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The Materials Flow of Mercury in the United States

By Stephen M. Jasinski



UNITED STATES DEPARTMENT OF THE INTERIOR

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Bruce Babbitt, Secretary**

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	ppm	part per million
g/mt	gram per metric ton	mg	milligram
kg	kilogram	mt	metric ton
kg/yr	kilogram per year	mt/yr	metric ton per year
lb	pound	st	short ton

THE MATERIALS FLOW OF MERCURY IN THE UNITED STATES

By Stephen M. Jasinski¹

ABSTRACT

This report describes the materials flow of mercury in the United States. It examines the mining and production of mercury and the manufacturing, uses, and ultimate disposal of mercury. Materials flowcharts were prepared for 1989 and 1990. An effort was made to include estimates for all major anthropogenic sources including fossil fuel combustion, waste incineration, and nonferrous metal mining operations.

Mining and mineral processing released about 100 mt/yr of mercury to the environment in both 1989 and 1990. The combustion of fossil fuels released 175 mt/yr in the same years. The manufacturing, use, and disposal of products containing mercury accounted for the release of 1,037 mt of mercury in 1989 and 938 mt in 1990. The manufacture of chlorine and caustic soda was a major source of recycled mercury, but it was all reused within the industry. Recovery from all waste products accounted for 36% of reported consumption in 1989 and 42% in 1990. The losses from manufacturing and end use have been declining, whereas mercury emitted from combustion sources has not been strictly regulated and will likely become the largest source of mercury releases to the environment.

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INTRODUCTION

Concerned about the ultimate fate of mineral-derived materials in the United States, the U.S. Bureau of Mines initiated a series of studies in 1990 to assess their potential impact on the environment. This study of mercury, one of the more toxic metals in common use, examines the major components of the domestic materials flow for mercury for the period 1941 through 1990, and looks at the materials flow for 1989 and 1990. The study is based primarily on data contained in publications by the Bureau, the U.S. Environmental Protection Agency (EPA), and others. It is not intended to be a detailed investigation of any specific source of mercury discharge to the environment, but to look at the contribution of each major source to total domestic mercury emissions.

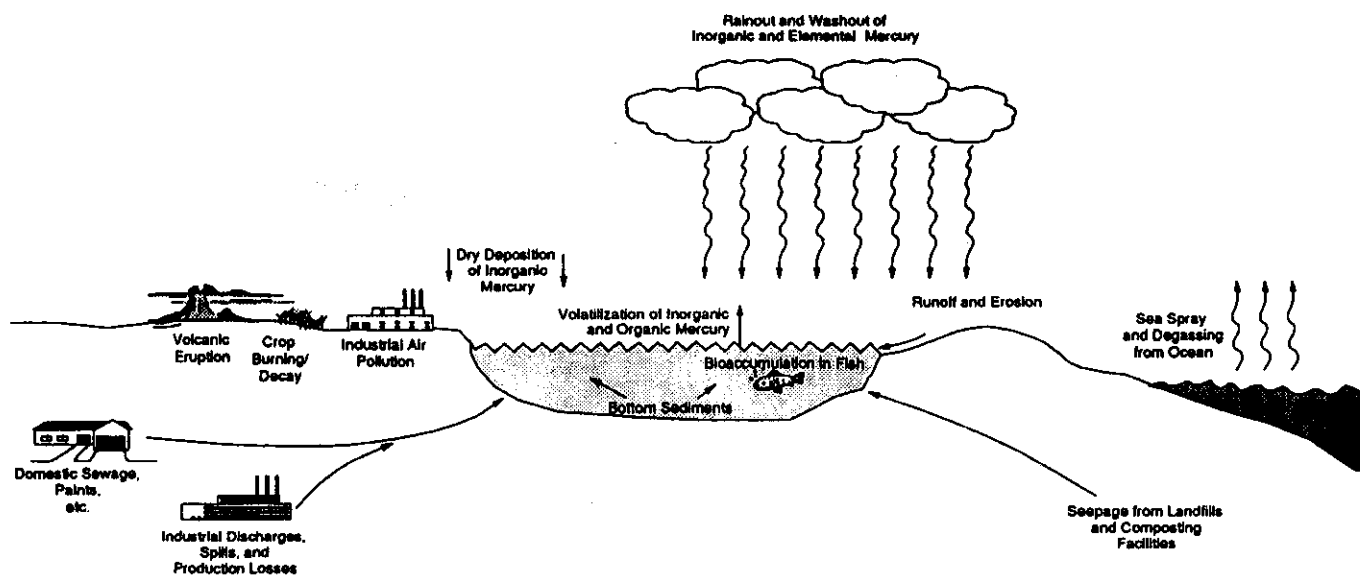
Many uses of mercury have been phased out over the past 20 years. This was due in part to several unrelated incidents of mercury poisoning to humans in Iraq, Japan, and the United States in the 1950's and 1960's that increased awareness of the toxicity of the metal and its compounds. The disposal of mercury and other toxic substances went virtually unregulated for decades in the United States. Large amounts were discharged into lakes, streams, and rivers. The effects of these practices were publicized around 1970, when significant amounts of mercury were found in fish in the Great Lakes and in swordfish caught in coastal waters. This aroused public concern and led to the passage of environmental laws by the U.S. Congress and State governments limiting the discharge of mercury and other substances.

The creation of the EPA in 1970 gave a single Federal Government agency control over dealing with mercury-related poisoning. Previously, the Food and Drug Administration, the Department of Agriculture, and other agencies regulated use of chemicals and pharmaceuticals containing mercury.

The EPA prepared a detailed materials balance study on mercury in 1975, but since then, the domestic use pattern has changed considerably and losses to the environment have been reduced by many industries. For example, in 1970, there were 79 mines that produced mercury as the primary product in the United States; at the end of 1990, there were none. The use of mercury in agricultural chemicals, pharmaceuticals, alkaline batteries, and paint virtually has been eliminated. The chlorine and caustic soda industry has greatly reduced its losses of mercury through improved production methods and the gradual phaseout of mercury cells, none of which has been installed since 1970. Mercury emissions from waste combustion sources have been reduced owing to less mercury being discarded and tighter emissions controls.

Mercury flows to the environment from a great many sources. There have been more than 3,000 documented uses for the metal (7);² each has dispersed a small amount to the environment. Figure 1 shows the movement of mercury through the environment. Natural emission

²Italic numbers in parentheses refer to items in the list of references at the end of this report.



Source: Reference 9.

Figure 1.—Movement of mercury through the environment.

sources, such as from volcanic eruptions and natural degassing, or vaporization, of mercury from the Earth's crust account for about 1,000 mt/yr in the United States, and average 5,000 mt/yr globally (9, 13, 15). However, these figures are at best rough estimates, because there have not been any detailed quantitative studies. For this report, anthropogenic losses were considered to be all releases to the air, land, and water, including placement in landfills and losses from incineration. In 1989 and 1990, total U.S. anthropogenic mercury emissions were no more than one-fifth of the total mercury released globally from natural sources. Data on losses to the environment are unavailable for other countries; however, the use of mercury for amalgamation of gold ores in South America and industrial uses in Eastern Europe, has increased concern on this issue. It is highly probable that these areas of the world have each contributed more mercury to the environment in recent years than the United States.

The combination of fossil fuel combustion and waste and sewage sludge incineration in the United States released 274 mt of mercury to the environment in 1989, and 234 mt in 1990, which, aside from a degree of regional concentration, can be characterized as geographically widespread (6). However, mercury emitted from combustion sources has not been strictly regulated and is the largest anthropogenic source of mercury emitted to the environment.

In this report, losses from each step of the flow of mercury are discussed. Some of the figures for losses from

the consumer products sector were taken from the 1992 EPA report *Characterization of Products Containing Mercury in Municipal Solid Waste, 1970 to 2000* (29). The most comprehensive account of mercury losses to date was given in the 1975 EPA report *Materials Balance and Technical Assessment of Mercury and Its Compounds on National and Regional Bases*, which detailed losses from all sources and through all pathways (31). That report was the source of some of the emissions factors used in the present study, and of information on which historical loss patterns were based. However, much of the information in it is not relevant to the usage pattern of 1990 because several of the uses studied in the report have been eliminated and technological changes have occurred in others since 1975. In 1993, the EPA released the report, *Locating and Estimating Air Emissions from Sources of Mercury and Mercury Compounds (L&E)*, which is a comprehensive study of all possible sources of mercury air emissions in the United States (26). This was the source of current air emissions data. Consumption data and historical mining losses were taken from mercury chapters in the USBM's *Minerals Yearbooks*. Since 1990, the consumption and disposal patterns for mercury have changed, with the elimination of mercury from alkaline batteries and paint and a decrease in overall usage. These changes are discussed briefly in the summary and will be examined in detail in future reports.

BACKGROUND

Mercury has been recognized and used for more than 2,000 years. There are references to mercury in the writings of ancient Greek and Roman scholars, including Theophrastus of Eresus, Pliny the Elder, Dioscorides, Strabo, and Vitruvius. It is likely that ancient cultures used the mercury ore cinnabar before the discovery of mercury itself. The ore could be mixed with other material to produce a natural red pigment, which probably was used in religious ceremonies, cosmetics, and art works. The recovery and purification of precious metals was apparently the primary use for mercury metal. In medieval times, mercury was also important in alchemy.

Mercury consumption was small until the mid-16th century, when the patio amalgamation process for silver recovery was developed. Later, mercury was used in instruments, such as barometers and thermometers. Despite the development of alternate uses, the recovery of gold

and silver continued as mercury's primary use until the 20th century.

Mercury, chemical symbol Hg (*hydrargyrum* in Latin), also known as quicksilver, is element number 80 in the periodic table. Its atomic weight is 200.59. Mercury is the only metal that is a liquid at "room temperature." In its liquid form, mercury has a silvery white color with a faint bluish tinge. Below its melting point, -38.35 °C, it is a white solid. In its gaseous state, it is a colorless vapor.

Besides liquidity at ordinary temperatures, mercury has other properties that contribute to its usefulness. It is relatively stable, has high surface tension, is dense, has a high vapor pressure, and its coefficient of linear expansion remains nearly constant over the entire temperature range of its liquid state. It conducts electricity and readily alloys (amalgamates) with most metals except iron. Most mercury compounds are toxic.

NATURAL SOURCES OF MERCURY IN THE ENVIRONMENT

Nearly every part of Earth's ecosystem, including air, sediments, soils, vegetation, and water contain some mercury. This is attributable to the natural degassing or volatilization of mercury from the Earth's crust, in which the average mercury concentration has been estimated at 0.08 ppm (8). Mercury has a high vapor pressure at normal atmospheric temperatures and it is constantly emitted from the earth, although it rarely occurs in toxic concentrations. Open pit mining of mercury-bearing ore can increase local outgassing by exposing fresh surfaces from which mercury escapes.

Mercury is also released to the environment through emissions from volcanic eruptions, forest fires, erosion of

mercury-bearing soils and rocks, evaporation of mercury-containing water, and animal excretions. Annual natural mercury emissions in the United States are about 1,000 mt. It is probable that, on a global scale, natural airborne emissions account for the release of a larger quantity of mercury than all anthropogenic air losses, but they are not well documented (29). The concentration of natural mercury emissions in any given locality is usually quite low, but human-related mercury emissions often result in higher than normal localized levels.

ANTHROPOGENIC SOURCES OF MERCURY

Anthropogenic losses of mercury to the environment derive from a wide variety of "point" (distinct) sources such as mining, the smelting of mercury-bearing ores, coal and oil combustion, waste and sewage sludge incineration, cement and lime manufacture, and electric lamp manufacturing. Mercury also enters indirectly through "non-point" sources, such as landfills, dental uses, laboratories, and paint usage, where mercury has been deposited from aerosols or from water. It is currently impossible to evaluate all non-point sources, but available data for point source emissions allow for reliable estimates of non-point emissions. For example, a study in Sweden estimated that one-fifth of global anthropogenic losses of mercury are from non-point sources (9).

FOSSIL FUEL COMBUSTION

The combustion of coal, natural gas, and petroleum, all of which contain trace amounts of mercury, results in the vaporization of much of the contained mercury and its release to the atmosphere, from which ultimately it is deposited in soil or into bodies of water. In the United States, the average mercury content for all types of coal combined is 0.21 ppm (6). In 1989, 807 million mt of coal was consumed in the United States and in 1990, 812 million mt was used (5). If the average mercury content of the coal was 0.21 ppm, as much as 130 mt of mercury (assuming 25% emissions control) could have been emitted to the atmosphere from coal combustion in each of those years. This is the largest single source of anthropogenic mercury emissions in the United States.

That part of the mercury in coal that is not emitted to the atmosphere during combustion is trapped in bottom ash and recoverable fly ash. Landfills are often the ultimate repositories for this material. Among the most important uses of coal, and potentially the largest emissions

sources, are electric power generation, coke ovens, and industrial uses. Since the 1970's, most coal-burning plants have installed either scrubbers, electrostatic precipitators (ESP), multiple cyclones, or baghouses on the stacks to capture much of the sulfur, particulates, and other by-products of burning fossil fuels that are emitted to the atmosphere. A considerable amount of the mercury is still believed to be emitted because the systems were designed to remove particulates and nitrogen oxides, not mercury. The control of mercury emissions depends greatly on the type of pollution control system and the temperature of the combustion gases passing through the system, as mercury will condense onto small particles at lower temperatures. Multiple cyclones capture very little mercury, ESP's up to 50%, and scrubbers capture 50% to 90% (6, 26). The EPA used an average of 25% mercury emissions control for the United States (26).

