; therefore, control is not as efficient as possible at some smelting plants.

FIGURE 2  
PRIMARY SMELTING PROCESS OF COPPER<sup>2/</sup>



### (c) Emission Estimates

Primary copper production is a major source of atmospheric cadmium emissions. Two sets of emissions factors have been found, one for emissions from uncontrolled facilities, and one for facilities with the baghouse filter. In an uncontrolled smelter, emission factors range from a possible  $7 \times 10^{-2}$  pounds/ton of copper to  $2.9 \times 10^{-1}$  pounds/ton of copper.<sup>2,7,8,10/</sup> A best judgement figure of  $1.5 \times 10^{-1}$  pounds/ton of copper was developed from an average of five mass balance estimates. If all copper is produced without the use of control devices, 108 tons of cadmium would be released yearly. However, copper smelters employing baghouse control devices release only  $7 \times 10^{-3}$  pounds for every ton of copper produced.<sup>2/</sup> Five tons per year are emitted from these smelters. EEA's estimate for uncontrolled copper smelter emissions is very closely aligned to GCA's of 110 tons/year,<sup>2/</sup> while EPA<sup>2/</sup> and Mitre<sup>11/</sup> estimates equal 234 tons and 388 tons, respectively. Both these emissions estimates were made at earlier dates before certain data were available.

### (d) Future Trends

There are several possible applications which would create an increased demand for copper, and some technologies which will cause a decrease in copper consumption. The factors should combine to increase copper production by 4.8 percent annually through 1985.<sup>9/</sup>

The recent energy shortages have encouraged the development of solar energy applications and electric cars. In comparison to the conventional 1975 model car with 41 pounds of copper, the electric car is expected to contain about 200 pounds per car. Desalinization technology, which employs copper alloy tube, has become an industry of significance in countries such as Saudi

Arabia. Fire sprinkler systems are becoming a required part of any new inhabited building, and this is expected to increase copper demand and production. An increasing use of electronics in the telephone industry has reduced the use of copper conductors, and glass fiber optics will produce the same effect. Therefore, emissions of cadmium from primary copper production are expected to increase to 13.4 tons/year by 1985 in controlled smelters.

#### 4. Cadmium

Unlike the other three metals discussed, cadmium is not mined, but rather is a by-product of other metal productions--primarily zinc. "Blue Powder," a part of the volatile product from zinc distillation, was at one time the major source of cadmium metal for commercial production. Most of the cadmium which is present in zinc and lead ore is now removed in earlier stages of processing.

There are several major sources of cadmium. Dust and fumes collected in the bag filters and ESP during roasting and sintering of the ores, and the cadmium and zinc filter cakes resulting from the purification of zinc sulfate solutions are two important sources.

Additional flue dusts, primarily from Mexico, are imported to meet consumption demands.

##### (a) Process

There are two basic methods used to recover cadmium; one which serves to extract the metal from zinc ore roasting and sintering flue dusts, the other which extracts the metal from

any leaching residues. Other processes are used to remove the metal from other flue dusts and slab zinc redistillation.

It is first necessary to insure that as much cadmium as possible is incorporated into the roasting and sintering flue dusts. This is done in one of two ways. In one, after roaster flue dusts have been returned to the roasted zinc ore concentrates, zinc chloride or sodium chloride is added. Sinter-scalping, the second method used to concentrate cadmium in flue dusts, involves releasing the "top" part of the sinter to zinc smelting, and recycling the bottom part (where most cadmium is collected) through sintering.

These dusts are then usually processed for cadmium recovery, which entails several steps. First, the cadmium is treated with sulfuric acid to become cadmium sulfate. During this treatment, lead is precipitated, filtered, and sent to a lead smelter in the form of lead sulfate. Next, a sponge is formed by addition of acid and zinc dust to the cadmium sulfate solution. The sponge is then washed and dried, mixed with coke and distilled. The resultant vapor is condensed and cast into metal balls or ingots. Any distillation residues are directed back to the sintering process. The sponge can also be purified through treatment with a high-grade zinc dust and converted to molten cadmium metal by adding molten caustic soda. This process decreases airborne emissions when compared to the direct melting of sponge.

In electrolytic production, the cadmium loss to flue dust is not as great, so that the dusts must be returned to the roasted zinc ore before sulfuric acid treatment in order to ensure sufficient cadmium concentration. The resulting solution is then mixed with zinc dust to remove any copper and to

produce a zinc-cadmium cake. This cake is often subjected to an air or steam treatment preceeding a sulfuric acid and electrolytic treatment. The final cadmium sulfate solution is obtained by adding zinc dust to the cake to produce a cadmium metal sponge which, in turn, is redissolved in the electrolyte. This solution is then electrolyzed to metal, deposited onto aluminum cathodes, stripped from the cathodes, and melted to cast ignots.

Cadmium is also recovered from lead and copper ores, though this is not usually done. Generally, it is not an economical practice.

It is also possible to obtain cadmium from the redistillation of contaminated zinc slab. The distillation is a two-step process. First, the impure zinc is placed in a still at a temperature which distills the zinc and cadmium to be condensed in a second still, while the lead remains behind. The zinc-cadmium mixture is then distilled at a temperature such that the cadmium is vaporized, while the zinc remains in a molten form. The cadmium is then condensed and cast.

See Figure 3 for a flow diagram of cadmium recovery from the above processes.

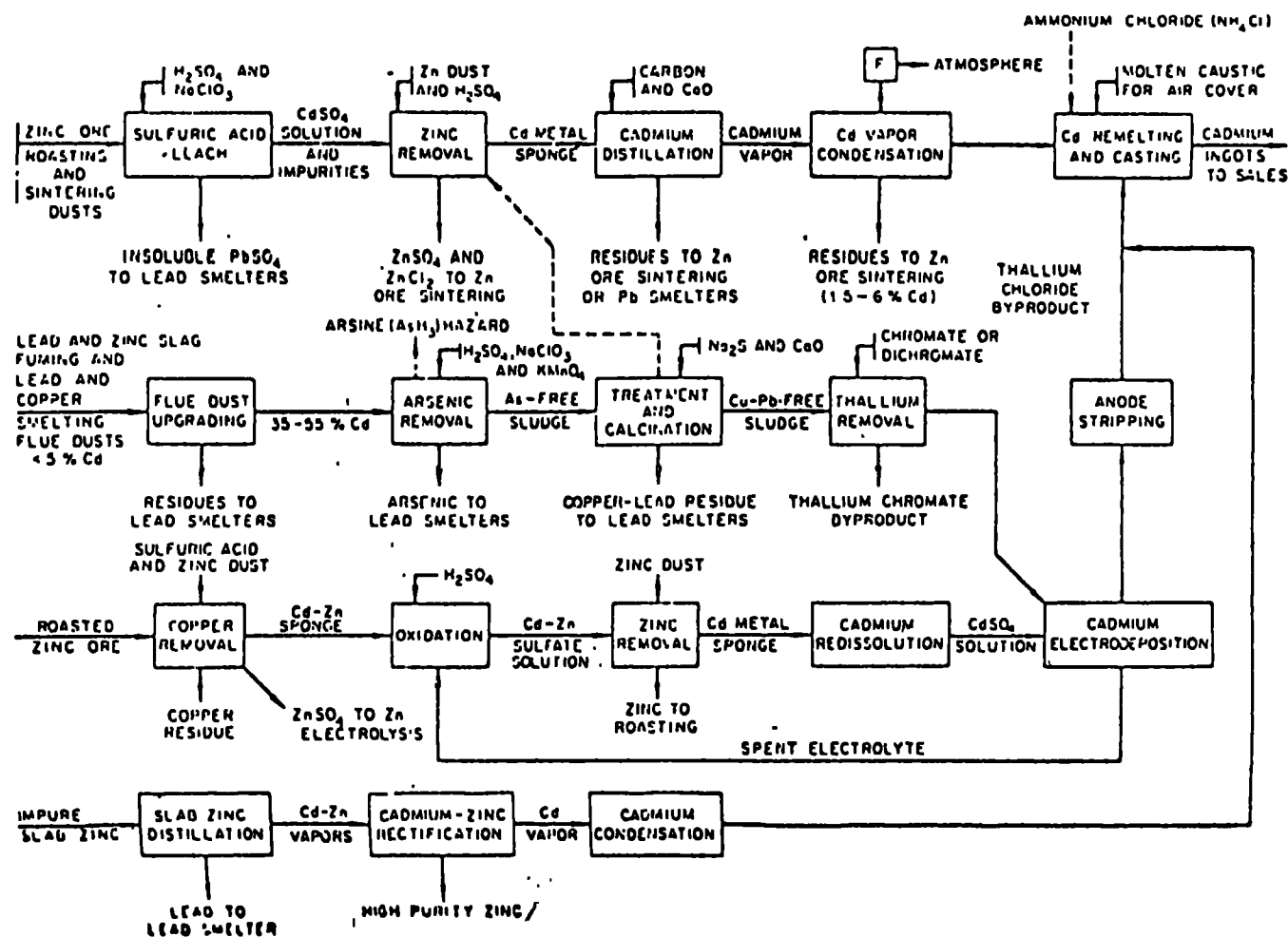
#### (b) Emissions Sources and Control

Emissions are again a result of the high temperature processes involved in the production of cadmium metal. Cadmium distillation and vapor condensation are major sources of cadmium emissions. Most cadmium purification processes are wet, so that many steps do not contribute to airborne cadmium. Most smelters employ high efficiency bag filters or ESPs as control devices to prevent cadmium emissions.<sup>1/</sup>



FIGURE 3

PRIMARY SMELTING PROCESS OF CADMIUM<sup>2/</sup>



### (c) Emissions Estimate

EEA's emissions estimate is lower than estimates by the EPA and GCA due to EEA's use of current data on control technology. Emission factors ranged from 25 to 30.5 pounds/ton cadmium produced.<sup>7,8,10/</sup> A "best judgement" (the average of three mass balance estimates) of 28 pounds of cadmium produced was used, together with a 1974 production figure of 3,088.2 tons<sup>12/</sup> to reach the estimated emissions of two tons of cadmium emitted from facilities with a 95 percent control efficiency. EPA<sup>2/</sup> estimated that cadmium production resulted in 60 tons/year and GCA<sup>2/</sup> estimate equals 50 tons.

### (d) Future Trends

Cadmium production has decreased quite steadily in the past five years, resulting in a drop from 3,760 tons in 1972 to 702 tons in 1976.<sup>12/</sup> This is due, in part, to the decreased use resulting from environmental regulations and is closely associated with the drop in production of zinc. However, cadmium production is not expected to continue its downward trend, but rather to increase along with zinc production in the near future. At present, cadmium is used for a variety of items which will be discussed in the following sections. However, it is possible that the producers of solar energy equipment could become large consumers of the metal. Cadmium production is linked to zinc production and, therefore, is expected to increase at a similar rate. Emissions are projected at less than one ton/year by 1985.

## D. Iron and Steel

The iron and steel industry contributes a large amount of cadmium into the air. These emissions are a result of the

melting of cadmium-coated scrap, usually number two steel scrap.\* Descriptions of the four major types of plants, including the sintering strand, the open hearth, the basic oxygen furnace, and the electric arc, are included with current industry trends. The blast furnace, which emits almost no cadmium, is excluded.

## 1. Sintering

The sintering plant receives two different materials which require processing. Beneficiation of very fine iron ore and flue dusts is accomplished at the sinter plant and different iron-bearing materials become agglomerated at the plant. Sintering of the above materials ensures a higher iron content, lessens moisture, and often removes some sulfur. This renders the resultant product a more suitable feed for the blast furnace.

### (a) Process

To accomplish the sintering, a mixture of fine ore and powders of carbon sources, such as anthracite and coke breeze, are placed on a traveling grate. The grate moves over a series of windboxes where the mixture is lit with a burner. As air is pulled down through the ore with fans, the ore mixture burns, agglomerating the ore particles. The use of sinter aides the performance and productivity of blast furnaces.

### (b) Emission Sources

During the heating of the mixture of fine ore and other materials (blast furnace and other flue dusts), cadmium escapes

---

\*Steel is often galvanized with cadmium to protect it from corrosion. When the scrap is melted, cadmium is emitted.

into the atmosphere. Because the flue dust, and other such materials contain amounts of cadmium, any heating of this material causes cadmium to volatilize.

(c) Control

Sinter strands employ one or more of three types of control devices. The cyclone is employed alone, or more often with a baghouse or ESP. In 1976, approximately 66 percent of the sinters used little or no control, while 34 percent employed at least one of the above methods.<sup>13/</sup>

(d) Emissions Estimate

The estimate of airborne cadmium emissions emanating from the sintering process was developed from two sets of EPA stack sampling tests for which a semi-quantitative analysis technique, emission spectroscopy (ES), was used. Sampling runs had been taken for both controlled and uncontrolled sinter plants, so emission factors were developed for both. The uncontrolled emissions factor of  $2 \times 10^{-3}$  pounds/ton<sup>14/</sup> of feed indicates that approximately 22 tons of cadmium result from the production of  $21.94 \times 10^6$  tons of sinter.<sup>13/</sup> With a rotoclone plus ESP control, the sinter windbox tested had an average emission factor for two runs of  $9.5 \times 10^{-4}$  pounds/ton of feed.<sup>14/</sup> Assuming this emission factor is representative of all sintering operations, the total annual emissions of cadmium from these sintering operations equal 5.4 tons yearly ( $11.35 \times 10^6$  tons of sinter<sup>13/</sup>). Total emissions from sintering equal 29.4 tons yearly.

---

\*Comparative emissions estimates will be discussed at the conclusion of the iron and steel section, as other estimates are not broken down by process.

#### (e) Future Trends

Sinter strand production is expected to increase slightly between 1974 and 1985. A decrease in production occurred between 1974 and 1975. However, by 1977, a recovery had been made and production increased slightly over 1974 (33.3 MM tons in 1974; 34.0 MM tons in 1977). Based on the historic growth rate, it is expected that sinter production will reach 40 million tons/year by 1985.<sup>13/</sup> However, sinter capacity will remain constant at 46.9 million tons<sup>13/</sup> through at least 1983. By 1985, it is expected that all facilities will be in compliance with control regulations, and all will employ some control device. On this basis, cadmium emissions from sintering are expected to equal 19 tons/year by 1985.

#### 2. Basic Oxygen

The basic oxygen process was developed and first used in the early 1950's. It has become a highly competitive form of producing steel and has replaced much of the open hearth production.

##### (a) Process

The basic oxygen furnace is a cylindrical steel furnace, lined with refractory material, which has an opening at only one end. For charging and tapping, the furnace vessel rotates around a lateral axis. Slag is retained in the furnace and is then tapped off by way of a tap-hole near the mouth of the furnace. The charge materials used in the basic oxygen furnace include hot metal from blast furnaces (70-80 percent), scrap, cold pig iron, and iron oxide.

In the process, the furnace is first tilted for the addition of scrap and hot metal. It is then brought to a vertical position. Next, an oxygen injection lance is placed in the furnace producing a reaction flame which is visible along the furnace mouth. Through an overhead chute, fluxes of lime and fluorspar are funnelled into the furnace causing the reaction flame to rapidly decrease. Temperature readings are taken and the refined metal and slag samples are analyzed after the carbon content reaches the desired level. Lastly, the furnace is tilted to tap steel into a ladle.

#### (b) Emission Source and Control

Emissions of cadmium result from the melting of scrap in the furnace. From the time the furnace is charged with the scrap, cadmium contained in the scrap is volatilized in the furnace.

The emissions from the basic oxygen furnace are controlled primarily by ESPs. However, approximately 40 percent of all controlled basic oxygen furnaces use high energy venturi scrubbers to aid in the abatement of airborne cadmium emissions.<sup>1/</sup> Approximately 98.5 percent of all existing basic oxygen furnaces employ some type of air pollution control device.<sup>13/</sup>

#### (c) Emission Estimate

To determine emissions resulting from the basic oxygen process, emissions factors were developed. For uncontrolled furnaces, an emission factor of  $4.1 \times 10^{-5}$  pounds/ton of steel was developed by assuming a reported concentration of cadmium in the particulate of 80 ppm and the AP-42 particulate emission factor of 51 pounds/ton of steel.<sup>15/</sup> Production of steel in

these facilities equaled  $1.2 \times 10^6$  tons.<sup>13/</sup> The emission factor of  $1.2 \times 10^{-5}$  pounds/ton of steel for furnaces controlled by a venturi scrubber or ESP is the average for six EPA stack tests using analysis by emission spectroscopy.<sup>14/</sup> Production of steel at these facilities equaled  $78.8 \times 10^6$  tons.<sup>13/</sup> Emissions from this source are estimated by EEA to be less than one ton/year.

#### (d) Future Trends

The basic oxygen furnace is considered to have a substantial growth potential through 1985. It is thought that as much as 75 percent of the 1985 steel production in the U.S. will be done by this process.<sup>16/</sup> Obviously, emissions will increase (to .7 tons/year); however, the source will remain one which does not produce over one ton of cadmium emissions each year.

### 3. Open Hearth

Open hearth production of steel has been decreasing steadily over the past ten years due to economic and environmental concerns. However, the process does account for 25 percent of the steel produced<sup>16/</sup> and is a source of cadmium emissions.

#### (a) Process

A reverberatory type hearth furnace is heated alternately by a combustion flame from either end of the hearth. At regular intervals, the gas flow is reversed in order to recover sensible heat from the exhaust gases. This is accomplished by passing them through brick checkers which are at either end of the furnace. At each reversal, the brick checkers are hot enough to heat the incoming combustion air so that the high

flame temperatures needed to melt and refine raw materials are reached more readily. The furnace is charged with scrap and heated to incipient melting by oil, gas, or tar flames which move across the top of the hearth. Hot metal is added to the furnace at this point. The next step involves addition of the necessary flux and oxidizing materials to refine the mix while it boils.

(b) Emission Source

The cadmium is volatilized when the scrap is melted.

(c) Control

An ESP is used to control about 80 percent of the existing open hearth furnaces, while the other 20 percent are without any kind of control.<sup>13/</sup>

(d) Emissions Estimate

Open hearth emission factors have been made for both the controlled and uncontrolled operations. A "best judgement" estimate of  $5.78 \times 10^{-3}$  pounds/ton of steel<sup>3/</sup> is determined to best represent estimates between  $4.07 \times 10^{-3}$  pounds/ton of steel and  $7.49 \times 10^{-3}$  pounds/ton of steel.<sup>3/</sup> The ESP control reduces emissions to between  $2.08 \times 10^{-5}$  pounds/ton of steel and  $1.33 \times 10^{-4}$  pounds/ton of steel.<sup>3,14,17/</sup> This recent series of stack tests using AA analysis has produced a "best estimate" of  $1.1 \times 10^{-4}$  pounds of steel. From this, and a production figure of  $29.06 \times 10^6$  tons,<sup>13/</sup> it was determined that controlled open hearth facilities contribute two tons of cadmium into the atmosphere each year. Uncontrolled emissions, with a production level of  $7.64 \times 10^6$  tons,<sup>13/</sup> equal approximately 22 tons/year, resulting in a total of 24 tons of cadmium emissions yearly.



#### (e) Future Trends

As has been stated, the open hearth is not environmentally and economically competitive with other steel-making processes. Since 1965, open hearth steel production capacity has dropped from 110.82 MM tons/year to 37 MM tons/year.<sup>13/</sup> It is expected to continue declining through 1985 to 21.1 MM tons/year.<sup>13/</sup> No new open hearth facilities are planned, therefore, NSPS will have no bearing upon the control of the open hearth facilities or amount of their emissions. Emissions, assuming that 100 percent of the open hearths will use some control device, are estimated to be about one ton/year by 1985.

#### 4. Electric Arc

The electric arc furnace, the fourth method by which steel is produced, has enjoyed steady growth since its initial installment in 1906. At present, it accounts for the production of approximately 27.3 MM tons of steel each year.<sup>13/</sup> The process allows for the production of a large variety of objects and is flexible in operation, which accounts for its growing popularity.

##### (a) Process

Steel scrap is the principal material used for feed in electric arc steel-making, while iron sponge is occasionally used as a portion of the feed. Scrap is processed in a furnace which is shaped like a cylindrical shell, shallow in depth, with a large diameter. A removable roof on the shell allows for the insertion of three graphite electrodes. High performance refractories completely line the shell and roof.

Steel-making is accomplished in a series of heats, each producing a certain tonnage of some form of steel. Each cycle begins when a partial charge is loaded into the top of the furnace, the roof is closed, and the electrodes are lowered into the furnace. The electrodes are placed so that the electric current produces an arc between them and the charge. After the melting of the partial charge, the remainder is added and melting continues to the end of the heat. The entire process usually requires three to four hours for completion. When the process is completed, the heat is placed in a transfer or teeming ladle, while the slag is dumped into a slag pit.

The process is used to produce a large number of different steel products such as structural steel, specialty alloys, tool steels, super alloys, and stainless steels.

#### (b) Emissions Sources and Control

The melting process which the steel scrap undergoes in the electric arc produces the resulting cadmium emissions. Because the primary feed for the arc furnace is steel scrap, this process produces the largest amount of cadmium emissions of any of the steel production operation. (Sintering, with a slightly higher amount of cadmium emissions, is a raw materials processing operation.) Control is accomplished with the use of a baghouse and the occasional use of a scrubber or ESP. Approximately 90 percent of all electric arc furnaces employ some method of control.<sup>14/</sup>

#### (c) Emissions Estimate

It is estimated that the electric arc furnace emits  $3.4 \times 10^{-3}$  pounds of cadmium/ton of steel. This "best judgement" estimate was developed from estimates between  $2.7 \times 10^{-3}$  pounds/

ton of steel and  $5 \times 10^{-3}$  pounds/ton of steel by assuming a particulate cadmium concentration of 735 ppm from EPA ES stack test results,<sup>14,15/</sup> and the AP-42 particulate emission factor of 4.6 pounds of particulate/ton of steel. Using this emission factor, and a production figure of  $27.3 \times 10^6$  tons, EEA estimated that at a 90 percent control efficiency, cadmium emissions from this process equal approximately 4.6 tons/year.

#### (d) Future Trends

The electric arc furnace is a steadily growing method of producing steel. The increase in the electric arc is a result of several factors which include the viability of the "mini-mill" concept, the applications possible for high-intensity arc furnace technology, larger amounts of scrap available due to growth of the basic oxygen furnace coupled with decline of the open hearth, and increasing economic viability of direct ore-reduction processes. Therefore, an historic growth rate was used to project that there will be an increase of about 11 MM tons produced by the electric arc through 1985. Emissions will increase somewhat; however, all electric arcs will be controlled in some way. NSPS standards will have some effect upon the process, as expansion seems of existing plants quite likely.

#### 5. Total Iron and Steel Emissions

To compare EEA's iron and steel emission estimates with estimates of other studies, it was necessary to total all processes.

#### 6. Total

EEA's emissions estimate of 190 tons/year is not in agreement with most others (Davis--1,000;<sup>7/</sup> Mitre--1,000;<sup>11/</sup> EPA--78;<sup>2/</sup> GCA--400;<sup>2/</sup> and Sargent--11.5<sup>6/</sup>). Control technology

assumed was based on the Temple, Barker, and Sloane steel study (1976),<sup>13/</sup> which was unavailable at the time previous estimates were made. Several emission factors were also based upon data previously unavailable. It is possible that a higher degree of control technology was assumed here. Production figures could also vary among the sources. However, the cause of the wide variation in estimates is not fully understood.

#### E. Secondary Smelting

Secondary smelting processes involving zinc, lead, and copper are not viewed as large emitters of cadmium when each is viewed as an aggregate (all zinc smelters; all copper; all lead). Each metal will be dealt with individually in the following discussion.

##### 1. Secondary Zinc

###### (a) Process

Of the three secondary smelting processes, the zinc process releases the largest amount of cadmium into the air. Zinc can be melted, "sweated," or vaporized in processing. To recover the zinc from scrap, sweating is the most common procedure. The furnaces employed to carry out this process include rotary, reverberatory, or muffle furnaces. In zinc melting, the scrap is combined with ingot and rejects, and is melted to create a molten bath. After light scrap is added to the bath, it is heated to the correct pouring temperature and poured. The zinc vaporization is carried out in retort furnaces to reclaim zinc from alloys and to recover zinc from its oxide (among other processes). Distillation and muffle furnaces are

used to separate zinc from the alloy which is then processed and converted to zinc metal.

(b) Capacity

A total production figure for the industry (182,665 tons in 1974,<sup>12/</sup>) is possible to obtain but no figures of individual plant capacity or production are available.

(c) Source and Control

The source of cadmium emissions from all three processes is the melting of the material at high temperatures. In preparing the scrap material for charging, no control device is used or needed. Sweating furnaces are equipped with an afterburner and a baghouse, while distillation furnaces are equipped with baghouses. Only 20 percent of the sweating furnaces use control devices, while almost all distillation furnaces employ devices.<sup>1/</sup>

(d) Emissions Estimate

Cadmium emissions from zinc secondary smelting operations are small. This is due to the fact that most of the cadmium has already been volatilized during primary smelting.

Uncontrolled emission estimates between  $8 \times 10^{-3}$  pounds/ton of zinc and  $1.4 \times 10^{-2}$  pounds/ton of zinc produced<sup>8,10,18/</sup> were found in the literature. A "best judgement" factor of  $1 \times 10^{-2}$  pounds/ton of zinc produced was then derived from the mass balances. The 1974 production figure was used to compute an emissions estimate of less than one ton of atmospheric cadmium resulting from the process yearly. EPA<sup>2/</sup> estimated emissions from this process to be two tons/year, as did GCA.<sup>2/</sup> Sargent combined all secondary non-ferrous metal processing to obtain an emissions estimate of 2.4 tons yearly.<sup>6/</sup>

#### (e) Future Trends

Production of zinc through secondary smelting is expected to increase slightly through 1985 to 223,000 tons according to the Bureau of Mines forecast.<sup>19/</sup> There is no reason to assume a dramatic increase or decrease in production. Cadmium emissions would thus increase slightly to over one ton/year, but emission control will improve so that the increased production as a whole should not cause a large net increase in emissions.

### 2. Secondary Lead

#### (a) Process

Secondary lead smelting is a process from which cadmium emissions are derived. Lead automobile storage batteries, lead-sheathed cable and wire, aircraft tooling dies, type-metal drosses, and lead dross and skims are the materials most commonly sweated to obtain lead. To process materials with a small percent of the metal, a rotary furnace, or sweating tube, is usually employed. A reverberatory-box type furnace is used when dealing with material of high lead content.

Blast furnaces are also used frequently in secondary smelting of lead storage batteries. Lead is charged into the furnace at the beginning of the operation in order to provide molten metal to fill the crucible. Limestone and iron flux float on the top of the lead to inhibit its oxidation. The molten metal is poured when proper conditions are reached.

#### (b) Capacity

As with zinc, capacity of individual plants could not be obtained for this study. However, 1974 total production was 698,698 tons.<sup>12/</sup>

(c) Emissions Source and Control

Airborne cadmium emissions emanate from the melting process during which cadmium is volatilized. The control measure used with both reverberatory and blast furnaces is generally a baghouse, occasionally in combination with an ESP.<sup>1/</sup>

(d) Emissions Estimates

The amount of cadmium produced by secondary lead smelters has not previously been estimated. Emission factors for this process were developed from EPA stack testing results. Three factors for three different combinations of furnace type and control technology were used to compute emissions estimates. However, because of difficulty in obtaining production data, the most conservative emissions factor of  $2 \times 10^{-6}$  pounds/ton of lead was used.<sup>14/</sup> Combined with the production figure for secondary smelters, the emission factors produce a relatively low estimate of total emissions very low (less than one ton).

(e) Future Trends

The production of secondary lead is expected to increase through 1985. It is felt that the growth of this sector of the lead industry will largely account for the growth of the entire industry. However, until the long-term effects of both the OSHA regulations and EPA rulings are determined, secondary producers will be reluctant to increase capital expenditures for new plants and equipment. This indicates that the impact of NSPS will be minimal at best. At a growth in production of 3.26 percent per year,<sup>1/</sup> emissions are expected to increase but remain under one ton/year.

### 3. Secondary Copper

Scrap serves as the primary feed for most secondary copper operations. The scrap received usually contains many impurities including cadmium. During the processing, which is discussed below, these impurities are removed and copper metal is cast for re-use.

#### (a) Process

Scrap can be processed mechanically or by a pyrometallurgical process. At medium temperatures, sweating is done to remove metals which have a low melting point. Burning removes insulation which was not removed mechanically from copper wires. To remove excess cutting fluids from machine shop chips and borings, vaporization occurs in a heated rotary kiln. The blast furnace produces a product called "black copper" which is a concentrated material. Concentration is produced by taking scrap and charging it at the top of a vertical furnace, together with coke, a reducing agent and a fluxing material. The concentrated material plus some slag are drawn out at the bottom of the furnace.