All the mercury contained in oil is assumed to be emitted to the atmosphere during combustion, because of limited data on the amount of mercury actually captured by the emission controls. For petroleum products, the typical mercury content values are: residual oil, 0.06 ppm; distillate oil, 0.40 ppm; and crude oil, 3.5 ppm (26). Emission control procedures of oil-burning facilities vary by the size of the unit. Larger oil-fired boilers employ flue gas cleaners designed to remove soot and other particulate matter. These have little effect on mercury emissions. ESP's are commonly used at oil-burning powerplants similar to those used in coal plants, but there are no data on the control of mercury emissions. However, a larger amount of oil is used for residential and commercial heating, consumed in heaters and furnaces, which typically have no emission control devices. In both 1989 and 1990, the combustion of oil resulted in about 10 mt of mercury being emitted to the environment (26).

Mercury contained in natural gas is removed, usually by filtering the gas through an activated carbon filter before it enters the commercial pipeline system; therefore, very little is believed to be emitted from combustion. However, there have been few studies on the mercury content of natural gas. Losses of mercury could be expected from burning of natural gas at oil wells, releases from gas fields, and from disposal of the filter media.

LIME AND CEMENT MANUFACTURE

The mercury content of limestone ranges from 0.02 ppm to 2.3 ppm (30). The manufacture of cement results in mercury emissions to the atmosphere mainly from kilns. Some fugitive emissions of mercury occur from dry grinding of the clinker, but these are quite small. The EPA uses an emissions estimate of 0.087 g/mt for the entire production process (26). Using these emissions factors, about 6 mt of mercury could have been emitted from these sources in both 1989 and 1990.

Data are unavailable to formulate estimates of emissions of mercury from lime kilns in the United States.

MUNICIPAL SOLID WASTE (MSW) AND REFUSE INCINERATION

Burning mercury-bearing products present in commercial and household waste can result in air and land emissions. The amount of mercury released depends on the type of incinerator and emission control used. It was estimated that in 1989, 97 mt of mercury-bearing material was potentially emitted from MSW incinerators and in 1990, 57 mt was emitted (22). Among the incinerated products contributing to mercury emissions are batteries, fluorescent light tubes, mercury vapor lamps, thermometers, and products containing mercury pigments or paints.

Almost all of the sludge generated by sewage treatment plants contains some mercury. The sludge is usually buried or incinerated. The average mercury content of sewage sludge is 5 g/mt and emissions from incinerators average 0.018 g/mt for units with venturi control, which accounts for 33% of the incinerators, and 1.6 g/mt for units with other control methods (26). By applying these factors to the estimated 1.5 million mt of sludge processed annually, 1.6 mt of mercury is emitted to the atmosphere each year from both types of incinerators combined and about 1 mt is placed in landfills.

Medical waste incineration is another major source of emissions. Sources of mercury include mercury oxide batteries, which are used widely in medical equipment, thermometers, sphygmometers, and pigments. As with all incinerators, the type of emissions controls determine the amount of mercury released. In 1990, it was estimated

that medical waste incineration released 58.7 mt to the atmosphere; approximately the same amount was emitted in 1989.

MINING AND BENEFICIATION

Mercury Ores

There are more than 30 minerals that contain mercury (see table 1), but nearly all mercury mined today is extracted from cinnabar (HgS) ores. Historically though, commercial operations have exploited deposits of corderoite, livingstonite, metacinnabar, and native mercury.

Table 1.—Mercury-bearing minerals

Name	Formula
Arquerite	AgHg_3 , Ag_5Hg_3 , Ag_2Hg , Ag_2Hg_5
Barcenite	Antimonate of mercury.
Bordosite	AgHgI , $\text{AgCl} \cdot 2\text{HgCl}$
Calomel	HgCl
Cinnabar	HgS
Coccinite	Hg_2OCl
Coccinite (variation)	HgI_2
Coloradoite	HgTe
Corderoite	$\text{Hg}_3\text{S}_2\text{Cl}_2$
Eglestonite	$\text{Hg}_2\text{Cl}_3\text{O}_2\text{H}$
Gold amalgam	$(\text{Au}, \text{Ag})\text{Hg}$
Guadalcazarite	$\text{Hg}_3 \cdot \text{Zn} \cdot \text{Se}$
Hermesite	Tetrahedrite + Hg.
Kalgoorlite	$\text{Ag}_2\text{Au}_2\text{HgTe}_4$
Kleinite	$\text{Hg}_2\text{N}(\text{Cl}, \text{SO}_4) \cdot n\text{H}_2\text{O}$
Kongsbergite	Mercurian silver.
Lehrbachite	$\text{HgSe} + \text{PbSe}$
Levigianite	$\text{HgS} + \text{Zn}$
Livingstonite	HgSb_4S_7
Magnolite	Hg_2TeO_4
Metacinnabar	HgS
Montroydite	HgO
Moschellandsbergite	Ag_2Hg_3
Mosesite	$\text{Hg}_2\text{N}(\text{Cl}, \text{SO}_4, \text{MoO}_4, \text{CO}_3) \cdot \text{H}_2\text{O}$
Onofrite	Selenian metacinnabar.
Potarite	PdHg
Schwartzite	Mercurian tetrahedrite.
Terlingualite	Hg_2ClO
Tiemannite	HgSe
Tocornalite	$(\text{Ag}, \text{Hg})\text{I}$

Source: Reference 7.

Cinnabar occurs worldwide, most minable deposits being in areas of late orogenic (mountain building) or volcanic activity. Today, as in the past, the major mercury mines are in either the orogenic belt stretching from Spain to the Himalayas, or in the orogenic belt surrounding the Pacific Basin. Historically, five areas of the world have dominated mercury production. These are the Monte Amiata district in Italy, the Huancavelica district in Peru, the Idria district in Slovenia, the Almaden district in Spain, and the State of California in the United States.

Historically, domestic mercury mines have used well-established open pit and underground mining methods. However, most domestic mercury deposits are small and irregular, precluding the use of the large-scale mining techniques typical of many nonferrous metal operations.

Several methods have been used to beneficiate the ores. When either the mercury-bearing material or the mercury-barren material can be readily identified, hand-sorting is possible. For those ores where the mercury-bearing minerals break more easily than the gangue, crushing and screening enable enrichment of the furnace feed. Jigging and tabling further separate mercury-bearing material from waste material. Still, these gravity methods reportedly are less successful than flotation, owing in part to excessive mercury losses, or the production of an inferior concentrate.

The McDermitt Mine, located in Humboldt County, NV, was the last operating mercury mine in the United States. It closed in November 1990. It was an open pit operation and used flotation to produce mercury concentrate. Ore at the McDermitt deposit is in Miocene-age lake sediments and in a breccia found beneath the lake sediments. The major mercury-bearing minerals are cinnabar and corderoite.

Mercury ores and concentrates are roasted to recover the metal. Heating the feed material is done in either retorts or mechanical furnaces. For mercury, roasting is a very efficient distillation process. Heating volatilizes the contained mercury, which is then recovered in liquid form by cooling the vapor. Generally, the roasting system consists of a retort or furnace to heat the ore or concentrate, a condenser to cool the mercury-bearing exhaust gases, and auxiliary equipment such as dust collectors, exhaust fans, settling tanks, and soot machines.

Various materials have been used in the construction of mercury condensers. Early systems consisted of wood, brick, masonry, or ceramic tile chambers. These materials tended to be porous and mercury accumulated in the stacks. The mercury-bearing soot often was scraped or washed out and hoed by workers to recover the metal. When the stacks were replaced, some of the old brick or wood would be retorted, but many of the old stacks were buried. This probably contributed a fairly large amount to the environment before 1910 (4). Other materials used in the construction of condensers include cast iron, sheet steel, Monel metal, and glass. Before 1900, many mines

in the United States probably had mercury condenser losses as high as 40% of the input (4). A USBM study conducted in 1918 showed that two mines in California had reduced condenser losses of mercury from near 40% to 5% of the input (4). This report was believed to have prompted other mines to improve efficiency. However, it was not until about 1930 that this was accomplished throughout the industry (20). Mercury condenser losses at the McDermitt Mine, the last primary mercury mine to operate in the United States, were less than 1% (14).

Other Nonferrous Ores

Nonferrous metal ores, such as those from which copper, gold, lead, and zinc are extracted, often contain trace amounts of mercury. Domestic copper ores average about 0.5 ppm mercury, and gold ores average about 9 ppm (31). Mercury emissions from mining are small, even though the rate of natural degassing can be increased by exposure of fresh ore surfaces.

The processing of nonferrous ores typically involves crushing and grinding the ore, followed by selective flotation to produce a concentrate containing the mineral or minerals of interest. The concentrate contains most of the mercury originally in the ore, but mercury is lost in the dust created by crushing and grinding the ore, and in the tailings from the flotation process. Smelting or roasting the concentrate creates the greatest potential for emissions, owing to the ease with which mercury vaporizes. For example, in the production of copper it was estimated in 1975 that in a typical reverberatory furnace operation, 56% of the mercury in copper concentrate was emitted to the atmosphere during smelting. The fly ash, dust, and slag generated by smelting contained an additional 37% of the original mercury. Other intermediate products contained the remaining 7% (31).

Since 1975, all but one copper smelter in the United States has switched to the flash furnace smelting method, which combines the roasting and smelting process to produce a high-grade copper matte from concentrates and flux. There have not been any detailed studies of mercury emissions from flash furnaces, however, much less mercury is emitted from flash furnaces owing to greater efficiency of the process. Most of the mercury emitted from the stack gases reports to the sulfuric acid plant. Electrostatic precipitators, capture the remainder of the emissions (26).

DOMESTIC SUPPLY

The earliest recorded U.S. mercury mine production dates from 1850, in California, and was closely associated with the discovery of gold and development of the domestic gold mining industry. From 1850 to the early 20th

century, California dominated domestic mercury production. Two mines have accounted for most of the State's production, the New Almaden Mine in Santa Clara County, and the New Idria Mine in San Benito County.

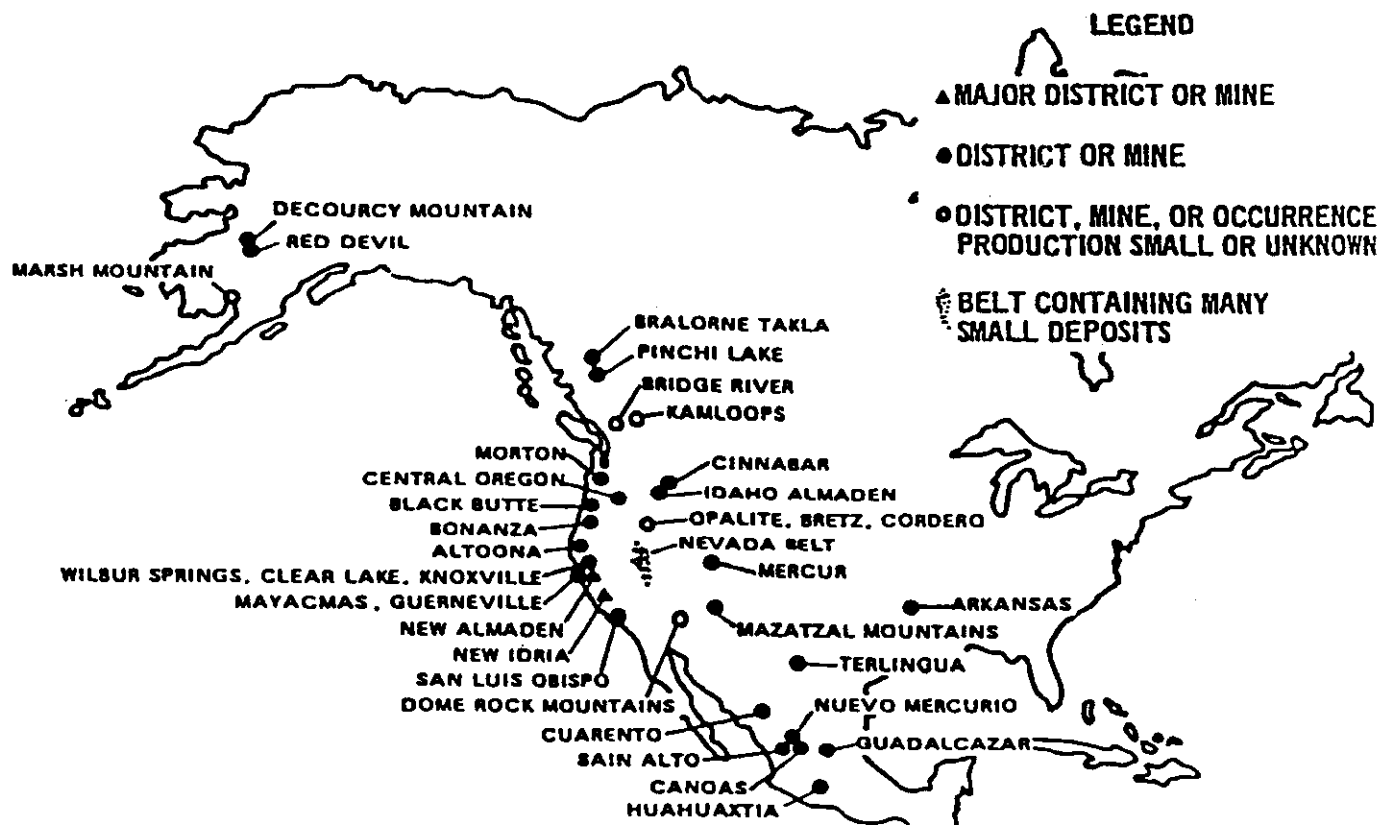
Mercury also has been produced in Alaska, Arizona, Arkansas, Idaho, Nevada, Oregon, Texas, Utah, and Washington. (See figure 2.)