After the scrap is processed, it undergoes smelting and refining, melting, and alloying in a variety of furnaces, including the reverberatory, the rotary, or the crucible. The choice of one over the other is dependent upon the quantity of scrap to be melted and the type of alloy to be produced. The reverberatory and rotary furnaces are direct-fired furnaces in which the hot, high-velocity combustion gases are in direct contact with the metals in the charge. It is thus difficult to effectively capture the emissions from these types of furnace with a hood.



During charging, all the scrap material is usually not placed in the furnace at one time due to the large quantities involved. After charging, the melting process occurs. The burners are set to ensure a very rapid melt-down, and additional oxygen may be added at this time. Refining, the next process which the metal undergoes, involves fluxing the molten bath of metal to cause selective oxidation. In alloying, virgin metal or specialized scrap may be added to modify the final product of the melt. The last step is the pouring of the molten metal from the furnace into a mold. This can be done by tapping the furnace directly to an automated mold line, or into a ladle from which it is transferred to a mold line.

#### (b) Source of Emission and Control

Almost all processes in secondary copper smelting produce some emissions of cadmium. Sweating involves a very small loss of metal fume, as does burning. However, the rotary kiln which vaporizes copper and cadmium can cause a large amount of emissions. Usually, afterburners are employed to complete combustion and decrease emissions. The processes which result in combustion leading to air-borne cadmium emissions include those involving the blast furnaces, direct fire furnaces, charging, melting, refining, and alloying. During wire burning, no control devices are employed. However, in sweating, an afterburner and baghouse are used. The blast furnace is equipped with a baghouse, while the reverberatory and rotary furnaces both are equipped with a hood and baghouse.

#### (c) Emission Estimate

Approximately 38 tons of cadmium emissions result each year from secondary copper processing. Emission factors estimates range from a minimum of 2.6 pounds/ton of copper scrap to a

maximum of 4.0 pounds/ ton of copper scrap.<sup>28/</sup> The factor used (three pounds/ton of copper) is the average of two mass balances. A 1974 production figure of 513,308 tons of copper was also used.<sup>12/</sup> EEA's estimate is lower than all others which have been made up to this point (Davis--125;<sup>7/</sup> Mitre--125;<sup>11/</sup> EPA--65;<sup>2/</sup> GCA--70<sup>2/</sup>). This is because a greater number of control devices and a greater efficiency of control were assumed by EEA (90 percent particulate control efficiency for the nearly universally employed baghouse). The Sargent figure of 2.4 tons of cadmium released per year from secondary non-ferrous metal processing is lower than any of the others.<sup>6/</sup>

#### (d) Future Trends

The Bureau of Mines predicts that production of secondary copper will increase five percent each year to 1985.<sup>20/</sup> Using 1975 as a base, this would mean 800,000 tons of secondary copper would be produced by the industry in 1985. Emissions would also increase substantially through 1985 to 60 tons.

#### F. Manufacturing

The production of paint pigments, plastic stabilizers, and nickel-cadmium batteries result in cadmium emissions into the air.

##### 1. Cadmium Pigments

Cadmium compounds, principally the sulfides and sulfoselenides, are used as coloring agents in paints and plastics. The sulfide compounds are used to impart colors of yellow to orange, while sulfoselenide colors range from light red to dark maroon.

In order to "stretch" the pure cadmium pigments, white barium sulfite is often mixed with the pure pigments to create "cadmium lithopones."

(a) Process

The use of these pigments is widespread due to their stability in light at relatively high temperatures in various chemicals, in various weather conditions, and in moisture. This makes use of the cadmium pigments in plastics which require high temperature molding extremely practical. Other uses include artist's colors, rubber, and printing inks.

The preparation of these pigments does cause release of airborne cadmium emissions. By heating cadmium and sulfur ( $\text{Cd} + \text{S} \xrightarrow{\text{Heat}} \text{CdS}$ ), cadmium sulfide is produced. It can also be made by precipitating an aqueous solution of soluble cadmium salts and soluble sulfides or  $\text{H}_2\text{S}$ . Color variations (yellow to orange) are produced when the temperature of the  $\text{H}_2\text{S}$  solution is altered (a cold acid solution yielding yellow, and the hot solution producing orange). In preparing cadmium sulfoselenide pigments, selenium is added to solutions of barium salts. This solution is, in turn, reacted with  $\text{CdSO}_4$ . To remove any unreacted selenium, the final product is calcined with excess sulfur. In all of the above processes each must contain a calcination or drying step. Without calcination, the pigments would not be dry and would be impossible to compound.

(b) Emissions Source and Control

Any loss of cadmium to the environment during the manufacture of cadmium pigments originates from the dust which is

produced during calcination. However, all facilities which are involved in pigment production have installed baghouses to minimize emissions.

#### (c) Emissions Estimate

The emissions factor used to calculate cadmium emissions was the mass balance estimate developed by Davis<sup>7/</sup> and cited by Anderson.<sup>8/</sup> A factor of 15 lbs/ton of cadmium charged is suggested as the emission factor for this process. With production of 1,212 tons in 1974,<sup>6/</sup> nine tons of cadmium/year are released into the air. Davis, Mitre, and GCA all estimate emissions from this process to be 11 tons/year. The estimates of seven tons/year by the EPA and 9.5 tons/year by Sargent are in closer agreement with EEA's than other figures.

#### (d) Future Trends

The use of cadmium pigments is expected to increase slowly during the near future to 1,560 tons, which will slightly increase emissions from this source (11.3 tons). Substitutes for cadmium pigments are available (zinc, lead, and barium chromates). The yellow cadmium-based dye used in printing inks has proven extremely difficult to bleach on paper recycling operations. However, it is expected that cadmium pigment production will steadily increase (two percent growth rate).<sup>6/</sup>

### 2. Plastic Stabilizers

In order to protect plastics from degradation by heat and light, it is necessary to add stabilizers to them, especially to PVC and related polymers. Most plastics which are destined for use outdoors are stabilized in this manner.

#### (a) Process

Stabilizers must counteract the loss of acid, usually HCl, by the PVC because this is usually the first step in degradation of the plastic. Cadmium stearates, which are long, straight-chain organic esters, will react with the HCl to produce weak organic acids and ionized cadmium chloride. When used with no other additives, this stearate successfully lends the desired heat and light stability to the plastics. When combined with barium compounds, epoxides, or organic phosphates, the stearate is even more effective. Because it is the least expensive of the available cadmium plastic stabilizers, it is also the most popular. Other compounds used include cadmium laurate and cadmium recinoleate.

#### (b) Emission Sources and Control

Any airborne cadmium emissions which result from the processing of plastic stabilizers originate from the handling of pulverized cadmium oxide. The cadmium oxide is used to prepare cadmium soap or other organic stabilizers. The procedure involving the mixing of the prepared compound with the plastic is not believed to produce any appreciable emissions. All cadmium stabilizer producers use baghouses to control the emissions resulting from the process.<sup>1/</sup>

#### (c) Emissions Estimate

It is believed that the stabilizer industry is responsible for very little of the total cadmium in the air. Using an emissions factor of six pounds/ton of cadmium charged<sup>7,8/</sup> developed by EPA from a mass balance analysis and a production figure of 991.8 tons, EEA estimates that three tons of cadmium/year are released into the air in the production of stabilizers. Other estimates, including those made by Davis, Mitre, and GCA

agree with that of EEA, while EPA<sup>2/</sup> estimates one ton of cadmium a year from the stabilizer process and Sargent<sup>6/</sup> estimates a release of 2.9 tons yearly.

#### (d) Future

Because of ever-increasing FDA bans on the use of the cadmium compound plastic stabilizers, particularly for use in plastic food wrappings, a constant annual production is projected for this product.<sup>21/</sup> Although figures show a slight increase (due to a small market recovery after 1973-1974), emissions are estimated to remain constant through 1985. The development of a calcium-zinc stabilizer, which can equal cadmium stabilizers in performance and cost, has also caused a decrease in the use and production of the stabilizer.

### 3. Batteries

The nickel-cadmium battery is perhaps the only product from which cadmium can be recovered. Developed prior to 1900 by Jungar, it is superior to other batteries in efficiency and longevity. However, during processing, relatively small amounts of the material are released into the air.

#### (a) Process

The "pocket" electrode is used most frequently in the nickel-cadmium battery to form the cadmium plate. This electrode is produced by pulling active materials (cadmium sponge) into perforated pockets on a nickel steel frame. Active materials, such as the cadmium sponge, react with the electrolyte solution of the battery to produce a charge.

There are two methods used to prepare the active materials. In one, powdered cadmium or a cadmium compound is dry-mixed with

an expander, often iron, and then inserted into the pockets. Electrolytic coprecipitation of cadmium and iron from an acid electrolyte also produces an active material to be inserted into the electrode. This process requires filtering, washing, drying, ball-milling, and blending of the precipitate to produce the final product. The electrodes are then filled with one of the mixtures by insertion of machine-made brickettes or loose dust. To prevent dusting during this process, petroleum oil is often added in small amounts.

Recently, plates which have the cadmium deposited into them have been used successfully in cadmium-nickel batteries. The production of the plate can occur in four ways, all of which involve depositing cadmium, cadmium oxide, or cadmium hydroxide onto a nickel screen or onto a porous nickel plaque. The methods to accomplish this include:

- Soaking the plate in cadmium formate solution prior to thermal decomposition in air;
- Electro-deposition from a solution of a soluble cadmium salt, most often nitrate;
- Soaking in cadmium nitrate solution prior to reduction in an atmosphere of hydrogen; and
- Forcing a paste of active material into the nickel support.

At some point, either after or before the battery is assembled, the electrodes are subjected to the "formation" treatment. This entails submitting the electrodes to several charge-discharge cycles. This serves to remove impurities and loose particles.

#### (b) Emissions Source and Control

There are several potential sources of airborne cadmium emissions from the production of the nickel-cadmium battery. All procedures which involve dry powdered cadmium and cadmium compounds, and the reduction and thermal decomposition steps which require high temperatures contribute to the emissions. During production of active materials, cadmium is released into the air. With adequate control, however, this industry should not prove to be a source of a large amount of airborne cadmium. Controls used by this industry are unknown at this point, both in kind and number.<sup>1/</sup> Adequate techniques, such as baghouses or ESPs, are available to the industry but are considered to be extremely expensive.

#### (c) Emissions Estimate

EEA estimates that, based upon a mass balance emission factor of two pounds/ton of cadmium charged,<sup>7,8/</sup> and a production figure of 628.14 tons,<sup>6/</sup> less than one ton of emissions per year are released by the process. With the exception of Sargent (0.7 tons/year),<sup>6/</sup> all others did not report a specific emissions estimate from battery production.

#### (d) Future Trends

The EPA estimates that the amount of cadmium used in batteries in 1985 will increase between 15-20 percent,<sup>6/</sup> while the Bureau of Mines predicts only small increases.<sup>6/</sup> The large increase predicted by EPA is based upon several factors. These batteries are also used in calculators and portable garden, power, and hobby tools, all of which are expected to increase in demand due to relatively low prices and increasing popularity.



EEA's estimated future emissions from the production of nickel-cadmium batteries are based on EPA's estimated emission factors and indicate that approximately two tons/year may be released from this industry.

#### G. Fossil Fuel Combustion

Cadmium is found in fossil fuels, and therefore, these fuels are a potential source of cadmium emissions. It has been determined that coal-fired and oil-fired power plants, fuel oil, diesel oil, and gasoline are all responsible for some airborne cadmium.

##### 1. Coal-Fired Power Plants

The coal-fired power plant represents a source of cadmium air emissions which is small unless the fly ash is not collected.<sup>21/</sup>

##### (a) Process

To produce power, steam is generated using a fossil fuel. The fuel and a stream of air which has been preheated are directed to a furnace or a series of burners where combustion occurs. Because the process is not carried out under perfect conditions, incomplete combustion usually results. Incomplete combustion and the incombustible nature of some fuel constituents cause pollutants, such as fly ash, to be generated by the process. The heat from the combustion chamber heats water which is contained in a series of pipes in a boiler and generates steam.

##### (b) Source of Emissions and Control

Emissions of cadmium particulates from coal-fired power plants originate from the combustion of the coal. Impurities,

such as cadmium, which exist in the coal, are volatilized, and condense on the particulate matter or fly ash. Devices used to control the emission of fly ash include ESPs and fabric filters.<sup>1/</sup> Approximately 97 percent of the coal-fired power plants employ one of the above control devices.<sup>1/</sup>

(c) Emissions Estimate

The emissions from coal-fired power plants were estimated using emission factors developed from stack test results reported in several sources and the total coal consumed by such plants. These stack tests resulted in factors ranging from  $1 \times 10^{-4}$  to  $1 \times 10^{-1}$  pounds/ton of coal (uncontrolled)<sup>14,22,23/</sup> and from  $1 \times 10^{-6}$  to  $7 \times 10^{-4}$  pounds/ton of coal (controlled with ESP).<sup>2,8,10,14/</sup> Best estimate factors were then developed by taking geometric means of the stack test. It was found that the emissions due to uncontrolled coal-fired power plants burning  $3.913 \times 10^8$  tons of coal,<sup>42/</sup> with an emissions factor of  $1 \times 10^{-3}$  pounds/ton of coal equals approximately 196 tons. If all facilities were controlled with an ESP or its equivalent, an emission factor of  $6 \times 10^{-5}$  pounds/ton of coal would be used together with the tonnage to estimate that 12 tons of cadmium would be released yearly. The controlled estimate is much more likely, as nearly all coal-fired power plants employ high efficiency particulate control equipment. Other emissions estimates have treated fossil fuel combustion in total, thus, a comparison will be made on the basis of total emissions. It was found that the emissions due to power plants (if all were uncontrolled), with an emission factor of  $1 \times 10^{-3}$  pounds/ton of coal,<sup>14,22,23/</sup> would be 196 tons yearly. If all facilities were controlled with an ESP or its equivalent, and an emission factor of  $6 \times 10^{-5}$  pounds/ton of coal,<sup>2,8,10,14/</sup> is assumed, they would emit seven tons of cadmium yearly. The controlled

estimate is much more likely, as nearly all coal-fired power plants employ high efficiency particulate control equipment.

#### (d) Future Emissions

Studies indicate that coal will become a more important source of power in the near future, and its use will increase, especially if the National Energy Plan is implemented. Therefore, uncontrolled emissions from this source will become greater. However, with increased control and improved technology, emissions will increase only slightly.<sup>24/</sup>

### 2. Oil-Fired Power Plants

Oil-fired power plants are similar to coal-fired power plants in terms of process and emissions. These plants produce a slightly smaller amount of cadmium air emissions than the coal-fired variety.