Domestic mercury production reached its peak of more than 2,700 mt/yr in 1877. Traditionally, the U.S. mercury mining industry has consisted of a few large operations and many small mines. In 1965 for example, the Bureau reported that 149 domestic mines produced 675 mt of mercury. Of the producing mines in 1965, only five produced more than 34 mt each. Fourteen mines produced between 3 mt and 34 mt. The remaining 130 mines produced less than 3 mt each. Table 2 shows the components of the U.S. mercury supply from 1941 to 1990.

As late as 1969, the United States had more than 100 active mercury mines. But, growing awareness of the potential hazards associated with exposure to mercury resulted in the enactment of various environmental and occupational safety regulations. Declining markets and the costs of complying with these regulations forced the collapse of the domestic mercury mining industry in the early 1970's. By the end of 1976, the United States had fewer than 10 producing mines.

In 1989 and 1990, only the McDermitt Mine in Nevada produced mercury as a principal product. Nine gold mines in California, Nevada, and Utah produced mercury as a byproduct, with nearly all the newly mined mercury coming from Nevada. Table 3 lists the mines that recovered mercury in 1989 and 1990. The McDermitt Mine closed in late November 1990. Company officials attributed the closure to several factors, including poor market conditions, a ban on the use of mercury in certain paints, and excessive Government stockpile sales.

From 1900 through 1990, the United States imported more than 66,000 mt of mercury. U.S. mercury imports were at their highest levels in the late 1940's and early 1950's, peaking at 3,556 mt in 1949. The development of new applications for mercury, such as batteries, and the growth in chlorine and caustic soda production were the primary reasons for the high imports. Other reasons for the growing reliance on foreign-produced mercury at that time included the Nation's involvement in the Korean war, and Government purchases for the National Defense Stockpile. U.S. mercury imports increased again in the mid-1970's following the collapse of the domestic mining industry.



Source: Reference 16.

Figure 2.—Mercury deposits of North America.

Table 2.—U.S. mercury supply

(Metric tons)

	Mine production (a)	Secondary production (b)	Imports (c)	Exports (d)	Supply (a+b+c-d)		Mine production (a)	Secondary production (b)	Imports (c)	Exports (d)	Supply (a+b+c-d)
1900	983	0	1	353	631	1946	874	138	479	113	1,378
1901	1,031	0	1	389	643	1947	801	121	448	137	1,233
1902	1,190	0	NA	460	730	1948	496	75	1,101	50	1,622
1903	1,236	0	NA	610	626	1949	342	48	3,556	48	3,898
1904	1,201	0	NA	717	484	1950	156	69	1,933	46	2,112
1905	1,039	0	1	460	580	1951	251	69	1,650	32	1,938
1906	887	0	0	220	667	1952	433	86	2,477	23	2,973
1907	733	0	8	175	566	1953	494	97	2,875	50	3,416
1908	672	0	7	102	577	1954	639	210	2,239	80	3,008
1909	717	0	7	231	493	1955	653	346	702	25	1,676
1910	701	0	0	65	636	1956	833	202	1,631	107	2,559
1911	723	0	214	10	927	1957	1,194	200	1,448	179	2,663
1912	853	0	38	11	880	1958	1,312	186	1,041	43	2,496
1913	688	0	78	39	727	1959	1,077	171	1,039	41	2,246
1914	563	0	279	49	793	1960	1,145	184	672	23	1,978
1915	716	0	191	115	792	1961	1,091	288	425	16	1,788
1916	1,018	0	193	302	909	1962	906	200	1,088	17	2,177
1917	1,230	0	177	367	1,040	1963	659	225	1,478	8	2,354
1918	1,119	0	229	105	1,243	1964	488	259	1,419	13	2,153
1919	729	0	362	310	781	1965	675	514	560	277	1,472
1920	456	0	482	53	885	1966	759	294	1,081	29	2,105
1921	216	0	361	13	564	1967	820	369	839	107	1,921
1922	217	0	576	10	783	1968	995	364	801	262	1,898
1923	270	0	615	11	874	1969	1,022	364	1,101	21	2,466
1924	343	0	448	7	784	1970	941	253	757	162	1,789
1925	312	0	709	7	1,014	1971	616	376	981	249	1,724
1926	260	0	884	4	1,140	1972	253	418	994	33	1,632
1927	384	0	687	NA	1,071	1973	77	267	1,587	12	1,919
1928	616	0	502	NA	1,118	1974	75	205	1,799	16	2,063
1929	816	0	514	NA	1,330	1975	254	260	1,512	17	2,009
1930	743	0	128	NA	871	1976	797	98	1,531	18	2,408
1931	860	0	19	172	707	1977	974	192	991	33	2,124
1932	435	0	134	NA	569	1978	833	123	1,437	NA	2,393
1933	333	0	700	NA	1,033	1979	1,018	148	912	NA	2,078
1934	532	0	351	NA	883	1980	1,057	234	325	NA	1,616
1935	604	0	269	NA	873	1981	962	146	428	NA	1,536
1936	571	0	624	9	1,186	1982	888	154	307	NA	1,349
1937	569	0	652	16	1,205	1983	864	474	441	NA	1,779
1938	620	0	81	25	676	1984	657	196	873	NA	1,726
1939	642	0	121	42	721	1985	570	185	651	NA	1,406
1940	1,302	0	6	332	976	1986	¹ 483	219	696	NA	1,398
1941	1,549	0	267	89	1,727	1987	¹ 34	265	636	NA	935
1942	1,753	0	1,342	269	2,826	1988	¹ 379	278	329	NA	986
1943	1,790	0	1,648	525	2,913	1989	¹ 414	137	131	221	461
1944	1,299	0	674	30	1,943	1990	² 562	108	52	311	411
1945	1,060	0	2,365	94	3,331	Total ³	67,407	9,815	66,398	9,617	134,000

NA Not available.

¹Comprises only mercury produced at the McDermitt mine, as reported in Placer Dome 10-K and annual reports. The mine closed in Nov. 1990.²Production from McDermitt and as a byproduct of gold mining.³Data may not add to totals shown because of independent rounding.

Table 3.—Mercury-producing mines in the United States

1989			
Mine	County and State	Operator	Primary product
Alligator Ridge	White Pine, NV	Amselco Minerals Inc.	Gold.
Borealis Project	Mineral, NV	Echo Bay Minerals Co.	Gold.
Carlin Mines Complex	Eureka, NV	Newmont Gold Co.	Gold.
Hog Ranch	Washoe, NV	Western Goldfields Co.	Gold.
Jerritt Canyon (Enfield Bell)	Elko, NV	Freeport-McMoRan Gold Co.	Gold.
McDermitt	Humboldt, NV	Placer Dome U.S. Inc.	Mercury.
McLaughlin	Napa, CA	Homestake Mining Co.	Gold.
Mercur	Tooele, UT	Barrick Mercur Gold Mines Inc.	Gold.
Paradise Peak	Nye, NV	FMC Gold Co.	Gold.
Pinson and Preble	Humboldt, CA	Pinson Mining Co.	Gold.
1990			
Borealis Project	Mineral, NV	Echo Bay Minerals Co.	Gold.
Carlin Mines Complex	Eureka, NV	Newmont Gold Co.	Gold.
Hog Ranch	Washoe, NV	Western Goldfields Co.	Gold.
Jerritt Canyon (Enfield Bell)	Elko, NV	Freeport-McMoRan Gold Co.	Gold.
McDermitt ¹	Humboldt, NV	Placer Dome U.S. Inc.	Mercury.
McLaughlin	Napa, CA	Homestake Mining Co.	Gold.
Mercur	Tooele, UT	Barrick Mercur Gold Mines Inc.	Gold.
Paradise Peak	Nye, NV	FMC Gold Co.	Gold.
Pinson and Kramer Hill	Humboldt, CA	Pinson Mining Co.	Gold.

¹Closed permanently in Nov. 1990.

Source: Reference 23.

From 1970 to 1990, the United States imported more than 17,000 mt of mercury. The primary source countries in order of magnitude were Spain, Canada, and Algeria. Other large exporters of mercury to the United States included China, Italy, Japan, Mexico, Turkey, and Yugoslavia.

Data for U.S. mercury exports, compiled by the Bureau of the Census are less complete than the series for domestic imports. In 1978, the merger of mercury with other materials into a single category for tariff purposes eliminated data on mercury exports, but with adoption of the Harmonized Tariff System in January 1989, data on U.S. mercury exports were available for the first time since 1977.

For the 40-year period from 1938 to 1977, the United States was a net importer of mercury. Yet, the export data available for 1989 and 1990 show that the United States is now a net mercury exporter. This change could have been anticipated, given the increasingly strict domestic regulations regarding mercury handling, emissions, and use.

During 1989 and 1990, the United States exported 532 mt of mercury. The primary recipient countries were the Netherlands and India, which received 36% and 16% of total U.S. exports, respectively. Other countries receiving U.S. mercury exports include Brazil, Canada, Colombia, Germany, and South Africa.

THE USES OF MERCURY

HISTORICAL USE PATTERN

Publication of mercury consumption data by end use began in the early 1940's. Prior to that, only limited data on mercury consumption were available. Over the years, different approaches to compiling the data were taken. From 1941 to 1979, the Bureau published consumption data by broad categories, combining similar uses. Starting in 1979, Standard Industrial Classification (SIC) codes were used by the USBM to separate the uses of mercury.

During the second half of the 19th century, the primary use for mercury was the recovery of gold and silver from

their ores by amalgamation. The ore was milled to free the precious metals. Mercury was then added to the milled ore, or during milling, to form an amalgam that was separated and processed to recover the precious metals.

Mercury used in amalgamation ideally was recovered and reused indefinitely with small losses. However, to ensure the maximum recovery of precious metals, often more mercury than was necessary was added to the crushed ore, resulting in larger losses. Excess mercury was occasionally separated from the amalgam by filtering or retorting, which volatilized most of the mercury, leaving the precious metals. Other areas where losses occurred

included spills, leaks in the system used to mix the mercury and crushed ore, and leaks in the retorts and condensing system. Despite the potential for recovery and reuse, much of the mercury was discarded on site, where it would migrate into nearby rivers and streams and settle into the sediment. It is still possible to find mercury in these sediments in some old gold mining areas in the Western United States (12). According to one estimate, mercury losses at one time may have been as high as 34 g/mt of ore processed (11). By 1912, improvements to the processes reduced mercury losses to between 2 to 4 g/mt of ore processed (17). Mercury losses in the United States associated with amalgamation and milling of quartz-gold ores averaged 24,000 kg/yr from 1912 to 1918. An additional 6,800 kg/yr to 9,000 kg/yr of mercury was estimated to have been lost in California alone from placer mining of gold ores during this same period and up to twice that amount may have been lost in the country as a whole (17-18).

Other important uses for mercury developed during the 19th century included the manufacture of felt; mercury acetate was used to thicken the fur, which produced higher quality material. This use was stopped in the 1940's owing to health concerns from breathing mercury vapor and new efficient production methods. Fulminate of mercury was used as an explosive material, primarily in blasting caps and ammunition. This use declined rapidly after World War II and was phased out for civilian use in the mid 1950's and for military use shortly thereafter. Vermilion pigment was produced naturally from cinnabar and used in art supplies and paints. Production ceased in the 1950's, but synthetic vermilion was produced for another 20 years. Mercury was also used in instruments such as barometers and thermometers, and in laboratories (7). Table 4 and figures 3, 4, and 5 contain data on domestic mercury consumption (1,23).

CHEMICALS AND ALLIED PRODUCTS

Chlorine and Caustic Soda Production

In 1989 and 1990, the largest domestic use for mercury was in the production of chlorine and caustic soda. The mercury cell is one of three types of electrolytic cells that are used to decompose sodium or potassium chloride by electrolysis. The other two are the diaphragm and membrane cells. In the mercury cell process there is a primary cell and a secondary or denuder cell. A flowing stream of mercury is the cathode in the primary cell. Feed material for the primary cell is a purified brine. Chlorine gas is liberated at the anode and sodium metal at the cathode. The sodium metal immediately amalgamates with the mercury cathode. After amalgamating, the cathode flows into the denuder cell. In the denuder cell, the amalgam encounters a stream of water. The water reacts with the amalgam to

produce sodium hydroxide (caustic soda), hydrogen gas, and mercury. (See figure 6.)

The rise in mercury cell production occurred after World War II with the development of the DeNora cell in Italy, which was licensed by Monsanto Co. in the United States. Nearly half of the new chlorine and caustic soda production capacity installed in the 1950's and 1960's used mercury cells. In 1970 there were 25 mercury cell plants, which produced 25% of the chlorine and caustic soda (25). In 1989, there were 19 operating mercury cell plants, representing 17% of U.S. production. In 1990, the number of plants remained the same, but mercury cells dropped to 16.25% of production. Only 1 of the 19 plants had installed a mercury cell before 1950 and the most recent was installed in 1970 (2). Since then, only membrane and diaphragm cells have been installed in the United States because of the potential environmental hazards of using mercury. The modern membrane cell process has been improved over the past decade to become more efficient than either the diaphragm or mercury cell and produce a higher quality product than either cell (26).

There are air, water, and land losses of mercury associated with chlorine and caustic soda production. Most of the loss is in wastewater and the brine that is bled from the end boxes of the mercury cells, such as the water collected from the floor of or below the room containing the mercury cells, which accumulates from the periodic wash-down of the cell room floor and equipment (19). Before May 1993, the resulting mercury-containing wastewater and sludges were stored on-site and ultimately sent to a landfill.

Effective May 8, 1992, the land disposal of certain mercury-containing sludges generated by chlor-alkali plants was banned by the EPA. Six companies received a 1-year variance because of the lack of processing facilities for such wastes (3,10). The EPA had determined that the best demonstrated available technology (BDAT) for treating such wastes is reclamation of the mercury by retorting. However, according to the six companies, conventional retorting was not suitable for their facilities because it is usually limited to small batches of high-mercury-content wastes and the plants produce high-volume, low-mercury-content waste material. The Chlorine Institute Inc., on behalf of the producers, demonstrated that there was a lack of treatment facilities for these wastes and subsequently contracted with a private firm to develop a thermal treatment that met the BDAT for processing low-mercury-content wastes. This new method can easily be adjusted to process different size waste streams (3, 10). All of the plants have since either constructed on-site treatment facilities or arranged to ship their waste material to be processed elsewhere. It has been estimated that about 25 mt/yr of mercury will be recovered from processing of sludge generated by chlor-alkali plants (3).

Table 4.—Mercury consumed in the United States, by end use
(Metric tons)

	Chemicals and allied products					Electrical uses			Instruments and related products			Total	
	Chlorine and caustic soda manufacture	Paint	Laboratory uses	Pharmaceutical uses	Agricultural chemicals ¹	Wiring devices and switches	Batteries	Lighting	Total electrical uses	Measuring and control instruments	Dental uses		Other uses ²
1941	5	23	6	92	68	NA	NA	NA	162	125	21	1,041	1,544
1942	19	42	10	279	53	NA	NA	NA	157	122	41	990	1,713
1943	24	93	12	502	56	NA	NA	NA	113	127	19	932	1,879
1944	23	84	9	288	135	NA	NA	NA	244	112	15	568	1,479
1945	21	57	12	384	99	NA	NA	NA	843	130	19	588	2,152
1946	19	34	9	141	108	NA	NA	NA	134	159	39	444	1,088
1947	24	26	11	105	194	NA	NA	NA	233	186	27	420	1,227
1948	28	34	15	117	243	NA	NA	NA	223	195	34	705	1,594
1949	26	58	12	119	161	NA	NA	NA	252	173	33	540	1,374
1950	45	108	22	207	155	NA	NA	NA	415	186	50	508	1,697
1951	53	86	18	95	267	NA	NA	NA	353	212	28	847	1,960
1952	86	41	22	48	203	NA	NA	NA	276	221	35	534	1,467
1953	82	23	43	64	239	NA	NA	NA	332	191	39	789	1,902
1954	74	18	39	64	264	NA	NA	NA	373	179	49	417	1,475
1955	107	25	34	54	255	NA	NA	NA	319	194	41	942	1,971
1956	116	18	34	55	342	NA	NA	NA	337	211	46	709	1,866
1957	139	20	31	60	218	NA	NA	NA	315	208	47	785	1,823
1958	157	20	33	49	216	NA	NA	NA	322	209	60	747	1,814
1959	201	121	38	59	260	NA	NA	NA	307	212	63	630	1,892
1960	214	146	45	60	223	NA	NA	NA	319	225	61	471	1,764
1961	209	209	51	87	195	NA	NA	NA	354	194	74	550	1,922
1962	252	161	60	116	237	NA	NA	NA	399	179	70	776	2,251
1963	276	229	43	141	185	NA	NA	NA	383	170	81	1,179	2,688
1964	330	225	55	12	182	NA	NA	NA	494	171	90	1,289	2,848
1965	302	292	39	14	128	NA	NA	NA	555	160	56	991	2,536
1966	398	308	76	8	103	NA	NA	NA	608	251	74	639	2,465
1967	493	247	67	10	144	NA	NA	NA	559	257	82	537	2,396
1968	602	364	69	15	132	NA	NA	NA	677	275	106	361	2,600
1969	714	335	67	25	112	NA	NA	NA	637	229	99	448	2,667
1970	517	357	62	24	70	NA	NA	NA	550	167	79	294	2,120
1971	419	297	62	24	51	NA	NA	NA	582	168	81	118	1,801
1972	397	283	20	20	63	NA	NA	NA	536	225	103	175	1,824
1973	451	262	23	21	63	NA	NA	NA	621	247	92	92	1,871
1974	582	235	16	21	34	NA	NA	NA	678	214	104	165	2,050
1975	525	239	12	15	21	NA	NA	NA	585	159	81	118	1,753
1976	553	270	21	2	21	NA	NA	NA	948	175	69	177	2,236
1977	370	288	14	W	20	NA	NA	NA	1,008	180	42	191	2,112
1978	385	309	14	W	W	110	843	31	985	120	18	216	2,047
1979	420	344	14	W	W	111	872	18	1,005	124	49	188	2,144
1980	326	297	13	W	W	106	959	36	1,106	105	61	125	2,033
1981	252	243	11	W	3	91	1,015	36	1,142	195	56	140	2,042
1982	215	234	10	W	1	69	858	28	955	106	35	131	1,687
1983	278	206	10	W	0	80	805	44	929	85	55	130	1,695
1984	253	160	9	W	0	94	1,024	51	1,169	98	49	147	1,885
1985	235	169	14	W	0	95	952	40	1,087	79	50	84	1,718
1986	259	179	20	W	0	103	750	41	901	63	52	114	1,588
1987	311	198	20	W	0	131	533	45	709	59	56	93	1,446
1988	354	197	26	W	0	176	448	31	655	77	53	141	1,503
1989	379	192	18	W	0	141	250	31	422	87	39	72	1,212
1990	247	22	32	W	0	70	106	33	209	108	44	58	720

NA Not available. W Withheld to avoid disclosing company proprietary data.

¹Includes pulp and paper manufacturing uses, 1941-72.

²Included in this category is mercury originally reported as redistilled in Minerals Yearbook chapters from 1941-58. If it were redistributed in the table, the amount used in electrical uses, measuring and control instruments, and dental uses would increase significantly. Other uses included in this category and the last year they were reported in the Minerals Yearbook are amalgamation, 1970; catalysts, through 1990; felt manufacture, 1942; fulminate, 1958; military uses, 1945; and vermilion pigment, 1944.

KEY

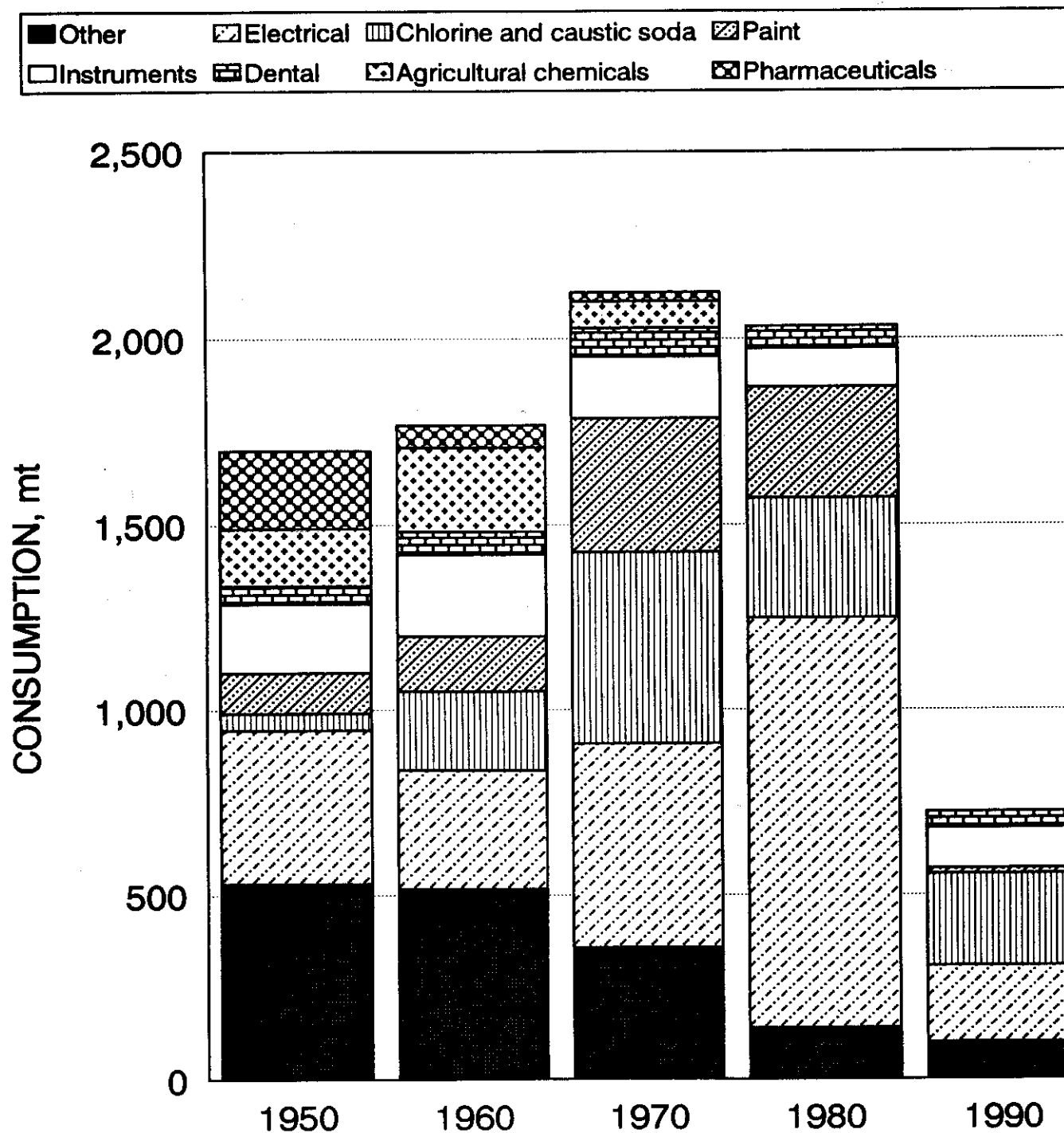


Figure 3.—Domestic mercury consumption at 10-year intervals, 1949-89.