#### (a) Process

For a description of the steam generation process, refer to coal-fired power plants. The major difference between coal- and oil-fired plants is that the firing mechanism and equipment required for oil are greatly simplified.

#### (b) Emissions Source and Control

Thermal processes are responsible for the cadmium emissions in almost every source, and oil-fired power plants are no exception. The combustion of oil to create steam releases small amounts of cadmium impurities into the air. Ninety-nine percent of the power plants are controlled with cyclones.<sup>1/</sup>

### (c) Emissions Estimate

The emission factor derived from EPA's emission test results using ES analysis is  $9 \times 10^{-7}$  pounds/gallon for a plant with ESP control.<sup>14/</sup> The range of estimates fell between  $7.1 \times 10^{-7}$  and  $4.4 \times 10^{-6}$  pounds/gallon. Combined with an oil usage figure of  $2.072 \times 10^{10}$ /gallon,<sup>42/</sup> this produces an estimated nine tons of cadmium a year resulting from oil-fired power plants.

### (d) Future Trends

Although oil is expected to increase in price and become increasingly difficult to obtain, usage in the next few years is expected to continue to rise.<sup>24/</sup> Emissions are projected to rise to approximately 20 tons/year.

## 3. Other Fuel Oil Combustors

Fuel oil, including residual and distillate fuels, are used in various boilers or burners to supply heat to the residential, commercial, and industrial sectors. The process of operation is similar to the combustion which occurs in the boiler of an oil-fired power plant, but usually on a much smaller scale.

### (a) Emission Source and Control

The incomplete combustion of the oil and the impurities in the oil result in emissions of various kinds, including cadmium. There are no controls on these sources of cadmium emissions.<sup>1/</sup>

### (b) Emissions Estimate

Estimates of cadmium emissions indicate that heating oil is not a large source. An emissions factor of  $3 \times 10^{-6}$  pounds/gallon<sup>14/</sup> for residual fuels was developed from an average of six reported cadmium concentrations in the fuel, assuming that all cadmium

was emitted. Distillate fuel emissions were calculated using the diesel oil emissions factor of  $7 \times 10^{-7}$  pounds/gallon of oil consumed, which is a best judgement figure based upon factors ranging from  $6 \times 10^{-7}$  pounds/gallon to  $2 \times 10^{-6}$  pounds/gallon.<sup>8,10,18,21/</sup> Residual fuel consumption equaled  $321.2 \times 10^6$  barrels, and distillate fuel consumption equaled  $613.9 \times 10^6$  barrels.<sup>39/\*</sup>

#### (c) Future Trends

The future consumption of heating oil will rise slowly through 1985 to  $900 \times 10^6$  barrels. To determine residual and distillate usage, proportions were assumed to be equal to that of 1974. Of total fuel consumed, residual fuel accounted for 60 percent and distillate for 40 percent. Emissions are 30.5 tons/year based on consumption figures of  $644.6 \times 10^6$  barrels of distillate fuel and  $336.3 \times 10^6$  barrels of residual fuel in 1985.

### 4. Diesel Oil

#### (a) Process

Diesel oil, which is burned in the diesel engine, is used by some automobiles, trucks, and other motor vehicles. An unregulated flow of air is fed into the engine and mixed with the fuel. This mixture reaches the cylinder or combustion chamber, is compressed, and ignited. The injection of the highly-purified gases into the cylinder causes a sudden reduction in pressure, in turn, creating air temperatures which cause the ignition. The energy of the burning mixture moves the pistons,

---

\*

As a result, cadmium emissions from residual combustion equaled 23.1 tons in 1974, emissions from distillate combustion equaled 8.4 tons in 1974, bringing 1974 emissions to a total of 31.5 tons.

and the pistons' motion is transmitted to the crankshaft that drives the vehicle. The burned mixture then leaves the car through the exhaust pipe.

(b) Emission Source and Control

The emission source is the thermal process which causes combustion of the oil itself. The emissions are actually released through the exhaust pipe, which accounts for almost 100 percent of the diesel engine's emissions. Control of cadmium emissions from this source is not practiced.

(c) Emission Estimate

Diesel fuel oil emits cadmium at a rate of between  $6 \times 10^{-7}$  pounds/gallon and  $2 \times 10^{-6}$  pounds/gallon.<sup>8,10,18,21/</sup> A best judgement figure, which assumes the emission of all the cadmium in the fuel (as measured by ES), is  $7 \times 10^{-7}$  pounds/gallon. With a consumption figure of  $11,179,686 \times 10^3$  gallon,<sup>39/</sup> and the "best judgement" factor, EEA estimates that less than one ton yearly is emitted.

(d) Future Trends

Diesel oil consumption is expected to rise by approximately four percent each year to 1985.<sup>38/</sup> Emissions from the combustion of the fuel are estimated to increase somewhat to 5.25 tons/year.

5. Gasoline

To complete the discussion of fossil fuels which release cadmium emissions during combustion, gasoline must be considered. The process which actually releases the cadmium is the combustion of gasoline within the engine. Therefore, a brief discussion of this will be included.

(a) Process

In the conventional automobile engine, a mixture of fuel and air is fed into a combustion chamber, or cylinder, by the carburetor, compressed, and ignited by a spark from a spark plug. The pistons are put into motion by the energy released from the burning mixture. Also released are certain particulates, including cadmium. The emissions pass out of the car through the exhaust system.

(b) Source of Emissions and Control

The source of emissions, as noted above, is the actual burning of the fuel which causes the volatilization of cadmium.

(c) Emissions Estimate

The emission estimate for gasoline is based on an emission factor of  $2 \times 10^{-8}$  pounds/vehicle mile traveled in one year. This factor assumes that all the cadmium in the fuel is emitted and that the vehicle operates at 15 miles/gallon. This best judgement factor was obtained from literature which listed emission factors between  $6.3 \times 10^{-11}$  pounds/VMT to  $4.5 \times 10^{-8}$  pounds/VMT.<sup>25,26,27,28,29/</sup> Total vehicle miles traveled by cars and motorcycles is estimated at  $1,330,074 \times 10^6$ ,<sup>39/</sup> producing estimated aggregate cadmium emissions of 13 tons/year.

(d) Future Trends

It is expected that vehicle miles traveled will steadily increase in the coming years.<sup>30/</sup> Even though the vehicle miles traveled is expected to rise, emissions are not projected to increase substantially.

## 6. Summary

EEA estimates that the five fossil fuel combustion processes release a total of 40 tons of cadmium into the atmosphere each year, assuming controlled coal-fired power plants. This figure is lower than estimates by GCA (250 tons/year);<sup>2/</sup> EPA (198 tons/year);<sup>2/</sup> and Sargent (130 tons/year),<sup>6/</sup> due to more stringent control technology assumptions.

### H. Miscellaneous

Several cadmium emission sources contain very small amounts of cadmium which are not intentionally part of the product. Fungicides, phosphate fertilizers, rubber tires, and cement all contain cadmium. Release of cadmium emissions from these sources occurs in the production and in the use of the product.

#### 1. Fungicides

The type of fungicide which is used primarily on golf courses contains a small amount of cadmium. When the fungicides are applied to the courses, usually in liquid form, some cadmium loss is experienced. This loss is dependent upon several factors, including spray particle size and atmospheric conditions.

##### (a) Emissions Estimate and Control

Emissions from this source are minimal (less than one ton/year). In order to develop this estimate, a production figure of 59,800 tons<sup>9/</sup> was combined with an estimated emission factor of  $1 \times 10^{-5}$  pounds/ gallon.<sup>8/</sup> No control devices are used in application of the fungicides.



## (b) Future Trends

Future growth in production of this product is difficult, if not impossible, to project.<sup>9/</sup> Many factors enter into the future of fungicide production. Leisure time is increasing, and "planned" communities which include recreation facilities are becoming a popular place in which to live and recreate. This would indicate that production would increase as more golf courses would require fungicides. Fungi may become immune to cadmium-containing fungicides, which would force a change in type of fungicide used. This would cause a decrease in emissions. Each year many variables, including weather conditions and infestation rate, also affect the use of the fungicides. EEA has used an historic growth rate to determine that emissions from fungicides will not increase greatly through 1985.

## 2. Fertilizers

Phosphate and superphosphate fertilizers also contain a small amount of cadmium. Associated with phosphate rock are a small number of impurities, one of which is cadmium. The cadmium remains with the phosphorus in processing and becomes a contaminant in both phosphate and superphosphate fertilizers.

### (a) Emissions Source, Control and Estimate

The cadmium emissions are released during application of the fertilizer, but not during processing of the material. There are no control methods employed, as there is an inadvertent loss of the material. The emissions estimate is based upon an emissions factor of  $2 \times 10^{-4}$  pounds/ton for superphosphate fertilizer (from an EPA estimate),<sup>6,8,31/</sup> coupled with the production figure of phosphate and superphosphate fertilizers

which equals  $85.35 \times 10^3$  tons.<sup>9/</sup> The cadmium emissions from both phosphate and super-phosphate fertilizers are a small portion of the total emissions (less than one ton). Other estimates include those by Davis,<sup>7/</sup> GCA,<sup>2/</sup> and Sargent,<sup>6/</sup> which are all under one ton.

#### (b) Future Trends

The future of phosphate and superphosphate fertilizers is uncertain in much the same way as that of fungicides. The industry experienced moderate increases in 1977 after lows in 1974-1975.<sup>9/</sup> In 1974, phosphate fertilizers were unavailable due to low production, while in 1975, pricing prevented farmers from making use of the fertilizer. Farmers who had done without the fertilizer in the previous years because of high prices found that a decreased use of fertilizer did not decrease crop yield.<sup>9/</sup> In 1976, production decreased due to oversupply in 1975 (addition of 1.5 million ton capacity plant) and decreasing use.<sup>9/</sup> Growth of the industry will be slow to moderate, with a projected four to five percent increase in production through 1985.<sup>9/</sup>

### 3. Rubber Tire Wear

Rubber tire wear is believed to be a source of several types of gaseous emissions and particulate matter emissions, including cadmium. The curing process in the rubber industry employs zinc oxide as an activator through which the cadmium enters rubber processing. As the tires are worn down during use, cadmium is released into the air. There are no controls employed. Several sources were used to estimate an emission factor of  $8 \times 10^{-9}$  pounds/VMT, assuming a mix of the types of rubber with various cadmium contents in the tire population.<sup>6,7,8,10/</sup>

Using total vehicle miles traveled per year,<sup>39/</sup> it was determined that rubber tire wear contributes a small amount of cadmium to the atmosphere (five tons/year). As mentioned in the discussion concerning gasoline, vehicle miles traveled will increase, causing emissions from rubber tires to also increase.<sup>30/</sup>

#### 4. Motor Oil Consumption

Motor oil combustion also contributes to cadmium emissions. Some oil is burned in the engine causing volatilization of cadmium and its release into the air. No emissions control is practiced. The emission factor of  $2 \times 10^{-9}$  pounds/VMT, reported by Anderson (1973)<sup>28/</sup> and Deane (1976),<sup>2/</sup> coupled with vehicle miles traveled for passenger cars only ( $1,028,121 \times 10^6$ ),<sup>44/</sup> indicates that the combustion of motor oil does not contribute large amounts of cadmium into the air (one ton/year). In estimating future cadmium emissions from this source, the same projection used for gasoline and rubber tire wear was employed and indicates that through 1985, emissions from this source will increase only slightly.

#### 5. Cement Plants

In the manufacture of cement, cadmium is released though in rather small amounts. Cement is a non-metallic mineral product composed principally of lime and silica, with alumina and ferric oxide acting as fluxing materials.

##### (a) Process

Cement is produced in one of two ways, either by the wet process or the dry process. The four basic steps in the

production process include quarrying and crushing, grinding and blending, clinker production, and finish grinding and packaging.

The materials which enter the kiln at the top end are dried by combustion gases which are passed through the kiln counter-current to the materials. The revolving of the kiln causes the raw materials to fall toward the clinkering zone as the carbon dioxide is removed from the calcereous material (the material containing cadmium carbonate which is the major constituent of limestone). After the partially-fused production clinker is cooled in the clinker cooler, gypsum or water is added and the mixture is ground in a ball and tube mill to the necessary fineness.

#### (b) Emission Source and Control

Limestone, which serves as a raw material in cement production, contains a small amount of cadmium. When it is processed, cadmium is released. Control measures used to prevent cadmium from becoming an airborne pollutant include cyclones, with or without ESPs, and baghouses.<sup>1/</sup>

#### (c) Emissions Estimate

There are many emission factors which apply to the various methods and steps of producing cement as determined by EPA ES stack testing. In estimating emissions, the most conservative dry process factor was used by EEA because an increasing number of plants are using the dry process. An emission rate of  $2.6 \times 10^{-6}$  pounds/ton of feed,<sup>14/</sup> together with the appropriate production figure of  $81,210 \times 10^3$ ,<sup>9/</sup> indicated that less than one ton of cadmium a year is released from the cement process. Previous studies have not estimated emissions from this process.

#### (d) Future Trends

The production of cement decreased between 1974 and 1975 due to several plant closings and slow housing starts. However, in 1976, home construction increased. Although there has been little plant expansion, or construction of new plants, it is felt that an annual (compounded) rate of 3.2 percent growth will continue through 1985.<sup>32/</sup> Because no new plants are planned, NSPS will not affect emissions, which, notwithstanding the increased production, will remain well below one ton.

#### I. Incineration

Incineration is a source of cadmium emissions due to the cadmium in the materials burned. These materials include plastics which contain cadmium stabilizers, objects painted with a cadmium-pigmented paint, and scrap metal coated with cadmium. Both municipal incinerators and sewage sludge incinerators emit cadmium into the air.

##### 1. Municipal Incinerators

The municipal incinerator is a major source of airborne cadmium emissions, emitting approximately 131 tons of cadmium per year. The following description of the process of the municipal incinerator assumes that there is no resource recovery and that volume reduction is the prime motivation.

##### (a) Process

First, the refuse is deposited in a receiving area which is essentially a pit up to 30 feet deep, 100 feet long, and 20 feet wide. From there, overhead cranes remove the refuse from the pit and deposit it in a feed hopper, which delivers refuse onto the combustion grates at a constant rate.

The most expensive part of the combustion plant, the grates, serve to transport refuse through the primary combustion chamber and simultaneously insure that the maximum refuse surface is directly in contact with fire. Many types of grates are used to accomplish this; among the most popular are moving belts, reciprocating grates, and drum-type rollers.

The refuse is carried into the primary combustion chamber and is burned. Here, in a conventional refractory furnace, 150 to 200 percent excess air is supplied in order to prevent refractory materials from erosion by high temperatures. A result of this process is a large amount of exhaust gas production. This necessitates the use of a secondary chamber, in which the exhaust gases are subjected to additional combustion. The gaseous emissions are then discharged through the chimney stacks.