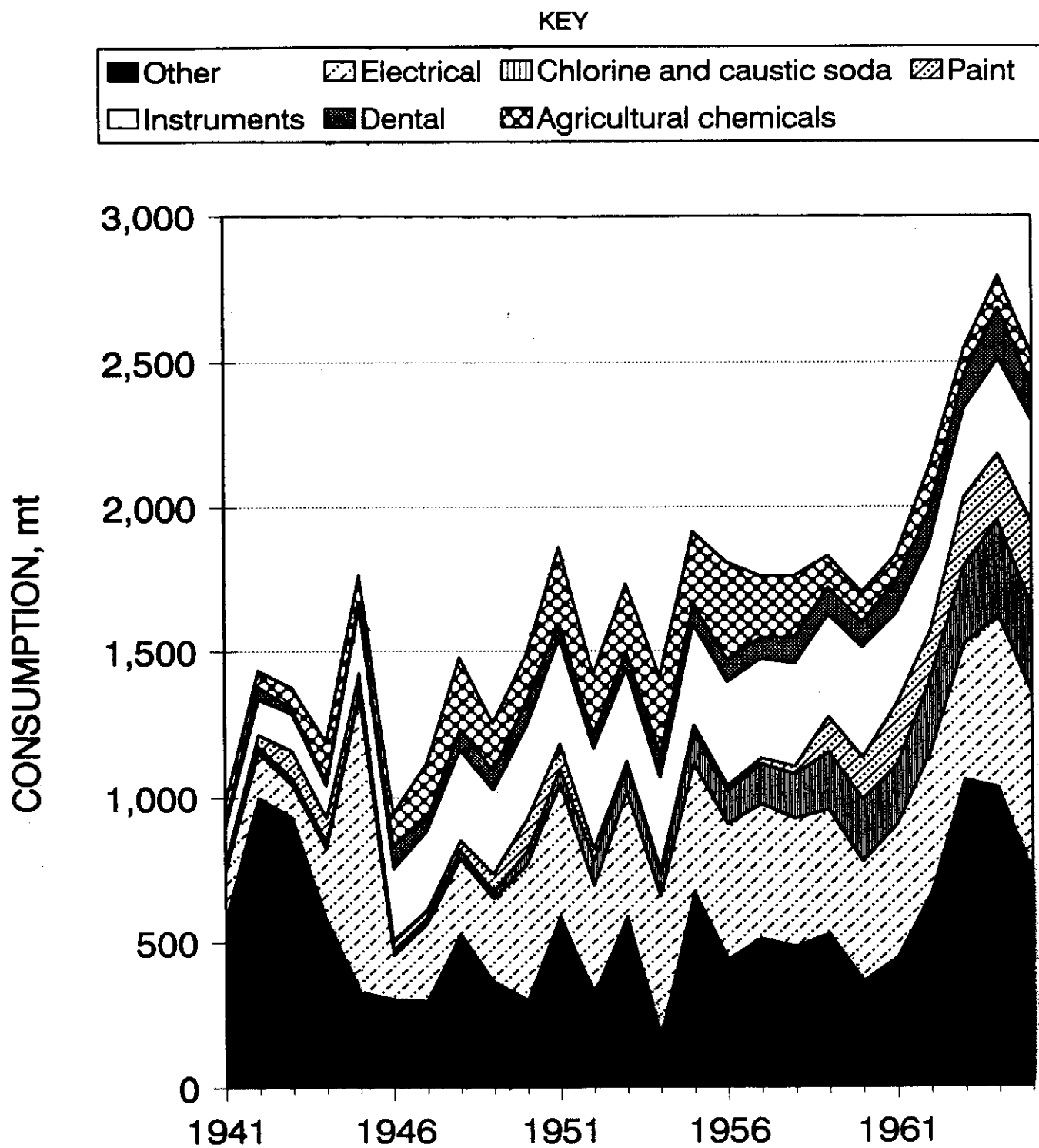
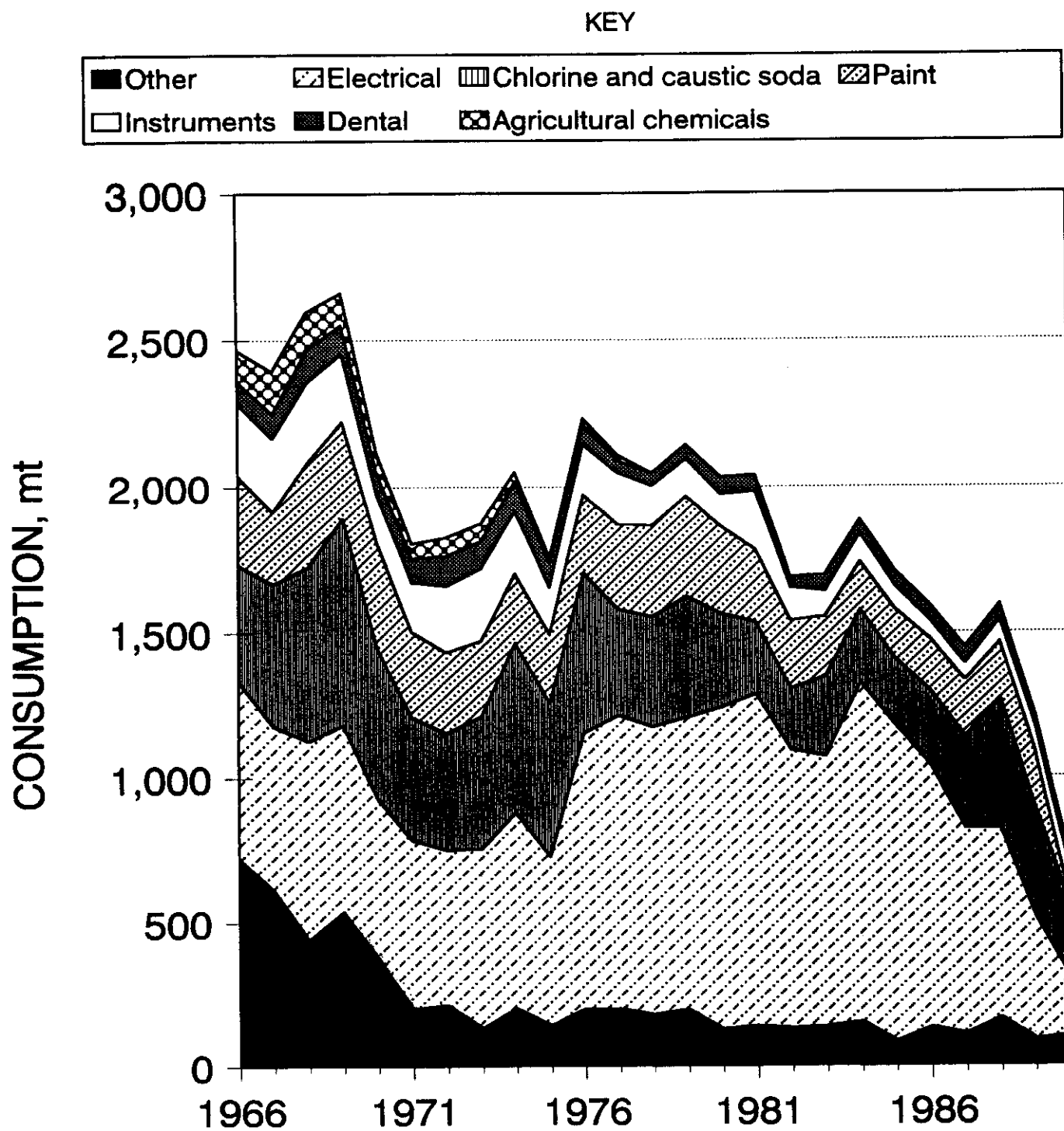
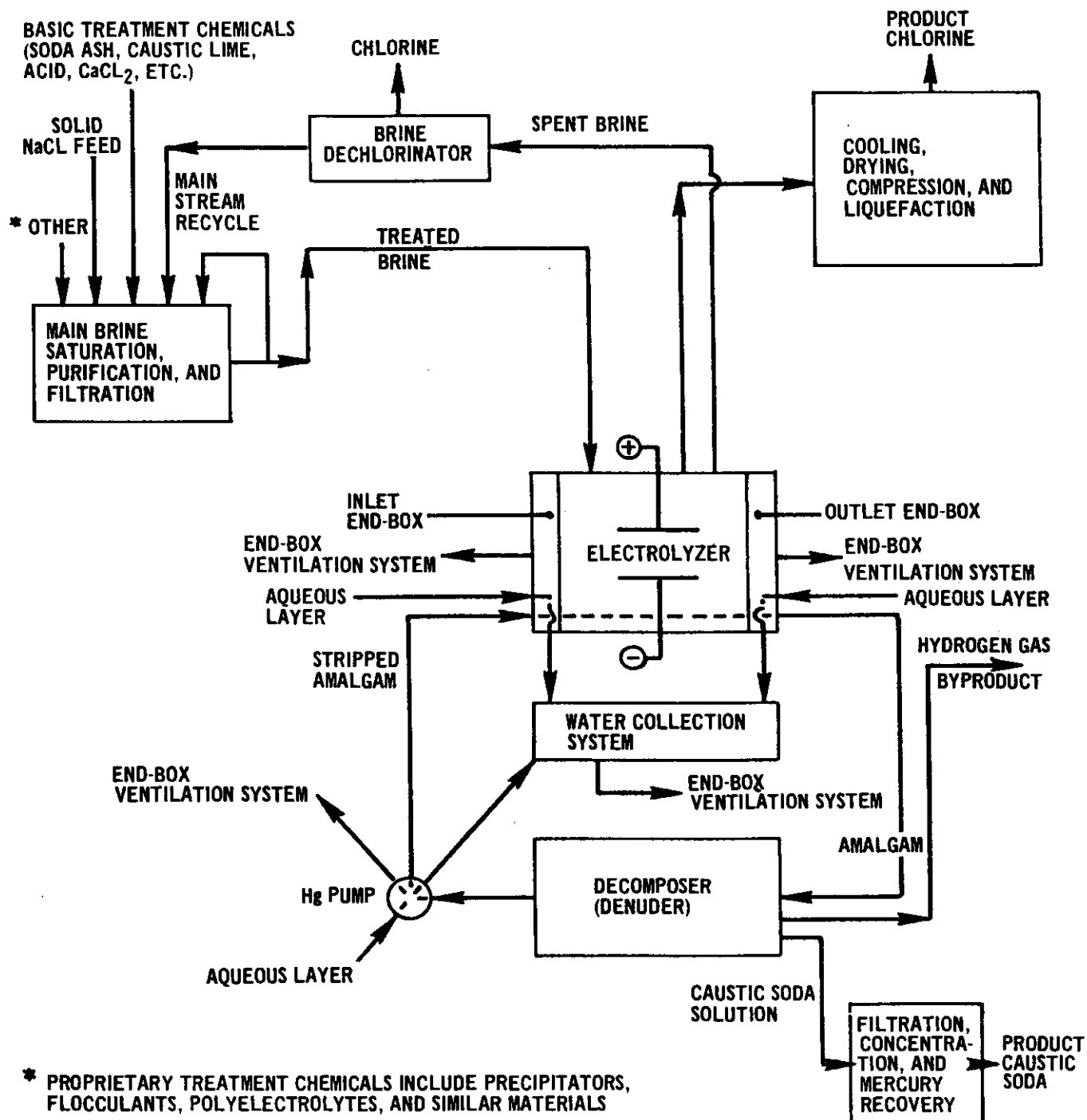


Figure 4.—Domestic mercury consumption, by end use, 1941-65.





Source: Reference 25.

Figure 6.—Basic flow diagram for a chlor-alkali mercury cell operation.

During the past 20 years, the quantity of mercury consumed (lost) in the manufacturing of chlorine and caustic soda has declined from 0.12 kg/mt (0.3 lb/st) of chlorine produced to 0.04 kg/mt (0.1 lb/st) of chlorine produced, according to the Chlorine Institute, Inc. The reduction in losses was attributed to a decline in the number of plants using mercury cells and increasingly stringent environmental regulations. The EPA also estimates the plants lose 0.75 kg of mercury per 100 mt of chlorine produced (27). The EPA also has set Federal air and water emissions limits. For air, the limit is 2.3 kg per day of mercury from all sources, with 1 kg maximum from point sources. Water emissions are limited to 0.0028 kg/mt of chlorine produced and a maximum of 0.0014 kg per day. This rule applies to plants installed before 1974, which includes all in the United States. Individual States also have water emission limits that are generally more stringent than the EPA.

According to the EPA Toxic Release Inventory (TRI), in 1989, 11,301 kg of mercury was released from chlor-alkali manufacturing; however, three plants did not report to the survey. An additional 52,879 kg of mercury contained in wastewater and sludges was transferred to landfills or containment facilities. In 1990, the TRI reported 10,982 kg of mercury released and 58,530 kg transferred. Two plants did not report in 1990 (28). The amount lost to the environment by the chlor-alkali plants used in this report is the total of releases and transfers for mercury and mercury compounds. Transfers were included because none of the waste material generated in 1989 and 1990 was reprocessed to recover the mercury. Table 5 shows the TRI data for releases and transfers from the production of chlorine and caustic soda in 1989 and 1990. The TRI data for releases of mercury correlate with the industry loss figure of 0.04 kg/mt of chlorine produced.

Table 5.—EPA Toxic Release Inventory data for releases and transfers of mercury from chlor-alkali production facilities

(Kilograms)

Company	Plant location	Releases		Transfers		Total	
		1989	1990	1989	1990	1989	1990
Akzo Chemicals, Inc.	LeMoyne, AL	1,021	796	454	2,948	1,475	3,744
Georgia Pacific Corp.	Bellingham, WA	680	680	2,268	5,443	2,948	6,123
B.F. Goodrich Group	Calvert City, KY	539	552	11,284	5,443	11,823	5,995
LCP Chemicals, Div. of the Hanlin Group:							
Do.	Acme, NC	497	498	50	49	54	547
Do.	Brunswick, GA	591	594	340	113	931	707
Do.	Moundsville, WV	673	617	1,139	435	1,812	1,052
Do.	Orrington, ME	386	464	462	246	847	710
Do.	Syracuse, NY ¹	12	11	2,591	159	2,603	170
Linchem, Inc.	Ashtabula, OH ²	591	818	1,005	0	1,596	818
Occidental Chemical Corp.:							
Do.	Delaware City, DE	252	169	3,879	3,680	4,131	3,849
Do.	Mobile, AL ³	NR	249	NR	2,767	NR	3,015
Do.	Muscle Shoals, AL	340	80	13,154	7,439	13,494	7,519
Do.	Deer Park, TX	576	NR	6,412	NR	6,988	NR
Do.	Niagara Falls, NY	41	15	25	1,395	66	1,410
Olin Corporation:							
Do.	Augusta, GA	602	604	966	2,749	1,568	3,353
Do.	Charleston, TN	2,608	2,375	0	2	2,608	2,377
Do.	Niagara Falls, NY ⁴	644	634	2,683	2,895	3,327	3,528
Pioneer Chlor-alkali	St. Gabriel, LA	569	591	5,827	11,403	6,396	11,994
PPG Industries, Inc.:							
Do.	Lake Charles, LA	NR	555	NR	11,249	NR	11,804
Do.	New Martinsville, WV	680	680	340	113	1,021	794
Vulcan Chemicals	Port Edwards, WI	NR	NR	NR	NR	NR	NR
Total		11,301	10,982	52,879	58,530	64,180	69,512

Do Same as above. NR Did not report.

¹Closed in 1988, releases and transfers from plant cleanup.

²Now ASHTA Chemicals, Inc.

³Converted to membrane cells in 1990.

⁴Closed in 1990.

Paint

An important use for mercury compounds over the last 50 years has been as a fungicide and biocide additive to paint. Before 1972, mercury compounds were used widely in antifouling paint for the bottoms of ships to prevent the growth of bacteria, barnacles, and seaweed. Mercury was found to leach from the paint into the water, and this use was banned by the EPA in 1972 (23).

In latex paint, mercury acted both as a preservative to prevent the growth of bacteria during storage, and as a fungicide to prevent mildew formation. Exposure to damp conditions was the primary consideration when choosing this type of paint. Phenylmercuric acetate and phenylmercuric oleate were the most common mercury compounds added to latex paint. In 1989, the manufacture of paint was the third largest use for mercury.

Paint is a dissipative use for mercury. The mercurials reenter the environment mainly through evaporation, but some are lost through flaking of the paint, through discarded paint residues, or demolition of buildings. In August 1990, the EPA in cooperation with the domestic paint industry, banned the use of mercury in interior latex paint. As justification for the action, EPA cited a risk of poisoning, especially to children, when using the paint in poorly ventilated areas. Subsequently, many manufacturers voluntarily removed mercury from exterior latex paint also, but its use has not yet been banned. As a result of the ban, consumption of mercury for paint in 1990 dropped nearly 90% from that of 1989. Despite this development, some mercury will continue to be added to the environment for several more years from previously painted surfaces.

ELECTRICAL USES

Wiring Devices and Switches

The development of semiconductor technology has eliminated many uses for mercury in wiring devices and switches. Products using mercury include rectifiers, oscillators, relays, and tilt switches.

Batteries

The standard mercury battery is a primary, or nonrechargeable, battery. It has a mercuric oxide cathode, a zinc anode, and uses either potassium hydroxide or sodium hydroxide as the electrolyte. Characteristics of the mercury battery are its high capacity-to-volume ratio, steady discharge rate, and high resistance to shock, vibration, vacuum, pressure, corrosive atmospheres, and high

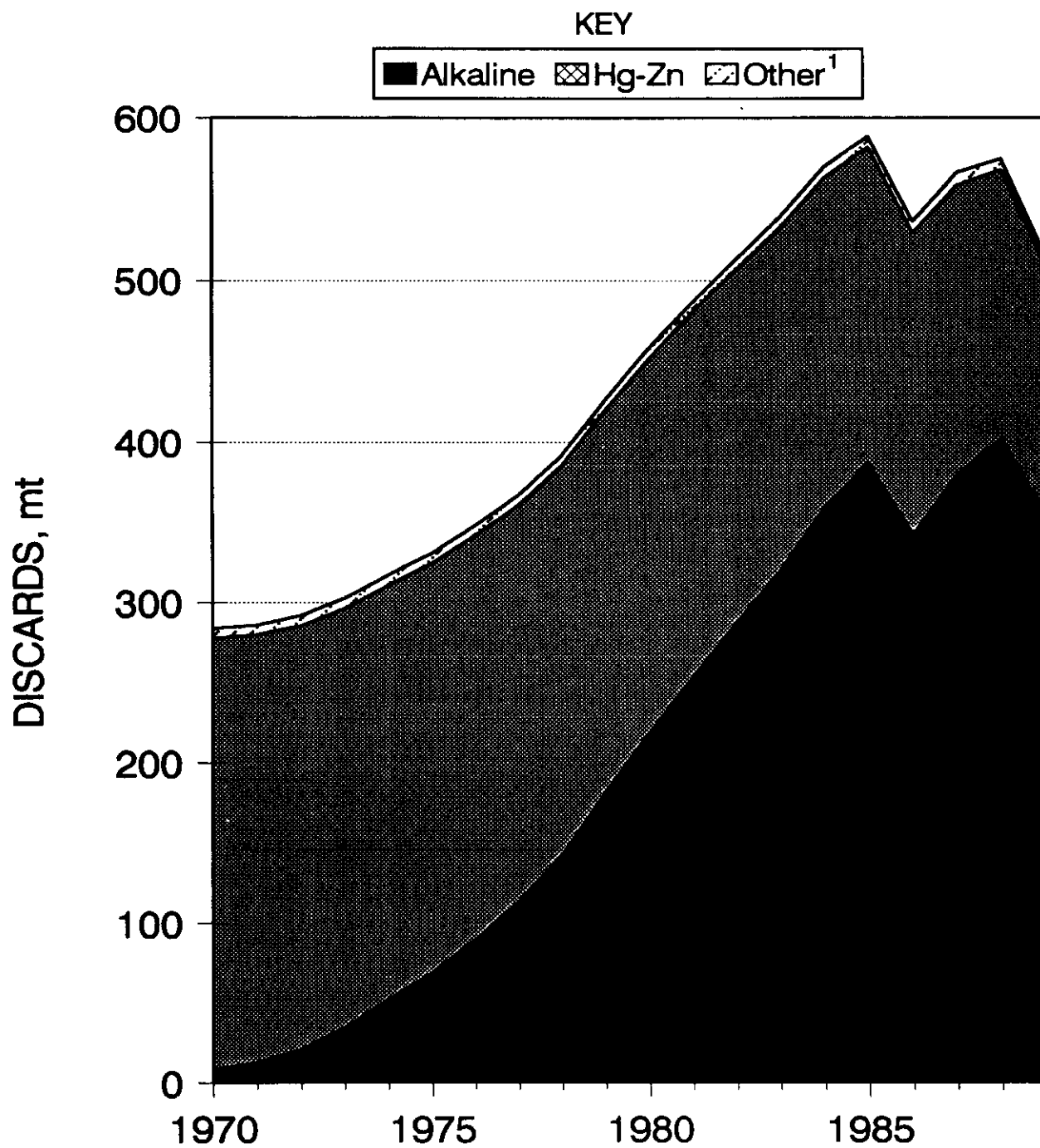
humidity (29). Mercury batteries come in three basic shapes, button cells, flat-pellet cells, and cylindrical cells. Button cells are generally the smallest of the three types. Hearing aids, watches, calculators, hospital electronics, and photographic and military equipment commonly use mercury cell batteries.

Besides the standard mercury battery, other batteries contain small amounts of mercury. The most common is the alkaline primary battery, which usually has a zinc anode and a manganese dioxide cathode, and uses potassium hydroxide as the electrolyte. These batteries may contain mercury in the insulating paper surrounding the battery or amalgamated with the anode. The mercury is used to prevent the buildup of hydrogen gas in the canister, which could cause the battery to leak. The mercury content of alkaline batteries in 1970 ranged from 0.00855 gram in a button cell to 0.7322 gram of mercury in a D cell battery. In 1993, the average amount of mercury in a button cell was 0.00428 gram and 0.02973 gram for a D cell (29).

Other consumer batteries that contain mercury include carbon-zinc (regular and heavy duty), zinc-air, and silver-oxide.

Battery manufacture was the second largest domestic use for mercury in 1989 and third largest in 1990. Since 1981, alkaline batteries have been the largest contributor of mercury to the municipal waste stream, surpassing the mercury-zinc cell.(29) This was attributed to the rise in consumer electronic items such as toys, portable radios, and tape players. The alkaline cell is the largest selling type of battery because of its relatively long life and low cost. Historically, recycling these batteries has been impracticable because of the large number of batteries involved, the difficulty of collecting the batteries, and the low mercury content per battery. The discarded batteries then end up in landfills or incinerators. (See figure 7.)

In recent years, several States have become concerned about the potential hazard posed by consumer disposal of small batteries, and their concentration in landfills. In response, three States (Connecticut, Minnesota, and New Jersey) have enacted legislation that calls for the elimination of mercury in batteries sold within their borders (29). Simultaneously, battery manufacturers have been working to reduce or eliminate mercury from various alkaline batteries, an effort that has met with some success. In 1990, the consumption of mercury in batteries dropped nearly 60% because of substitution of other metals for mercury. By 1993, several manufacturers had begun selling mercury-free alkaline batteries. By 1995, the use of mercury in alkaline batteries is expected to be eliminated in the United States (29).



¹Other includes carbon-zinc, silver oxide, and zinc-air batteries.
Source: Reference 29.

Figure 7.—Discards of mercury from household batteries in the United States, 1970-89.

Electric Lighting

Besides batteries, other electrical uses for mercury include fluorescent and mercury vapor lamps. All fluorescent lamp tubes contain a small amount of mercury. When voltage is applied across the length of the tube, electrons are injected into the evacuated tube, by a combination of thermionic and field emission, from heated electrodes at the ends. The current warms liquid mercury in the tube, volatilizing it until the vapor itself bears all the current. Bombarded by electrons, the atoms of the vapor emit ultraviolet radiation, which is absorbed by the phosphor and re-emitted as radiation in the visible wavelength range. The mercury reverts to its elemental form when the lamp is turned off. The average mercury content of a 4-foot tube, which has a lifespan of about 4 years, is 41.65 mg. By 1995, the industry plans to reduce the mercury content to 26.98 mg (24). The average mercury content of a compact fluorescent is 5 mg, but these bulbs have a much longer lifespan and it is too early to determine if they will decrease the amount of mercury that is discarded. Some States have passed laws limiting the land-filling of fluorescent light tubes, thus encouraging recycling. However, there are only a few companies that currently have the capability to recover mercury from the bulbs (24).

Mercury vapor lamps are high-intensity discharge lamps that are used in applications such as street lights, photography, flood lights, and underwater lighting. Mercury vapor lamps use less metal per bulb and are not as widespread as fluorescent lamps in usage.

INSTRUMENTS AND RELATED PRODUCTS

Measuring and Control Instruments

Thermometers, manometers, and barometers use mercury owing to the metal's uniform volumetric expansion in response to changes in temperature and pressure. Many

industries use mercury thermometers instead of electronic devices because of the accuracy, simplicity, and lower cost of mercury instruments. Electronic measuring devices also require periodic calibration and certification, which can be very expensive to a smaller company. However, many larger companies have switched to digital instruments whenever possible. The manufacturers of industrial mercury thermometers have made improvements to alleviate breakage of thermometers under normal conditions.

Mercury thermometers have been banned from use in food and beverage manufacturing and schools. Replacements include digital thermometers and thermometers using other liquids as the fill material.

Mercury is used in oral and rectal "fever" thermometers. According to a recent EPA study, as much as 15 mt of mercury may be disposed of annually from broken fever thermometers in the United States (29).

Mercury has been used extensively in thermostats. A small capsule of mercury provides the electrical connection in response to the change in temperature to engage the thermostat.

Other Uses

Other uses for mercury include catalysts, dental amalgams, laboratory uses, pharmaceuticals, and pigments. Mercury compounds were also used in past years in anti-fungal agricultural products, as preservatives in cosmetics, and as explosives. All these uses have been either banned by the EPA or voluntarily discontinued by the manufacturers.

Each use described above ultimately results in the dissipation of the contained mercury. While some material may be recycled, and the mercury recovered, generally the final destination of the product is the local landfill or incinerator. The elimination of mercury from uses such as batteries and a greater emphasis on recycling will lead to less mercury being lost to the environment.

MATERIALS FLOW DESCRIPTION

Mercury is present in the air, animals, plants, rocks, sediments, soils, and water. Although these background levels do not appear to present major problems, mercury is a toxic metal, which given sufficient concentration or exposure can cause sickness or death. Natural processes such as erosion, volcanic activity, and degassing of the earth's crust result in the cycling of mercury through the biosphere, while human activities increases this effect. Because these human activities and the resulting emissions are more localized phenomena, they may present a serious local problem, especially if the mercury enters the food chain.

Mercury has been found to move readily from one medium to another, especially when it settles into lakes and streams where bacteria act upon the mercury, converting it to methylmercury, a potent toxin. It bioaccumulates in the aquatic food chain when larger predatory fish eat smaller fish containing mercury. The mercury then settles in the flesh and organs of the larger fish, some of which are used as food by humans. The first reported widespread epidemic of mercury poisoning came from eating contaminated fish in the Minamata Bay area of Japan in the 1950's. There, a chemical plant, which used mercury as a catalyst, had discharged mercury-containing waste

sludge into the bay for years. In the last 20 years, instances of mercury poisoning among humans have been rare, but in some areas of the United States, people are still advised to limit their intake of certain game fish. Plants can also accumulate mercury from contaminated soils.