The resultant solid material and all material which remains unburned is deposited into a residue bin which empties directly into trucks. The trucks then carry the waste to a landfill.

#### (b) Source of Emissions and Control

Emissions result from the combustion of plastics, paint pigments, and metal scrap which subsequently causes the volatilization of cadmium in the three items. Control devices most commonly used to combat the particulate emissions are wet scrubbers. Bag filters, or ESP's, are used occasionally. Approximately 83 percent of the municipal incinerators use some sort of emission control, while 17 percent employ none.<sup>1/</sup>

#### (c) Emissions Estimate

EEA's emissions estimate was made using an emissions factor from some very recent source testing (AA analysis) and

the average rate of processing for a municipal incinerator. With the use of a scrubber or ESP, municipal incinerators release between  $6 \times 10^{-4}$  and  $1.0 \times 10^{-1}$  pounds of cadmium/ton of refuse.<sup>2,8,10,14,17,33/</sup> A best judgement factor of  $1.3 \times 10^{-2}$  pounds/ton of refuse was a result of the reported mean of  $1.8 \times 10^{-2}$  pounds minus the standard deviation of  $5 \times 10^{-3}$  pounds of cadmium/ton of refuse for the above recent stack test analysis.<sup>5/</sup> With a refuse figure of 20,143,620 tons<sup>34/</sup> and the best judgement emission factor, EEA estimates emissions to be 131 tons/year. EEA's emission estimate is higher than that of Davis (95 tons),<sup>7/</sup> Mitre (95 tons),<sup>11/</sup> EPA (48 tons),<sup>2/</sup> and Sargent (16 tons),<sup>6/</sup> but is in close agreement with that of GCA (150 tons).<sup>2/</sup> Because other estimates are fairly close to that made by EEA, one can surmise that the volume of municipal trash has increased since the others were made.

#### (d) Future Trends

It is difficult to project future emissions resulting from municipal incineration. Control device use is expected to reach 100 percent before 1985. The number of municipal incinerators has decreased five percent annually over the last several years.<sup>34/</sup> However, those incinerators which have begun operation recently have capacities much greater than those which are closing. Therefore, existing capacity does not accurately reflect an increase or decrease in the number of municipal incinerators. Predictions call for 49 additional incinerators by 1979.<sup>35/</sup> As a result of the decreases in number, but increase in capacity, it is concluded that emissions through 1985 will remain constant. The effect of NSPS upon these new plants, and the use of high efficiency control devices by all municipal incinerators, should support the above assumption.

## 2. Sewage Sludge Incinerators

### (a) Process

The steps in the sewage sludge process differ in some ways from those in the municipal incineration. First, the temperature of the feed sludge is raised to 212° F to evaporate water from the sludge. The vaporization and increase in temperature combine to raise the water vapor and air temperature of the gas, which in turn, serves to bring the volatiles of the sludge to ignition. End products are water, sulfur dioxide, carbon dioxide, and inert ash.

The multiple hearth is the most common incineration unit. A number of solid refractory hearths with a central rotating shaft are encompassed by a circular steel shell. "Rabble" arms, connected to the rotating shaft, serve to agitate the sludge which drops from one hearth to another through openings in each hearth. An inner cold air tube, which cools the rabble arms, runs through the central shaft. The shaft has an outer tube which serves a similar function for hot air. Continuous feeding can be accomplished in this manner.

### (b) Emissions Source and Control

As sludge is volatilized, cadmium is released into the air. Sewage sludge contains only a small amount of cadmium, originating from plastics or pigments, plus contaminants which may have become incorporated into the sludge from industrial or domestic wastewater. Until recently, it was possible to meet current emissions standards with the use of afterburners. However, present control of sewage sludge incineration emissions includes wet scrubbers.<sup>1/</sup>



### (c) Emission Estimate

Multiple hearth sewage sludge incinerators controlled by a scrubber are estimated by EPA to emit  $7 \times 10^{-6}$  pounds of cadmium/ton of dry sludge.<sup>8/</sup> EEA estimates that less than one ton results from incineration of 1,460,000 tons of sludge<sup>36/</sup> each year.

### (d) Future Trends

Sewage sludge production may increase to 17,000 tons/day<sup>35/</sup> by 1985, and assuming that 25 percent of this amount is incinerated,<sup>36/</sup> the emission of cadmium will increase along with the amount incinerated. However, exist several condition these conclusions. The fact that control devices are now becoming commonplace supports may lower the rate of cadmium emission increases. On the other hand, recent bans on off-shore dumping and continually decreasing land-fill space may increase the amount of sludge incinerated. Because these factors will probably serve to counteract each other, EEA assumed that 25 percent of all sewage sludge would be incinerated, so that less than one ton of cadmium a year is expected to be emitted through 1985.

## J. Summary

To determine the population affected by various concentrations of airborne cadmium, it was necessary first to determine sources of airborne emissions. Next, the specific part of each process from which emissions emanate was discerned and emission estimates were calculated. The emission estimates (Table V-2) were based upon emission factors (Table V-1) and production figures (Table V-2). Future emission estimates were also discussed (Table V-2).

TABLE V-2  
CADMIUM EMISSION FACTORS

SOURCE	MINIMUM	MAXIMUM	BEST JUDGEMENT
<u>PRIMARY METALS PROCESSING</u>			
<u>ZINC</u>			
Coking	$9.04 \times 10^{-1}$ / TZnThru (STK,AA)	$3.78^{1b}$ / TZnThru (STK,AA)	$2.34^{1b}$ / TZnThru (STK,AA)
Sintering w/Cyclone	$4.06^{1b}$ / TZnThru (STK,AA)	$8.58^{1b}$ / TZnThru (STK,AA)	$6.32^{1b}$ / TZnThru (STK,AA)
Sintering w/Cyclone & ESP	$1.52^{1b}$ / TZnThru (STK,AA)	$2.80^{1b}$ / TZnThru (STK,AA)	$2.16^{1b}$ / TZnThru (STK,AA)
Roasting			~0 (EST)
Horizontal Retort			$6 \times 10^{-31b}$ / TZnProd (EST)
Vertical Retort	$1.2 \times 10^{-21b}$ / TZnThru (EST)	$8.76 \times 10^{-21b}$ / TZnThru (STK,AA)	$6.5 \times 10^{-21b}$ / TZnThru (STK,AA)
Electrothermic			$1.2 \times 10^{-21b}$ / TZnProd (EST)
Overall (Not Electrolytic)	$1.43^{1b}$ / TZnProd (EST)	$2.96^{1b}$ / TZnProd (STK,AA)	$2.5^{1b}$ / TZnProd <sup>1/</sup>
Electrolytic			~0
<u>LEAD</u>			
Overall Smelter	$5.2 \times 10^{-21b}$ / TPbProd (EST,MB)	$2.6 \times 10^{-11b}$ / TPbProd (EST,MAX CONC) <sup>2/</sup>	$1.1 \times 10^{-11b}$ / TPbProd (EST, AVE CONC) <sup>3/</sup>
Blast Furnace w/Baghouse			$5.25 \times 10^{-31b}$ / TZn (STK,ES)
<u>COPPER</u>			
Uncontrolled Smelter	$7 \times 10^{-21b}$ / TCu (EST,MB)	$2.9 \times 10^{-11b}$ / TCu (EST,MB)	$1.5 \times 10^{-11b}$ / TCu <sup>4/</sup>
Smelter w/Baghouse (~95%)			$7 \times 10^{-31b}$ / TCu (EST)
<u>CADMIUM</u>			
	$25^{1b}$ / TCdProd (EST,SURV,MB)	$30.5^{1b}$ / TCdProd (EST,MB)	$28^{1b}$ / TCd <sup>5/</sup>
<u>SECONDARY METALS PROCESSING</u>			
<u>IRON &amp; STEEL</u>			
Sinter Windbox-Uncontrolled	$1.35 \times 10^{-31b}$ / TFeed (STK,ES)	$2.63 \times 10^{-31b}$ / TFeed (STK,ES)	$2 \times 10^{-31b}$ / TFeed
Sinter Windbox w/Rotocyclone & ESP	$9.33 \times 10^{-41b}$ / TFeed (STK,ES)	$9.76 \times 10^{-41b}$ / TFeed (STK,ES)	$9.5 \times 10^{-41b}$ / TFeed
Blast Furnace-Controlled			~0 (EST) <sup>6/</sup>
Open Hearth-Uncontrolled	$4.07 \times 10^{-31b}$ / TSteel (STK,AA)	$7.49 \times 10^{-31b}$ / TSteel (STK,AA)	$5.78 \times 10^{-31b}$ / TSteel (STK,AA)
Open Hearth w/ESP	$2.08 \times 10^{-51b}$ / TSteel (EST,CONC)	$1.33 \times 10^{-41b}$ / TSteel (STK,AA)	$1.1 \times 10^{-41b}$ / TSteel (STK,AA)
Basic Oxygen Furnace			$4.1 \times 10^{-51b}$ / TSteel (CONC) <sup>7/</sup>
Uncontrolled			$1.2 \times 10^{-51b}$ / TSteel <sup>8/</sup>
w/Entrail or ESP	$3.45 \times 10^{-61b}$ / TSteel (STK,ES)	$2.79 \times 10^{-51b}$ / TSteel (STK,ES)	
Electric Arc Furnace	$2.7 \times 10^{-31b}$ / TSteel (EST,CONC) <sup>9/</sup>	$5 \times 10^{-31b}$ / TSteel (EST,STK,CONC) <sup>10/</sup>	$3.4 \times 10^{-31b}$ / TSteel (EST,STK,11 COIL) <sup>11/</sup>
Overall-Uncontrolled	$2.2 \times 10^{-61b}$ / TSteel (EST,MB)	$3.5 \times 10^{-31b}$ / TSteel (EST,MB)	$1.7 \times 10^{-51b}$ / TSteel <sup>12/</sup>
<u>SECONDARY ZINC-UNCONTROLLED</u>			
	$8 \times 10^{-31b}$ / TZn (SURV,MB)	$1.4 \times 10^{-21b}$ / TZn Prod (MB)	$1 \times 10^{-21b}$ / TZn Prod <sup>13/</sup>
<u>SECONDARY LEAD</u>			
Blast Furnace w/3 Cyclones & Baghouse	$5.9 \times 10^{-71b}$ / TPb (STK,ES)	$3.5 \times 10^{-51b}$ / TPb (STK,ES)	$2 \times 10^{-61b}$ / TPb <sup>14/</sup>
Reverberatory Furnace w/ Cyclone & Baghouse	$5.9 \times 10^{-71b}$ / TPb (STK,ES)	$4 \times 10^{-41b}$ / TPb (STK,ES)	$1.6 \times 10^{-61b}$ / TPb <sup>15/</sup>
Reverberatory Furnace w/ 3 Cyclones & Baghouse	$6.5 \times 10^{-91b}$ / TPb (STK,ES)	$2 \times 10^{-41b}$ / TPb (STK,ES)	$5 \times 10^{-71b}$ / TPb <sup>16/</sup>
<u>SECONDARY COPPER-UNCONTROLLED</u>			
	$2.6^{1b}$ / TCu Scrap (EST,MB)	$4^{1b}$ / TCu Scrap (EST,MB)	$3^{1b}$ / TCu Scrap <sup>17/</sup>
<u>MINING OF ZINC-BEARING ORES</u>			
Zinc Ore			$2 \times 10^{-11b}$ / TCd in Ore (EST,MB)
Lead Ore			$1 \times 10^{-31b}$ / TZn in Ore (EST,MB)
Copper Ore			$1 \times 10^{-41b}$ / TPb in Ore (EST,MB)
			$3.2 \times 10^{-51b}$ / TCu in Ore (EST,MB)
<u>MANUFACTURING</u>			
Alloys & Solders-Controlled			$10^{1b}$ / TCd Charged (SURV)
Pigments w/Baghouse			$15^{1b}$ / TCd Charged (EST,MB)
Stabilizers (for Plastics) w/Baghouse			$6^{1b}$ / TCd Charged (EST,STK)
Batteries (Ni-Cd)			$2^{1b}$ / TCd Charged (SURV)
Miscellaneous (X-Ray Screens, Cathode Ray Tubes, Nuclear Reactor Components, etc.)			$2^{1b}$ / TCd Charged (EST)