Major occurrences of human mercury poisoning also occurred in the 1960's in Iraq, from eating bread made from wheat treated with a mercury-containing fungicide and in New Mexico from eating meat from an animal that had been fed similarly treated grain. In both cases, the grains were intended for planting, not consumption. These instances helped to make the public aware of the toxic nature of mercury and led to its ban from use in agriculture. Many uses have been eliminated and those that remain use less mercury. A concerted effort is made to recycle or eliminate mercury wherever possible in most industrial applications, as Federal and State Government regulations limit discharges of and occupational exposure to mercury. See table 6 for a list of Federal regulations that have had a major impact on mercury.

The Superfund Amendment and Reauthorization Act of 1986 required the EPA to create the TRI, which lists releases of mercury and other compounds from manufacturing sources to air, land, and water, and transfers to treatment facilities and landfills. The TRI is a good starting point in documenting losses, but it does not report all losses because fossil fuel combustors, lime and cement kilns, and incinerators are exempt from reporting. Manufacturing and processing facilities that have more than 10 employees and use more than 11,340 kg (25,000 lb) of a listed substance are required to report. Companies that use more than 4,536 kg (10,000 lb) for nonmanufacturing

uses also are required to complete the TRI survey. The threshold limit for manufacturing in 1987 was 34,019 kg (75,000 lb), it was lowered to 22,680 kg (50,000 lb) in 1988 and lowered to the present 11,340 kg in 1989. Table 7 shows TRI data for mercury and mercury compounds from 1987 to 1990. In 1989, more than 16 mt was released and 82 mt was transferred to treatment or disposal facilities. Mercury lost in the production of chlorine and caustic soda accounted for 80% of TRI losses and transfers of mercury in 1989. In 1990, 14 mt was released and 74 mt was transferred to treatment or disposal facilities. Nearly 85% of the reported mercury waste was generated by the chlor-alkali industry.

In 1991, the EPA asked more than 600 U.S. companies to voluntarily reduce releases and transfers of mercury and 16 other toxic substances. This plan, the 33/50 Program, called for the reduction of the release of these 17 substances by 33% by the end of 1992 and 55% by the end of 1995, compared with the 1988 TRI data. The 33% goal was achieved 1 year early, with a 34% reduction in releases from 1988 to 1991.

Losses shown in figures 8 and 9 include air, land, and water emissions and are not differentiated, unless otherwise noted. Figure 8 shows the components of the domestic mercury supply in 1989 and figure 9 shows similar information for 1990. Losses from mercury mining were relatively small. Some was lost in dust and tailings and from degassing from exposed surfaces, but usually these sources were localized. Extreme precautions are taken to prevent the escape of mercury vapor during the roasting process and from the condensers. The loss prevention techniques were described in earlier sections of this report.

Table 6.—Major Federal environmental legislation affecting mercury (EPA)

Year	Legislation	Summary
1970	Clean Air Act (P.L. 91-604)	Authorized EPA to set national standards for hazardous air pollutants. Mercury was designated as a hazardous pollutant in March 1971 and standards were enacted in April 1973 for mercury ore processing facilities and chlor-alkali plants.
1972 Amended 1975.	Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).	Canceled many pesticides that contained mercury. Gave the EPA more authority to regulate harmful pesticides.
1972	Federal Water Pollution Control Act (P.L. 92-500)	Gave EPA the enforcement authority to regulate the discharge of mercury into waterways. In Sept. 1973, mercury was designated a toxic pollutant. In Dec. 1973, effluent standards were set for mercury (amended in Mar. 1974). In Oct. 1973, the dumping of mercury or mercury compounds into the ocean became prohibited.
1974	Safe Drinking Water Act (P.L. 93-523)	EPA given the authority to set standards for hazardous substances in drinking water.
1978 Amended 1986 and 1987.	Resource Conservation and Recovery Act (RCRA)	Established regulations for the disposal of mercury-bearing waste.
1980 Amended 1986.	Comprehensive, Environmental Response, Compensation, and Liability Act ("Superfund") P.L. 96-510.	Established a \$1.6 billion fund for clean up of toxic waste sites. It was funded primarily by taxes on the production of certain hazardous substances. Reauthorized in 1986, with a \$8.5 billion appropriation for five years.

Source: Reference 23.

Table 7.—EPA Toxic Release Inventory data
(Metric tons, contained mercury)

Mercury	1987	1988	1989	1990
Releases:				
Fugitive or nonpoint air emissions . .	7.79	7.27	7.24	6.36
Stack or point air emissions	2.83	3.34	4.32	3.80
Discharge to water	0.96	0.63	0.71	0.40
Underground injection	0.00	0.00	0.00	1.90
Releases to land	<u>12.82</u>	<u>6.02</u>	<u>2.24</u>	<u>0.00</u>
Total	<u>24.40</u>	<u>17.27</u>	<u>14.51</u>	<u>12.46</u>
Transfers:				
Discharge to POTW ¹	0.47	0.73	0.50	0.02
Other offsite locations ²	<u>107.31</u>	<u>116.74</u>	<u>56.95</u>	<u>80.29</u>
Total	<u>107.78</u>	<u>117.48</u>	<u>57.45</u>	<u>80.31</u>
Total for mercury	<u>132.17</u>	<u>134.74</u>	<u>71.96</u>	<u>92.77</u>
Mercury compounds	1987	1988	1989	1990
Releases:				
Fugitive or nonpoint air emissions . .	0.34	0.45	0.93	0.36
Stack or point air emissions	0.72	0.62	0.89	0.17
Discharge to water	0.23	0.12	0.01	0.03
Underground injection	0.01	0.01	0.02	0.01
Releases to land	<u>0.11</u>	<u>0.02</u>	<u>0.12</u>	<u>0.01</u>
Total	<u>1.41</u>	<u>1.23</u>	<u>1.96</u>	<u>0.57</u>
Transfers:				
Discharge to POTW ¹	0.24	0.24	0.47	0.01
Other offsite locations ²	<u>21.91</u>	<u>8.00</u>	<u>25.60</u>	<u>16.34</u>
Total	<u>22.15</u>	<u>8.24</u>	<u>26.07</u>	<u>16.35</u>
Total for compounds ³	<u>23.56</u>	<u>9.47</u>	<u>28.03</u>	<u>16.92</u>
Grand total	<u>155.74</u>	<u>144.21</u>	<u>99.98</u>	<u>109.69</u>

¹Publicly owned treatment works (municipal wastewater treatment plants).

²Landfills, waste treatment plants, recycling facilities, and energy recovery facilities.

³Data may not add to total shown because of independent rounding.

Losses from beneficiation of gold ores are believed to be low, because of strict environmental controls, especially in heap-leaching operations. Various methods have been developed to precipitate mercury from cyanide leach solutions (21). Mercury that remains in the concentrate is recovered during the smelting and refining process. However, there has never been a detailed study of mercury losses from gold mining and smelting, and the EPA has never developed an emissions factor for smelting of gold and silver ores. Therefore, the amount of mercury lost from gold mining and processing is included with other nonferrous smelters loss figures. The mercury losses from copper smelting were discussed earlier. Lead smelting and refining emits about 8 mt/yr (26).

If the amount of mercury emitted from fossil fuel combustion is included with the above sources, 200 mt of mercury was emitted to the environment in both 1989 and 1990.

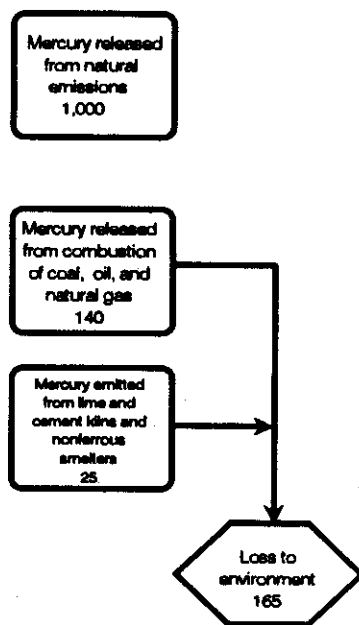
Figures 8 and 9 also show mercury manufacturing losses, which were based partially on EPA data. Manufacturing losses are relatively small for all industries. Extreme precautions are taken to ensure that no more than minimal amounts of mercury are released to the environment. Nearly all of the manufacturing losses are from

chlorine and caustic soda production and from the manufacture of paint.

Reliable estimates of the amounts in use and discarded were difficult to make because of the international trade of items containing mercury and lack of data on the lifespans of all products. The amount in use is an estimate based on recorded consumption and available lifespan information. Data were not available to accurately estimate the amount discarded from the use pool, except for batteries, which was calculated by the EPA. Although the figure shown for batteries is not consistent with the other data, it was used because it was the largest contributor of mercury to the solid waste stream.

The ultimate fate was based on the estimated lifespan of each major end use and the potential for future recycling. For example, fluorescent light tube recycling programs began in 1993, which is within the lifespan of products in use from 1990. Therefore, some of the mercury used in lighting will be recycled; whereas mercury contained in batteries will not be recycled, but will be eliminated from the product. The following is a list of the useful lifespans of mercury-containing products; these were used to determine the ultimate fate of the contained mercury and to estimate the amount in use (29).

Natural and incidental releases to air, land, and water, excluding incineration of wastes



Mined, recycled, and imported metal supplied to domestic and export markets

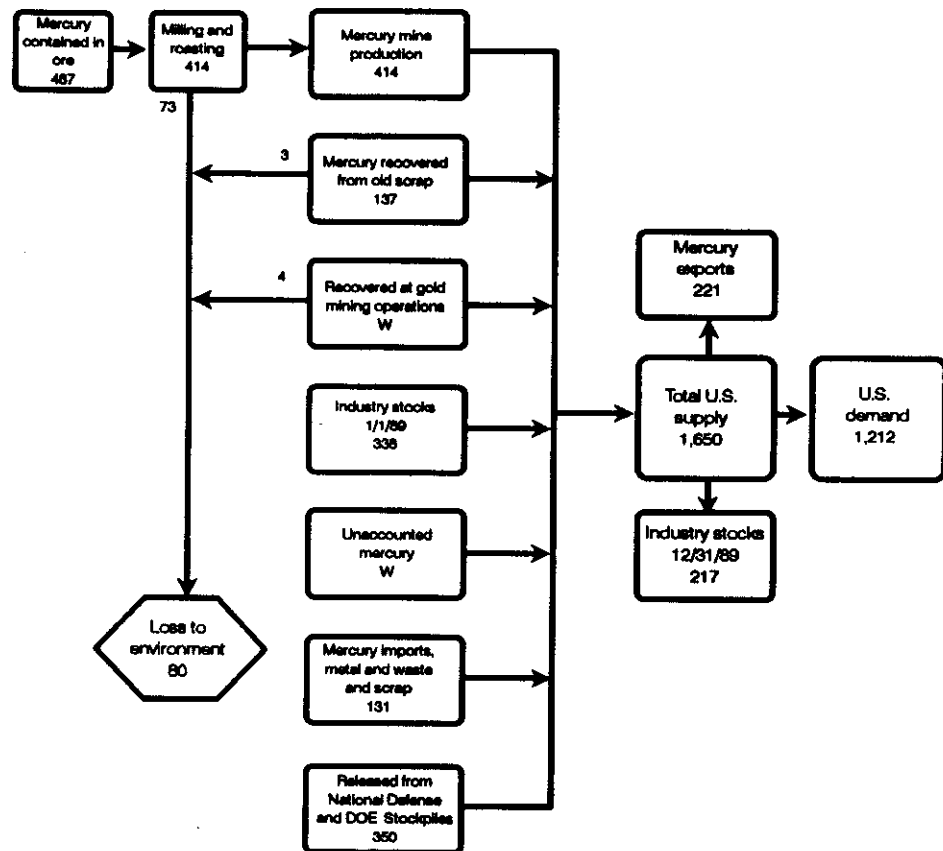


Figure 8.—Domestic flow of mercury in 1989. (Metric tons, mercury content)