TABLE V-2 (Continued)  
CADMIUM EMISSION FACTORS

SOURCE	MINIMUM	MAXIMUM	BEST JUDGEMENT
<b>FOSSIL FUEL COMBUSTION</b>			
Coal-Fired Power Plants			
Uncontrolled	$1 \times 10^{-41b}$ /TCoal (STK,AA)	$1 \times 10^{-11b}$ /TCoal (STK,ES)	$1 \times 10^{-31b}$ /TCoal <sup>19/</sup>
Controlled (ESP)	$1 \times 10^{-61b}$ /TCoal (STK,AA)	$7 \times 10^{-41b}$ /TCoal (STK,AA) <sup>19/</sup>	$6 \times 10^{-51b}$ /TCoal <sup>20/</sup>
Oil-Fired Power Plants			
Controlled (~ ESP)	$7.1 \times 10^{-71b}$ /gal (STK,ES)	$4.4 \times 10^{-61b}$ /gal (STK,CONC,ES) <sup>21/</sup>	$9 \times 10^{-71b}$ /gal (SURV,ES) <sup>22/</sup>
Heating Oil (Residual; #6 Fuel Oil)	$1.5 \times 10^{-61b}$ /gal (EST,CONC) <sup>23/</sup>	$4 \times 10^{-51b}$ /gal (EST,CONC,NA) <sup>24/</sup>	$3 \times 10^{-61b}$ /gal <sup>25/</sup>
Diesel Oil	$6 \times 10^{-71b}$ /gal (EST,CONC,ES) <sup>26/</sup>	$2 \times 10^{-61b}$ /gal (EST) <sup>27/</sup>	$7 \times 10^{-71b}$ /gal (EST,CONC,ES) <sup>28/</sup>
Gasoline (for 15 mpg, all Cd emitted)	$6.3 \times 10^{-111b}$ /veh-mi (EST,CONC) <sup>29/</sup>	$4.5 \times 10^{-81b}$ /veh-mi (EST,CONC) <sup>30/</sup>	$2 \times 10^{-81b}$ /veh-mi <sup>31/</sup>
<b>SEWAGE SLUDGE INCINERATORS</b>			
Multiple Hearth w/Scrubber	$1 \times 10^{-61b}$ /TSludge (DRY)(STK,ES)	$2 \times 10^{-51b}$ /TSludge (DRY) (STK,ES)	$7 \times 10^{-61b}$ /TSludge (DRY) (STK,ES) <sup>32/</sup>
Fluidized Bed w/Scrubber	$4 \times 10^{-71b}$ /TSludge (DRY) (STK,ES)	$3 \times 10^{-61b}$ /TSludge (DRY) (STK,ES)	$1.3 \times 10^{-61b}$ /TSludge (DRY) (STK,ES) <sup>33/</sup>
<b>MUNICIPAL INCINERATORS</b>			
Uncontrolled	$3 \times 10^{-31b}$ /TRefuse (EST)	$1.8 \times 10^{-21b}$ /TRefuse (STK,ES) <sup>34/</sup>	$6 \times 10^{-31b}$ /TRefuse (STK,ES) <sup>35/</sup>
Controlled (Scrubbers or ESP)	$6 \times 10^{-41b}$ /TRefuse (FLAA)	$1.0 \times 10^{-11b}$ /TRefuse (EST,MB)	$1.3 \times 10^{-21b}$ /TRefuse (STK,AA) <sup>36/</sup>
<b>INDUSTRIAL OIL INCINERATORS</b>			
Uncontrolled			$2 \times 10^{-61b}$ /gal (UNK)
<b>MISCELLANEOUS</b>			
Motor Oil Consumption (Vehicles)			$2 \times 10^{-91b}$ /veh-mi (UNK)
Rubber Tire Wear	$1 \times 10^{-101b}$ /veh-mi (EST,CONC) <sup>37/</sup>	$5 \times 10^{-81b}$ /veh-mi (EST,CONC) <sup>38/</sup>	$8 \times 10^{-91b}$ /veh-mi <sup>39/</sup>
Fungicides Application	$1.8 \times 10^{-61b}$ /gal (EST,MB) <sup>40/</sup>	$5 \times 10^{-51b}$ /gal (EST)	$1 \times 10^{-51b}$ /gal <sup>41/</sup>
Fertilizers Application	$1.7 \times 10^{-41b}$ /T (EST,MB)	$5 \times 10^{-21b}$ /T (EST,MB)	$6 \times 10^{-31b}$ /T <sup>42/</sup>
Superphosphate Fertilizers Application			$2 \times 10^{-41b}$ /T
<b>CEMENT PLANTS</b>			
<b>DRY PROCESS</b>			
Kiln w/Baghouse or ESP			$3 \times 10^{-41b}$ /TFeed (STK,ES)
Raw Mill Feed w/Baghouse	$3 \times 10^{-71b}$ /TFeed (STK,ES)	$4.1 \times 10^{-71b}$ /TFeed (STK,ES)	$3.6 \times 10^{-71b}$ /TFeed
Raw Mill w/Baghouse	$1 \times 10^{-71b}$ /TFeed (STK,ES)	$4.3 \times 10^{-71b}$ /TFeed (STK,ES)	$2.7 \times 10^{-71b}$ /TFeed
Raw Mill Air Separator w/Baghouse	$7.6 \times 10^{-71b}$ /TFeed (STK,ES)	$9 \times 10^{-71b}$ /TFeed (STK,ES)	$8.5 \times 10^{-71b}$ /TFeed
Finish Mill Feed w/Baghouse	$5 \times 10^{-71b}$ /TFeed (STK,ES)	$1.6 \times 10^{-61b}$ /TFeed (STK,ES)	$1 \times 10^{-61b}$ /TFeed
Finish Mill w/Baghouse		$1.3 \times 10^{-71b}$ /TFeed (STK,ES)	$1 \times 10^{-71b}$ /TFeed
Finish Mill Air Separator w/Baghouse			$2.6 \times 10^{-61b}$ /TFeed (STK,ES)
<b>WET PROCESS</b>			
Kiln w/ESP	$7.4 \times 10^{-61b}$ /TFeed (STK,ES)	$2 \times 10^{-41b}$ /TFeed (STK,ES)	$2 \times 10^{-51b}$ /TFeed <sup>43/</sup>
Raw Mill w/Baghouse			$2 \times 10^{-51b}$ /TFeed
Clinker Cooler w/ESP or Baghouse	$1.7 \times 10^{-61b}$ /TFeed (STK,ES)	$1 \times 10^{-41b}$ /TFeed (STK,ES)	$1 \times 10^{-51b}$ /TFeed <sup>44/</sup>
<b>PIPE KILN (PULVERIZED COAL)</b>			
Kiln w/Spray, Settle & Baghouse	$4.6 \times 10^{-51b}$ /TFeed (STK,ES)	$6.9 \times 10^{-51b}$ /TFeed (STK,ES)	$5.7 \times 10^{-51b}$ /TFeed

a/ EST = Estimate; MB = Mass Balance; SITE = Site Visits; SURV = Survey of Companies; UNK = Unknown (in literature); STK = Stack Sampling Results; CONC = Concentration of Cd in feed, fuel, or emissions (w/STK); ES = Emission Spectroscopy; AA = Atomic Absorption (FL-Flame); NA =

TABLE V-2

## AIRBORNE CADMIUM EMISSIONS--1974, 1985

<u>Source</u>	<u>Production 1974*</u>	<u>Emissions Estimate</u>	<u>Reference</u>	<u>Production 1985 (e)</u>	<u>Emissions Estimate</u>	<u>Reference</u>
<b>MINING</b>						
Zinc	478,850	<1	12	845,377	<1	41
Copper	1,414,246.8	<1	12	2,563,122	<1	41
Lead	603,024	<1	12	1,169,524	<1	41
<b>PRIMARY METALS</b>						
Zinc						
Pyrometallurgic	423,000	529	40	1,000,000	529	9
Electrolytic	121,945	0	40	-	-	-
Lead	866,095	2	40	790,000	2	9
Copper	1,435,662.4	5	40	3,849,844	13.4	9
Cadmium	3,088.2	2	12	1,139	<1	9
<b>SECONDARY METAL PROCESSING</b>						
<b>Iron and Steel</b>						
Sinter Windbox Uncontrolled	21.94x10 <sup>6</sup>	22	13	-	-	
Sinter Windbox w/Rotoclone and ESP	11.35x10 <sup>6</sup>	5.4	13	40x10 <sup>6</sup>	19	13
Basic Oxygen Furnace Uncontrolled	1.2x10 <sup>6</sup>	<1	13	-	-	
BOF w/Venturi or ESP	78.8x10 <sup>6</sup>	<1	13	1.73x10 <sup>6</sup>	<1	13
Open Hearth Uncontrolled	7.64x10 <sup>6</sup>	22	13	-	-	
Open Hearth w/ESP	29.06x10 <sup>6</sup>	2	13	21.1x10 <sup>6</sup>	<1	13
Electric Arc Uncontrolled	27.3x10 <sup>6</sup>	46	13	-	-	
Electric Arc Controlled	-	4.6	13	38.8x10 <sup>6</sup>	3.3	13
Blast Furnace Controlled	95.2x10	0	13	113.6x10 <sup>6</sup>	0	13
Overall Uncontrolled	12.84x10 <sup>6</sup>	95	13	-	-	
Zinc	182,665	<1	12	223,000	<1	19
Lead	698,698	<1	12	860,000	<1	9
Copper	513,308	38	12	800,000	60	20
<b>MANUFACTURING</b>						
Pigments	1,212.1	9	6	1,560	11.3	6
Stabilizers	991.8	3	6	1,179	3.5	6
Batteries	628.14	<1	6	2,200	2.2	6
<b>FOSSIL FUEL COMBUSTION</b>						
Coal-Fired Power Plants	3.913x10 <sup>8</sup> (Btu's)	7.04	42	530.750x10 <sup>6</sup>	15.9	24
Oil-Fired Power Plants	500x10 <sup>6</sup> (barrels)	9	42	732.2x10 <sup>6</sup> (barrels)	19.9	46
Heating Oil	935.1x10 <sup>6</sup> (barrels)	29.2 (1975)	45	980.9x10 <sup>6</sup> (barrels)	30.5	46
Diesel Oil	11x10 <sup>9</sup> (gallons)	<1	39	15.12x10 <sup>9</sup> (gallons)	5.25	38
Gasoline	1,330,074x10 <sup>6</sup> (VMT)	13	43	1,707,152x10 <sup>6</sup> (VMT)	17.1	44
<b>MISCELLANEOUS</b>						
Motor Oil	1,028,121x10 <sup>6</sup> (VMT)	<1	43	1,707,152x10 <sup>6</sup> (VMT)	1.7	44
Rubber Tire Wear	1,330,024x10 <sup>6</sup> (VMT)	5	43	1,707,152x10 <sup>6</sup> (VMT)	6.8	44
Fungicides	59,800	<1	9	92,769	<1	9
Fertilizers	8,535x10 <sup>3</sup>	<1	9	13,240x10 <sup>3</sup>	1.3	9
Cement	81,210x10 <sup>3</sup>	<1	9	94,537x10 <sup>3</sup>	<1	32
<b>INCINERATION</b>						
Sewage Sludge Incinerators	1,460,000	<1	36	1,551,250	<1	35,36
Municipal Incinerators	20,143,620	131	34	20,143,620	131	34
		991.24			882.3	

\* tons per year unless otherwise stated.

e = estimated

VMT = vehicle miles traveled

Airborne cadmium emissions derive from many sources including: primary metal processes, production of items which contain cadmium (such as cadmium paint pigments), fossil fuel combustion, incineration, secondary metal processing, and the use of items which inadvertently contain cadmium (e.g., rubber tires).

Emission factors were obtained through an extensive search of current data sources. Minimum, Maximum, and "Best Judgement" figures were developed using methods and data reported below, tested in what is believed to be the order of decreasing accuracy:

1. DATA: Stack tests usually conducted at only one location with multiple tests; samples analyzed by atomic absorption (AA) and results reported as cadmium emission factors or rates, or as cadmium concentrations in particulate matter and particulate emission rates or factors.

METHOD: Emission factors for cadmium taken directly or calculated with reported or assumed values of process parameters (e.g., uncontrolled open hearth).

2. DATA: Stack tests conducted at one or more location usually with one test per process; sampling train samples analyzed by emission spectroscopy, a semi-quantitative method, and reported as detected amounts or concentrations.

METHOD: Emission factors calculated with reported particulate emission factors or rates as above (e.g., uncontrolled sinter windbox).

3. DATA: Concentration of cadmium in particulate emissions, usually analyzed by emission spectroscopy (ES), but no particulate factors or rates reported (for a stack).  
METHOD: Cadmium emission factor calculated from the particulate emission factor or NSPS standard for the source type (e.g., maximum and best judgment factors for electric arc furnace).
4. DATA: Concentration of cadmium in fuel or feed reported for analysis by AA or ES.  
METHOD: Emission factor computed assuming 100 percent emission and typical fuel characteristics (e.g., heating oil). Primarily used for liquid fuels.
5. DATA: Survey of industrial plants or site visits conducted by EPA during development of original cadmium emission factors (e.g., minimum factor for cadmium processing).  
METHOD: Mass balances for specific processes. Emission factor determined from unaccounted-for cadmium or by expected emissions for typical process and control equipment relative to total production or raw materials (e.g., overall uncontrolled iron and steel).
6. DATA AND METHOD: Engineering estimates made when no other data is available (e.g., zinc roasting).

Table V-1 provides a listing of emission factors which were used in the EEA study (1974). Production figures were obtained for use with emission factors to determine the emissions from each

process (Table V-2). A comparison of emission estimates, including those of EEA, can be seen in Table V-3. Assuming various control technologies and use of them by a percentage of operating facilities, yearly cadmium emissions total 914 tons. EEA's projections to 1985 indicate that total airborne cadmium emissions, assuming all facilities employ some type of control technology, will approximate 972 tons.

TABLE V-3  
COMPARISON OF CADMIUM EMISSION ESTIMATES 1968-1977  
EMISSION ESTIMATES TONS/YEAR

<u>Source</u>	<u>Davis 1968</u>	<u>ORNL 1968</u>	<u>MITRE</u>	<u>EPA 1971</u>	<u>GCA 1974</u>	<u>EPA 1975</u>	<u>EEA 1974-77 Comparable</u>	<u>w/ Est. Control<sup>a/</sup></u>
Mining (Zn + Pb + Cu)	<1	<1	<1	<1	<1	<1	<1	<1
<u>Primary Metals</u>								
Zinc	-	-	619	644	500	102	529	529
Lead	1050	1050	55	163	65	-	48	2
Copper	-	-	388	234	110	-	108	5
Cadmium	-	-	-	60	50	-	43	2
<u>Secondary Metals</u>								
Steel Scrap	1000	<110	1000	78	400	10.5	104	95
Zinc	-	?	-	2	2	} 2.2	1	1
Copper	125	?	125	65	70		38	38
<u>Manufacturing</u>								
Pigments	11	11	11	7	11	9.5	9	8
Stabilizers	3	3	3	4	3	2.7	3	3
Miscellaneous	<2	<2	<2	<1	<2	<1	<1	<1
Incineration	95	95	95	48	150	16	131	131
Fossil Fuel Combustion	-	145-1100	-	198	250	130	59.2	40



TABLE V 3 (Continued)  
COMPARISON OF CADMIUM EMISSION ESTIMATES 1968-1977  
EMISSION ESTIMATES TONS/YEAR

<u>Source</u>	<u>Davis 1968</u>	<u>ORNL 1968</u>	<u>MITRE</u>	<u>EPA 1971</u>	<u>GCA 1974</u>	<u>EPA 1975</u>	<u>EEA 1974-77 Comparable</u>	<u>w/ Est. Control<sup>a/</sup></u>
Sewage Sludge Inc.	-	-	-	138	12	20	<1	.005
<u>Miscellaneous</u>								
Motor Oil	1	1	-	-	<1	-	<1	<1
Rubber Tires	6	6	-	6	6	5.2	5	5
Gasoline	-	-	-	-	-	50	13	13
Forest & Agr. Burning	-	-	-	-	50	-	-	-
Other	-	-	-	-	<2	-	4	42
TOTAL =	2294	1425-2380	2305	1650	<1688	300	1100.2	914

a/  
Reference Table Range of EEA Cadmium Emissions Estimates (Tons/Year) for control assumptions

## REFERENCES

1. Goldberg, A.J., A Survey of Emissions and Controls for Hazardous and Other Pollutants, EPA PB-223 568, Washington, D.C., February 1975.
2. Deane, G.L., Lynn, D.A., and Surprenant, N.F., Cadmium: Control Strategy Analysis, GCA-TR-75-36-G, Final Report for Environmental Protection Agency, Contract No. 68-02-1337, Task No. 2, April 1976.
3. Mineral Industries Surveys, Zinc, Lead, and Copper, Bureau of Mines, 1973.
4. Yost, K.J., et.al., The Environmental Flow of Cadmium and Other Trace Metals, Source Studies (Progress Report), National Science Foundation Grant, GI-35106, June 30, 1974.
5. Jacko, R.B. and Nuendorf, D.W., "Trace Metal Particulate Emission Test Results From a Number of Industrial and Municipal Point Sources," Journal of Air Pollution Control Association, 27 (10): 989-994, October 1977.
6. Sargent, D.J. and Metz, R.J., Technical and Microeconomic Analysis of Cadmium and Its Compounds, Environmental Protection Agency, 560/3-75-005, June 1975.
7. Davis, W.E. and Associates, National Inventory of Sources and Emissions: Cadmium, Nickel, and Asbestos, NAPCA-APTD-68, PB 192-250, February 1970.
8. Anderson, D., Emissions Factors for Trace Substances, Final Report, Environmental Protection Agency, 450/2-13-001, PB 230 894, December 1973.
9. \_\_\_\_\_, U.S. Industrial Outlook, U.S. Department of Commerce, Washington, D.C., January 1977.
10. Preferred Standards Path Report for Cadmium, Draft Document, ESED, Environmental Protection Agency, 1972.

11. Duncan, L.G., et.al., Selected Characteristics of Hazardous Pollutant Emissions, Mitre Corporation, Final Report for Environmental Protection Agency Contract No. 68-01-0438, 1973.
12. \_\_\_\_\_, Metal Statistics, 1977, American Metal Market, Fairchild Publishing, New York, New York, 1977.
13. Temple, Barker, and Sloane, Analysis of Economic Effects of Environmental Regulations on the Integrated Demand Steel Industry, Volumes I and II, December 1976.
14. Environmental Protection Agency Emission Test Results, Emissions Management Branch, OAQPS, Environmental Protection Agency, Durham, North Carolina.
15. Yost, K.J., et.al., The Environmental Flow of Cadmium and Other Trace Metals, Volume I, Purdue University Progress Report, July 1, 1972-June 30, 1973.
16. Arthur D. Little, Inc., Steel and the Environment: A Cost Impact Analysis, May 1975.
17. Jacko, R.B., Nuendorf, D.W., and Faure, F., "Fractional Collection Efficiency of Electrostatic Precipitator for Open Hearth Furnace Trace Metal Emissions," Environmental Science and Technology, 10 (10): 1002-1005, October 1976.
18. Basis For National Emission Standards for Cadmium, Battelle-Columbus, 1971.
19. Lucas, John, Bureau of Mines, personal communication, December 1971.
20. Coakley, Mr., Bureau of Mines, personal communication, December 1977.
21. Fulkerson, W., and Goeller, H.D., Eds., Cadmium, The Dissipated Element, ORNL National Science Foundation, ED-21, January 1973.
22. Klein, D.H., Anderson, A.W., et.al., "Pathways of Thirty-Seven Trace Elements Through Coal-Fired Power Plants," Environmental Science and Technology, 9 (10): 973-979, October 1975.
23. Lee, R.E., Jr., Crist, H.L., et.al., "Concentration and Size of Trace Metal Emissions From a Power Plant, a Steel Mill, and a Cotton Gin," Environmental Science and Technology, 9 (7): 643-647, July 1975.

24. \_\_\_\_\_, Project Independence, Federal Energy Administration, Washington, D.C., 1974.
25. Lee, R.E., Jr., and von Lehmden, D.J., "Trace Metal Pollution in the Environment," Environmental Science and Technology, 10 (10): 1011-1017, October 1976.
26. Fletscher, M., Sarofim, A.F., et.al., "Environmental Impact of Cadmium: A Review by the Panel on Hazardous Trace Substances," Environmental Health Perspectives, 7:253:323, May 1974.
27. Lagerwerff, J.V., and Specht, A.W., "Contamination of Roadside Soil and Vegetation With Cadmium, Nickel, Lead, and Zinc," Environmental Science and Technology, 4:583, 1970.
28. Scientific and Technical Assessment Report on Cadmium, Environmental Protection Agency 600/6-75-003, March 1975.
29. Junger, R.H., Lee, R.E., Jr., and von Lehmden, D.J., "The EPA Fuel Surveillance Network: I. Trace Constituents in Gasoline and Commercial Gasoline Fuel Additives," prepared for Environmental Science and Technology, 1975.
30. \_\_\_\_\_, National Functional System Mileage and Travel Summary, 1976, Department of Transportation, Washington, D.C., 1976.
31. \_\_\_\_\_, Determination and Evaluation of Environmental Levels of Cadmium, Battelle-Columbus, Lab Draft Report to Environmental Protection Agency, Office of Toxic Substances, July 13, 1977.
32. Pitcher, Charles, Bureau of Domestic Commerce, Construction and Forest Products Division, personal communication, December 1977.
33. Cross, F.L., Jr., Drago, R.J., and Francis, H.E., Metals in Emissions From Incinerators Burning Sewage and Mixed Refuse, NAPCA, 1969.
34. Fenton, Richard, "Present Status of Municipal Incinerators," May 1975.
35. \_\_\_\_\_, "Municipal Sludge: What Shall We do With It?," Current Focus, League of Women Voters, Washington, D.C., 1976.

36. Jones, Jerry, et.al., "Municipal Sludge Disposal Economics," Environmental Science and Technology, 11 (10), October 1977.
37. \_\_\_\_\_, Air Pollution Primer, National Tuberculosis Respiratory Disease Association, New York, 1969.
38. Shonka, D.B., Soeble, A.S., Patterson, P.D., Transportation Energy Conservation Data Book, Edition Two, Oak Ridge, ORNL-5320, October 1977.
39. \_\_\_\_\_, "Sales of Fuel Oil and Kerosene in 1975," Mineral Industry Surveys, U.S. Department of Mines, Washington, D.C., 1976.
40. \_\_\_\_\_, International Directory of Mining and Mineral Operations, Engineering and Mining Journal, McGraw Hill, New York, New York, 1976.
41. \_\_\_\_\_, Metal and Mineral Policy, 1973, U.S. Bureau of Mines, Washington, D.C.
42. Suprenant, Norman, et.al., Preliminary Emissions Assessment of Conventional Stationary Combustion Systems, Voluem II, Environmental Protection Agency, 600/2-76-0466, March 1976.
43. \_\_\_\_\_, National Highway Inventory and Performance Study, 1976, U.S. Department of Transportation, Federal Highway Administration, OMB No. 04-575308, July 1975.
44. \_\_\_\_\_, National Functional System Mileage and Travel Summary, 1976, Department of Transportation, Washington, D.C., 1976.
45. Bender, Ed and Readling, Charles, "Annual U.S. Energy Use Up in 1976," Department of the Interior News Release, Bureau of Mines, March 14, 1977.
46. \_\_\_\_\_, Market-Oriented Program Planning Study (MOPPS), U.S. Energy Research and Development Administration, Washington, D.C., September 1977.

## SECTION VI

### SCREENING OF CADMIUM SOURCE TYPES

#### A. Introduction

The ambient concentrations produced by the various individual cadmium emitters were estimated very conservatively in order to determine which source types could potentially produce significant levels of cadmium ( $<0.1 \text{ ng/m}^3$  annual average) in the ambient air. The average, "typical," and/or maximum plant capacity or production rates for each source type was collected from the industrial literature. For area sources, an area of emission was taken from the literature or estimated. For point sources, the stack characteristics in terms of ranges or "typical" values were compiled when available. The stack characteristics required were flow rate per production rate, stack temperature, and stack height. The primary references for this data were:

1. Vandegrift, A.E., Shannon, L.J., et.al., Handbook of Emissions, Effluents, and Control Practices for Stationary Particulate Pollutant Sources, Report for NAPCA Contract No. CPA-22-69-104, November 1970.
2. Deane, G.L., Lynn, D.A., and Suprenant, N.F., Cadmium: Control Strategy Analysis, GCA-TR-75-36-G, Final Report for EPA Contract No. 68-02-1331, Task No. 2, April 1976.
3. Katari, V., Isaacs, G., and Devitt, T.W., Trace Pollutant Emissions From Processing

Metallic Ores (Final Report), EPA-650/2-74-115, PB 238 655, October 1974.

4. Environmental Protection Agency Emission Test Results, Environmental Measurement Branch, OAQPS, Environmental Protection Agency, Durham, North Carolina.
5. Arthur D. Little, Inc., Steel and the Environment: A Cost Impact Analysis, a report to the Iron and Steel Institute, May 1975.

Often, little, if any, specific information was available for a given plant characteristic of a source type, so that an estimate had to be made. Such estimates were based on available information about the process, control equipment, and standard industrial practice.

The information on plant sizes in terms of capacity or production rate were extracted from the following sources:

1. Deane, G.L., Lynn, D.A., and Suprenant, N.F., Cadmium: Control Strategy Analysis, GCA-TR-75-36-G, Final Report for EPA Contract No. 68-02-1337, Task No. 2, April 1976.
2. International Directory of Mining and Mineral Operations, Engineering and Mining Journal, McGraw-Hill, New York, New York, 1976.
3. Arthur D. Little, Inc., Steel and the Environment: A Cost Impact Analysis, a report to the American Iron and Steel Institute, May 1975.

4. Metal Statistics 1977, American Metal Market, Fairchild Publications, New York, New York, 1977.
5. Sargent, D.J. and Metz, J.R., Technical and Micro-economic Analysis of Cadmium and Its Compounds, EPA-560/3-75-005, June 1975.
6. Fenton, R., "Present Status of Municipal Incinerators," Incinerator and Solid Waste Technology, J.W. Stephanson, et.al., Eds. ASME, New York, New York, 1975.
7. Jones, J.L., et.al., "Municipal Sludge Disposal Economics," Environmental Science and Technology, October 1977.
8. Weinstein, N.J., Waste Oil Recycling and Disposal, EPA-670/2-74-052, August 1974.

Most of the preliminary information, such as industry production figures, and some detailed information, such as the size of units for primary smelting and some of the miscellaneous sources, were taken from the first reference. The remaining references were the sources of maximum or "typical" plant size information for mining and primary smelting, iron and steel plants, secondary smelting, manufacturing using cadmium, municipal incinerators, sewage sludge incinerators, and lubricating oil incinerators, respectively.

Fossil fuel consumption was estimated for a typical plant size in the case of power plants and derived from the following government publications for fuel oil and gasoline:



1. "Sales of Fuel Oil and Kerosene in 1975,"  
Mineral Industry Surveys, U.S. Department of  
Mines, Washington, D.C., 1976.
2. National Functional System Mileage and Travel  
Summary from the 1976 National Highway Inventory  
and Performance Study, U.S. Department of Trans-  
portation, Federal Highway Administration, June  
1977.

The first document gives fuel consumption by state for residual, distillate, and diesel fuel. The diesel fuel consumption is further broken down by on-highway and off-highway uses. The second report gives the density of vehicle miles traveled in the urbanized area for the major metropolitan areas and the states.

The compiled plant characteristics for the various source types were then used to make "realistic," but very conservative, estimates of the effect of a "typical" or maximum size plant of each type on the concentration of cadmium in the ambient air. The effects of the area sources were estimated for screening purposes by using the Hannah-Gifford urban air pollution model, assuming a very conservative (especially for an annual average) wind speed of two m/s, or the Miller Holzworth urban model for cities for which it had been calibrated. The effects of individual plants of the various point source types were estimated for screening purposes by using EPA's PTMAX dispersion model using generally conservative emission rates, stack heights, temperatures, and flow rates. The PTMAX model is, in itself, conservative as it estimates hourly average ambient concentrations given an emission rate and set of stack concentrations, while the ambient concentration of interest is the annual average. An annual average is generally a factor of three to four lower than a 24-hour average concentration, which is, in turn,

generally a factor of two to three lower than an hourly average. In addition, the maximum concentration considered was the maximum for any wind speed and stability conditions. Thus, conditions which might occur for a short time, but which are unlikely to represent the annual average meteorological conditions, and which would occur very near to the plant, are often used to conservatively represent the worst realistic case. The emission rates (the products of the emission factors and production capacities or rates, expressed in grams per second) used were conservative in that it was generally assumed that a plant operated only 220 days per year and eight hours per day. If available, both the maximum and a "typical" plant size were considered for both the maximum and best judgement estimates of cadmium emission factors in order to assess the likelihood of the estimated concentrations. For some source types, the two different estimates of plant size or of emission factors were nearly equal, so only the more conservative case was calculated. The stack characteristics for which PTMAX was run were generally chosen to be the ones in the realistic range of characteristics for the plant type which would generate the most conservative (highest) maximum ambient concentration for a given emission rate (of one g/s) (i.e., low flow rate, low stack height, and low stack temperature). The following sections briefly outline the estimated conditions and the results of the screening of the various cadmium source types.

## B. Mining

The cadmium emissions from the mining of cadmium-bearing ores were very conservatively estimated using the area source approach. For the largest zinc mine of one million tons per year, it was assumed that the concentration of zinc in the ore was 2.6 percent and that the area of the mine was one square mile. For a wind speed of two m/s at these conditions, the

Hannah-Gifford model estimates a concentration of  $16 \text{ ng/m}^3$ . However, the Hannah-Gifford model was developed for urban areas by assuming a series of line sources which is not the case for an isolated source such as mine. A wind speed of five m/s is more generally typical; the average mine produces 500,000 tons/year; and a mine's property, if not its active area, is usually at least ten square miles. Therefore, it was presumed that a more realistic estimate of ambient concentration beyond the mine property would be at least two orders of magnitude lower and that even the largest mine would generate concentrations that were at most marginally significant ( $< 0.1 \text{ ng/m}^3$ ). Since most zinc mines are underground mines, emissions released to the atmosphere would be expected to be much lower, as they would only be the dust containing cadmium which is picked up, carried, and exhausted by the ventilation system, or which is picked up from storage piles by the wind or during movement of the ore. If the ventilation stack is assumed to be 20 m tall and to exhaust only  $0.90 \text{ m}^3/\text{s}$  at  $340^\circ \text{ K}$ , the maximum concentration at any meteorological conditions (A stability, 0.3 m/s wind) would be about  $60 \text{ ng/m}^3$ . However, less stable conditions or higher wind speeds reduce this estimate by at least an order of magnitude. Therefore, for an annual average with more realistic conditions of stack, meteorology, and operation, ambient concentrations of cadmium generated by emissions from zinc mining should be below significant levels.

The treatment and conclusions were similar for the other types of mining which handle significant amounts of cadmium. The largest lead mine produces 1.6 million tons/year and the lead concentration in ore is estimated at 1.6 percent, so the ambient concentration for a one mile square area source would be  $1.6 \text{ ng/m}^3$ . Since most lead mines are underground and the average production is only 350,000 tons/year, it is even more

unlikely that significant concentrations would be generated. The average lead-zinc ore in the U.S. contains 2.6 percent zinc and 1.6 percent lead, so that the very conservative application of the Hannah-Gifford model predicts a concentration of about  $28 \text{ ng/m}^3$  for a 1.6 million ton/year mine. Again, the same characteristics of this estimate, as those for zinc mining noted above, make this high a concentration extremely unlikely, so that levels below significant are presumed. Copper mines generally are surface mines producing as much as 19.6 million tons of ore per year. Assuming the maximum U.S. concentration in ore of 0.6 percent, and a rather conservative working area of ten square miles, an ambient concentration of  $0.09 \text{ ng/m}^3$  is predicted, disregarding the fact that the pit may be several hundred meters deep.

#### C. Primary Metals

The primary metal smelters were treated as point sources using very conservative plant and stack characteristics for screening purposes. The largest zinc smelter produces 250,000 tons/year, so this was used to calculate an emission rate for the various processes and the overall plant using the maximum emission factor. Assuming stack characteristics ranging from a ten m stack emitting about  $20 \text{ m}^3/\text{s}$  at ambient temperature for coke ovens, to a 120 m stack emitting  $235 \text{ m}^3/\text{s}$  at  $370$  to  $615^\circ \text{ K}$  for most of the processes, the range of estimated maximum concentrations ranged from  $96 \text{ ng/m}^3$  to about  $60 \text{ ng/m}^3$  for a horizontal retort and the overall process, respectively. Most of the individual processes would produce maximum ambient (hourly average) concentrations on the order of  $10 \text{ ng/m}^3$ , so that even for an average plant size of 100,000 tons/year, it is unlikely that concentrations lower than the significant level ( $0.1 \text{ ng/m}^3$ ) would be produced. This is so even for the "best judgement"

emission factors, as they are no more than a factor of two smaller than the maximum estimate emission factor.

Similarly the largest primary lead smelter produces 350,000 tons/year. Therefore, assuming a 60 m stack with a flow rate of  $160 \text{ m}^3/\text{s}$  at  $340^\circ \text{ K}$  for the overall smelter, and a flow rate of  $4.8 \text{ m}^3/\text{s}$  at  $330^\circ \text{ K}$  for a baghouse controlled smelter, the ambient concentrations produced by the two model plants would be  $8.7 \text{ ng/m}^3$  and  $520 \text{ ng/m}^3$ , respectively. Again, the average plant size is 52,000 tons/year and the "best judgement" emission factor is less than a factor of three lower, so it is unlikely that lower than significant levels would be produced. As the stack characteristics are similar for copper and cadmium smelters, the emission factors are at least as high, and the production rates are in the area of 200,000 tons/year, there is no question that these facilities also produce ambient concentrations far above the significant level (in the range of  $\text{ng/m}^3$  for copper and  $\text{mg/m}^3$  for cadmium).

#### D. Iron and Steel

The individual iron and steel processes were screened using representative sizes for that process, while the overall plant was screened using the maximum production rate of three million tons of steel per year. All of stacks were approximated as 40 m and the temperatures at  $310\text{--}340^\circ \text{ K}$ . The estimated concentrations range from  $8.3 \text{ }\mu\text{g/m}^3$  for a 13,055 ton/day controlled basic oxygen furnace (using the "best judgement" emission factor and  $95 \text{ m}^3/\text{s}$  at  $340^\circ \text{ K}$ ), to  $4.5 \text{ }\mu\text{g/m}^3$  for a 6,504 ton/day uncontrolled open hearth (using the maximum emission factor and the same stack conditions). The overall plant estimate (using a flow rate of  $220 \text{ m}^3/\text{s}$  and  $310^\circ \text{ K}$ ) ranged from  $1.6 \text{ }\mu\text{g/m}^3$  to  $13 \text{ }\mu\text{g/m}^3$  using the maximum or best judgement emission factor. For

the other processes (3,787 ton/day interstrand, 1,440 ton/day blast furnace, and a 1,344 ton/day electric arc), the estimated concentrations were generally on the order of  $0.1-0.1 \mu\text{g}/\text{m}^3$ . Since the controlled estimates for the conservative screening technique were as low as ten's of nanograms per cubic meter, it was possible that some plants, particularly small ones, might prove to produce insignificant concentrations. In the later analysis, it was found that some plants did produce very low, but generally significant, concentrations, but that iron and steel plants with sinter strands, which are difficult to control efficiently, or with very large capacity, are estimated to produce maximum annual average concentrations of as much as 100's of nanograms per cubic meter.

#### E. Secondary Smelting

The uncontrolled emissions of secondary zinc and copper smelters were found to produce significant ambient cadmium levels, while the controlled emission factors for secondary lead smelters were found to produce at most, marginally-significant concentrations even for the conservative screening procedure. The 45,000 ton/year maximum size plant with an assumed stack of 40 m emitting  $7.5 \text{ m}^3/\text{s}$  at  $340^\circ \text{ K}$  would generate a maximum concentrate of  $0.9 \mu\text{g}/\text{m}^3$ . A secondary copper smelter producing 52 tons is a seven-hour-day and using a 20 m stack with a flow rate of  $17.5 \text{ m}^3/\text{s}$  at  $370^\circ \text{ K}$  would generate concentrations which are another order of magnitude higher. Secondary lead plants with a "typical" production rate of 2,500 lb/hr with high efficiency control equipment were estimated to produce ambient concentrations less than six  $\mu\text{g}/\text{m}^3$ , even for the maximum emission factor, and a 20 m stack with a flow of  $0.9 \text{ m}^3/\text{s}$  at  $340^\circ \text{ K}$ . Using the "best judgement" emission factors, the highest maximum concentration generated by PTMAX, even for these very conservative

stack characteristics, was less than  $0.6 \mu\text{g}/\text{m}^3$ . Therefore, since the range of sizes of secondary smelters is generally small, and PTMAX estimates hourly, rather than annual averages, secondary lead smelters were eliminated from further consideration as a significant source of emissions.

#### F. Manufacturing

Very little information could be found about individual plants which manufacture products containing cadmium. Using the GCA estimates of the total production, the number of known plants, and the very conservative mass balance or survey estimates of emission factors, concentrations in the microgram per cubic meter range were estimated for very conservative stack conditions (20 m and  $0.90 \text{ m}^3/\text{s}$  at  $340^\circ \text{ K}$ ). Since there are probably many more, and thus smaller, plants with increased control efficiency and larger stacks, it was assumed that the emissions of individual manufacturing plants would not produce significant annual average concentrations of cadmium.

#### G. Fossil Fuel Combustion

The only point source that was considered that burns fossil fuel is power plants. Assuming a 300 MW(e) power plant (with ten million Btu/hr power MW(e) and 82 percent boiler efficiency), and a 130 m stack with a flow of  $285 \text{ m}^3/\text{s}$  at  $440^\circ \text{ K}$ , a coal-fired power plant would produce ambient concentrations of  $5 \text{ ng}/\text{m}^3$  with the "best judgement" emission factor and  $\sim 700 \mu\text{g}/\text{m}^3$  with the maximum emission factor. Assuming a 60 m stack with a flow of  $140 \text{ m}^3/\text{s}$  at  $440^\circ \text{ K}$ , the controlled coal- and oil-fired power plants were estimated to produce concentrations ranging from  $0.8 \mu\text{g}/\text{m}^3$  to  $40 \mu\text{g}/\text{m}^3$  for best judgement and maximum estimate emission factors. Thus, for more realistic conditions, power plants were generally thought to be marginally significant since some plants could probably produce significant

concentrations. Therefore, an annual average CRSTER run (using Dallas/Fort Worth meteorological conditions and a very conservative 40 m stack with a flow of  $\cong 105 \text{ m}^3/\text{s}$  at  $1,360^\circ \text{ K}$ ) was used to determine the critical emission rate which could cause a significant maximum annual average ambient concentration ( $\leq 0.1 \text{ } \mu\text{g}/\text{m}^3$ ) for each fuel type. The emission factors for each fuel type were then assumed to follow a log-normal distribution (with a probability of being exceeded of 90 percent for the minimum, 50 percent for the "best judgement" and ten percent for the maximum emission factor), and multiplied by the capacities in the Energy Data System (EDS) file to calculate the emission rates for uncontrolled and controlled power plants (assuming a 24-hour operation). Plotting these emission rates of log-probability, paper showed that only three plants had a probability greater than ten percent of exceeding the significant ambient cadmium concentrations. These three plants were the three largest plants listed in the EDS with no control equipment. Since all power plants have some particulate control equipment (generally of greater than 90 percent efficiency), individual power plants were thus eliminated as a significant source of cadmium.

The other fossil fuel combustion sources of heating oil, diesel oil, and gasoline were treated as area sources. For heating oil, the total distillate (including off-highway diesel) and residual used in New York State in 1975 (the highest state consumption in the nation) of 159 million barrels, was assumed to be burned in the urbanized area of Metropolitan New York City within New York State (1,634 mi) during a three-month period (24 hours per day). The ambient concentration, using the maximum emission factor and the Hannah-Gifford model with a wind speed of two m/s, was only  $0.09 \text{ } \mu\text{g}/\text{m}^3$ , so heating oil was eliminated as an individually-significant source. Similarly, the on-highway diesel fuel consumption of California (17.9 million



barrels) was assumed to be used in Metropolitan Los Angeles (1,724 mi) over the entire year. Using the maximum emission factor, the concentration generated by the Hannah-Gifford model for a two m/s wind is  $1.2 \text{ pg/m}^3$ . The Miller-Holzworth model for Los Angeles (city size 60 km) confirms this with a concentration of  $0.59 \text{ pg/m}^3$  for a mixing height of 300 m and one of  $3.1 \text{ pg/m}^3$  for a mixing height of 100 m and a wind speed of one m/s. The Miller-Holzworth model for Los Angeles was also used for gasoline consumption. The daily vehicle miles traveled per square mile (DVMT density) of 61.342 and an assumed mixing height of 300 m and wind speed of two m/s generated an estimated  $0.3 \text{ } \mu\text{g/m}^3$  for the maximum and  $0.15 \text{ } \mu\text{g/m}^3$  for the "best judgement" emission factor. For the Washington, D.C. Metropolitan area, the area with second highest DVMT density, the estimates are  $0.17 \text{ } \mu\text{g/m}^3$  and  $0.08 \text{ } \mu\text{g/m}^3$ . Therefore, because of the accuracy of the estimates and the conservative meteorological assumptions for the areas with the most usage, gasoline consumption was concluded not be an individually-significant source of ambient cadmium.

#### H. Miscellaneous

The miscellaneous sources of cadmium emissions are motor oil consumption, rubber tire wear, fungicides, and fertilizers with the exception of fungicides, for which no information or application rates was available, and which may be learned in the near future, these sources were treated by the area source methodology. The same analysis was used for motor oil consumption and rubber tire wear as was used for gasoline (i.e., the Miller-Holzworth model using DVMT density). For motor oil consumption, the calculated ambient concentrations are  $13 \text{ pg/m}^3$  for Los Angeles and eight  $\text{pg/m}^3$  for Washington, D.C. For rubber tire wear, the ambient concentrations are  $0.3 \text{ ng/m}^3$  and  $0.2 \text{ } \mu\text{g/m}^3$  using the "best judgement" emission factor for the two

cities, respectively. Thus, the individual automotive sources of cadmium do not produce significant ambient levels of cadmium, even in the cities with the highest DVMT density. When a high fertilizer application rate of  $20 \text{ g/m}^2\text{-year}$  was assumed, the ambient concentration using the Hannah-Gifford urban area model with a wind speed of two m/s was calculated as 18 and  $0.2 \text{ ng/m}^3$ , with the maximum and "best judgement" emission factors, respectively. As the maximum emission factor assumes that all the cadmium in the fertilizer is emitted into the air, and a high fertilizer application rate and conservative dispersion model for rural locations was used, it was concluded that fertilizers would not produce significant ambient concentrations of cadmium.

Cement plants are another source of cadmium emissions that was found to produce ambient levels of cadmium even when very conservatively modelled as a point source. Assuming the emissions from the entire cement production of 31 million pounds/year of the Lehigh Valley of Pennsylvania came out of one stack (60 m with a flow of  $115 \text{ m}^3/\text{s}$  at  $340^\circ \text{ K}$ ), the maximum ambient (hourly average) concentration would only be  $0.8 \text{ } \mu\text{g/m}^3$ . With the same production rate, and even more conservative stack characteristics (as low as 20 m with a flow of  $16 \text{ m}^3/\text{s}$  and  $295^\circ \text{ K}$ ), only a few of the individual processes would produce significant ambient (hourly average) concentrations. Therefore, for any individual cement plant, it was concluded that annual average ambient concentrations would be well below significant levels.

#### I. Incineration

The incineration cadmium sources of municipal, sewage sludge, and lube oil incinerators, were screened by using PTMAX and a point source treatment. Using a 35 m stack with a flow of

9.4 m<sup>3</sup>/s at 310° K, and the maximum or "best judgement" emission factor, the maximum and average capacities of 1,600 and 300 tons/24-hour day are estimated to generate ambient concentrations on the order of micrograms per cubic meter. Since the control equipment on incinerators is generally not of high efficiency, municipal incinerators were considered to be a significant source.

The maximum capacity sewage sludge incinerator of 7.5 tons/hour, which operates only three days a week, would generate an ambient concentration of less than three µg/m<sup>3</sup> even for a 20 m stack with a flow of 2.5 m<sup>3</sup>/s at 310° K. With a 35 m stack and the same flow rate, the maximum hourly average concentration is 1.7 ng/m<sup>3</sup> for the controlled multiple hearth maximum emission factor, but only 0.6 ng/m<sup>3</sup> for the "best judgement" emission factor for the same process (0.12 µg/m<sup>3</sup> for the controlled fluidized bed). It was, therefore, concluded that the annual average emissions would not produce significant annual average ambient concentrations of cadmium.

The only information that was available on lubricating oil incinerators was that the total amount incinerated was estimated to be 389 million gallons per year by a multitude of small sources. Assuming that the uncontrolled emissions from incinerating all the lubricating oil in the nation all came out of a 20 m stack with a flow rate of 0.9 m<sup>3</sup>/s at 340° K, an ambient concentration on the order of micrograms per cubic meter is estimated by PTMAX. Since there are probably thousands of such incinerators in the country, it is presumed that the annual average ambient cadmium concentrations generated by any one of them would be below significant levels.