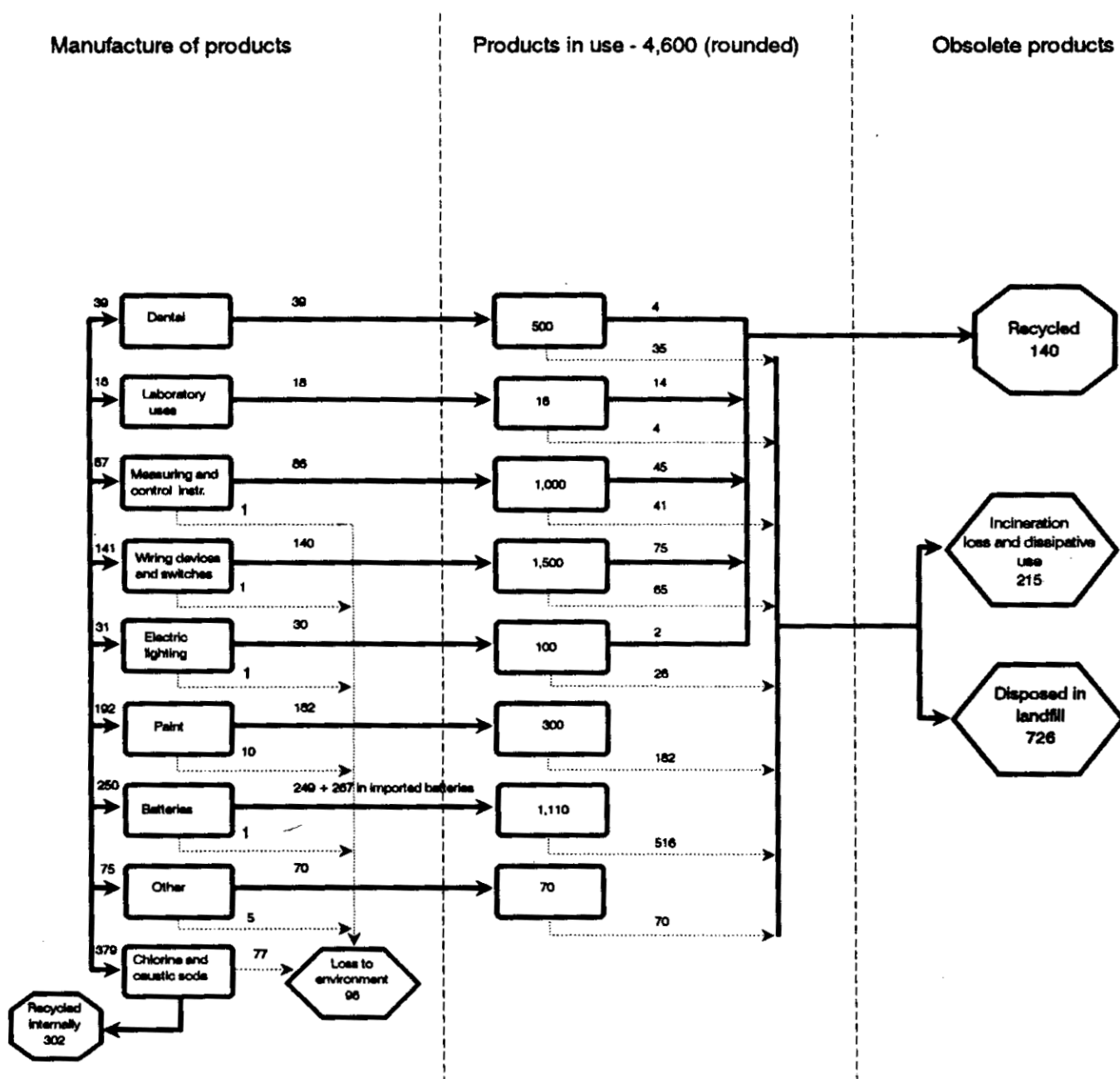
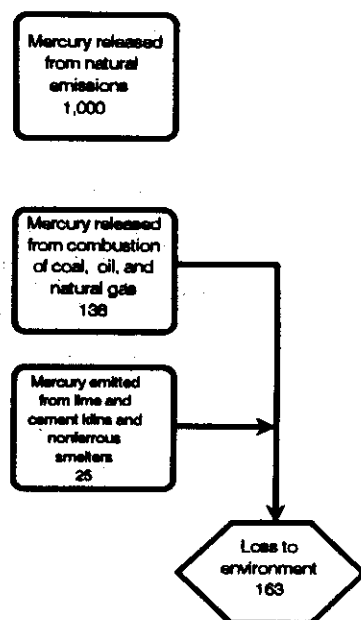


Figure 8.—Domestic flow of mercury in 1989—Continued. (Metric tons, mercury content)

Natural and incidental releases to
air, land, and water, excluding
incineration of wastes



Mined, recycled, and imported metal supplied to domestic and export markets

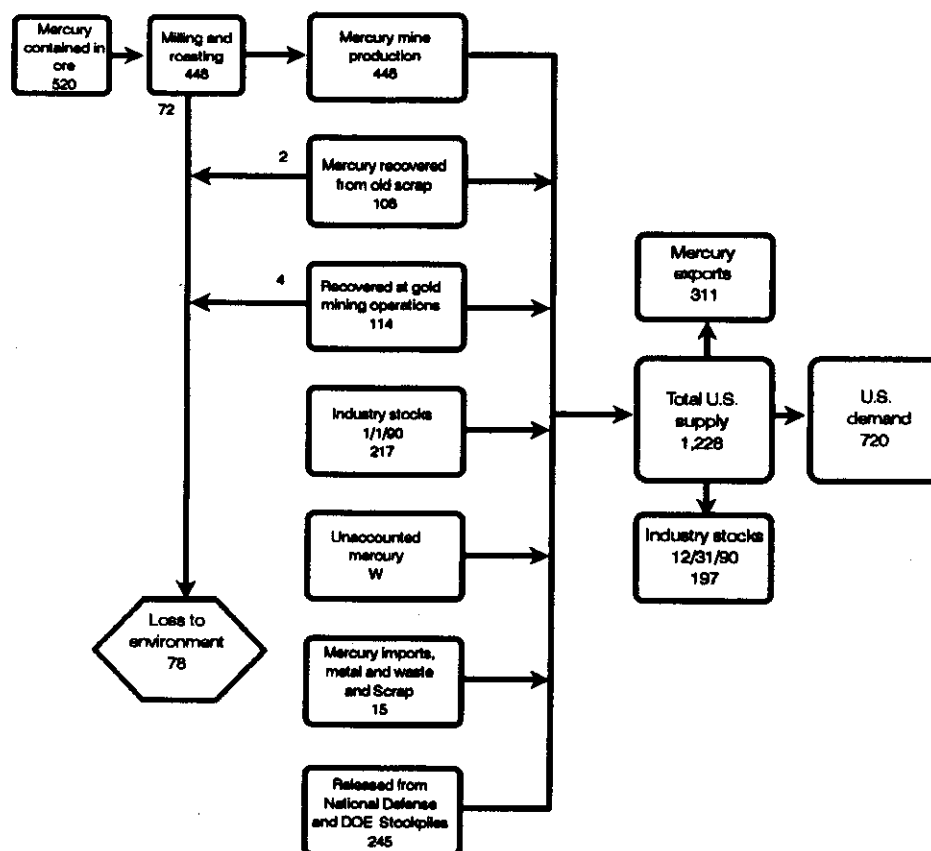


Figure 9.—Domestic flow of mercury in 1990.

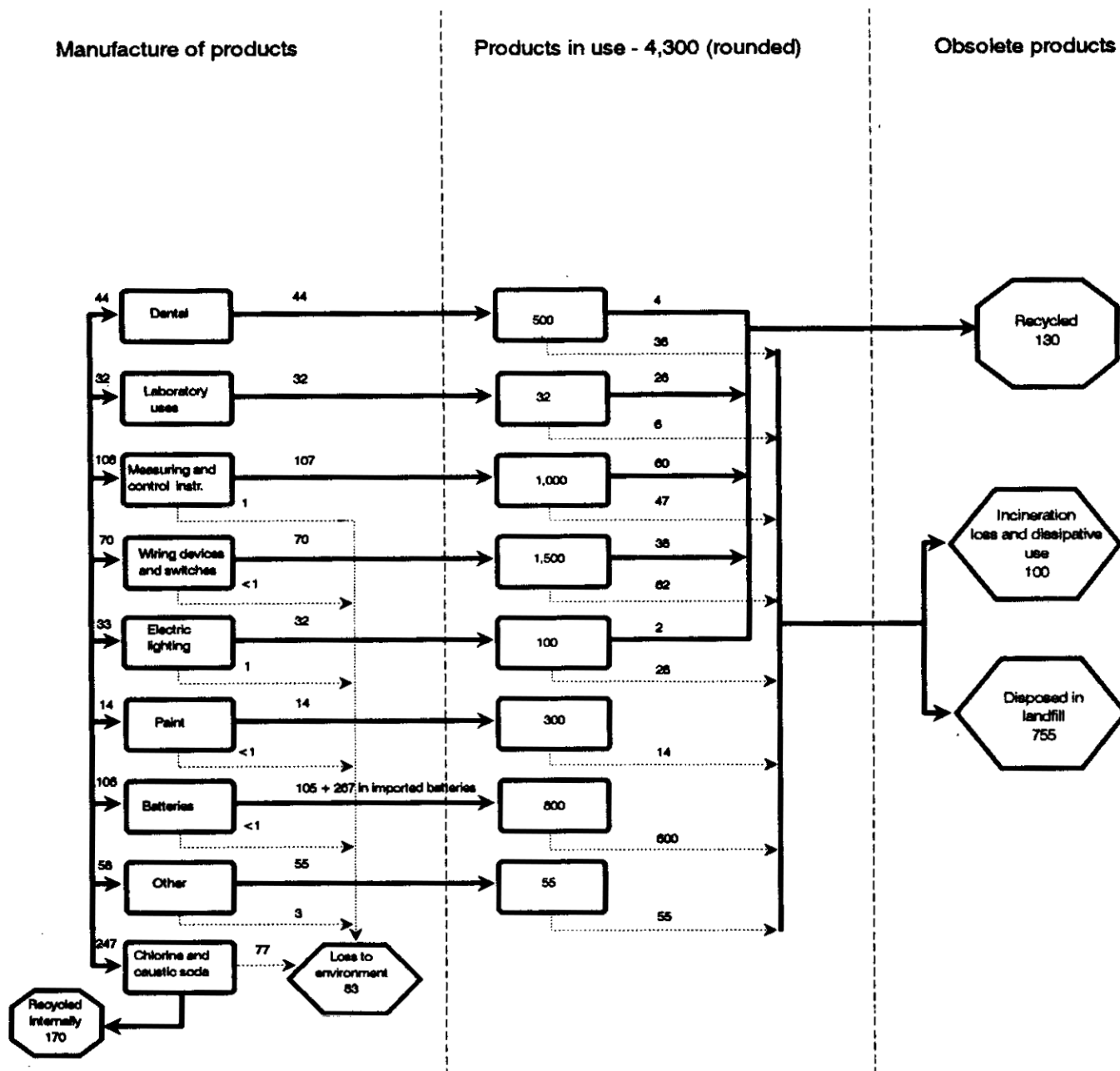


Figure 9.—Domestic flow of mercury in 1990—Continued.

Dental amalgams, laboratory mercury, electronic devices, and some control instruments have been recycled. The figure for consumer batteries, the largest contributor of mercury to the solid waste stream, was based on detailed data that were available from the EPA.

- **Paint** - Mercury contained in paint is a dissipative use and ultimately will end up in the environment primarily from mercury vapor emissions, which begin immediately upon application, erosion, or demolition of the painted structure. About 10% of the paint produced each year is never applied and is discarded within 5 years. It has been estimated that 66% of the mercury contained in paint is dissipated into the atmosphere; dissipation continues for at least 7 years. Consumption of mercury for paint should be near zero in 1993.

- **Switches** - 10% discarded after 10 years, an additional 40% after 30 years, and the remaining 50% after 50 years.

- **Batteries** - 2 years from purchase. It was assumed that batteries were purchased in the year of manufacture. A large amount of mercury enters the domestic waste stream from imported batteries and imported products containing batteries.

- **Fluorescent Lamps** - 4 years after production.

- **Thermometers** - 5 years.

- **Thermostats** - 20 years. Data are unavailable for other instruments.

- **Dental use** - 90% of current year consumption is used in teeth, 8% is lost in the dentists' offices during the first year and 2% is lost within 10 years. Ultimately all dental mercury is lost to the environment, though it is not widely dispersed.

- **Other Uses** - In 1989 and 1990, this category included small amounts of mercury used for catalysts, pharmaceuticals, and unclassified uses. A one year life was used because of limited data.

RECYCLING

Organized mercury recycling programs operated on a small scale in 1989 and 1990. More than two-thirds of recycling, in terms of the quantity of mercury recovered, involved internal reuse at chlorine and caustic soda production facilities. Another one-fourth of recycled mercury came from discarded instruments, wiring devices, and switches. The remainder, less than 4%, was derived from laboratory uses, dental amalgams, and electric lamps. Mercury used in paint, catalysts, and chemicals was dissipated into the environment without any potential for recovery. The remaining products, which have varying degrees of potential for recycling, were disposed of in landfills or incinerated. In the next decade, much of the mercury contained in products in use will be recycled where possible, as more States ban the disposal of mercury-bearing waste. However, the prevailing trend is to eliminate or reduce the use of mercury.

SUMMARY

This report represents a beginning in the evaluation of the total amount of mercury emitted to the environment in the United States, using data for 1989 and 1990. An effort was made to account for all sources of mercury lost to the air, land, and water. Recent EPA reports were instrumental for emissions factors and estimates of losses when reported data were not available. Mercury losses from end uses are primarily nondissipative and could have been recycled if the production capacity and incentive existed during this 2-year time frame. In 1989 and 1990, 64% and 71% of the mercury that was lost to the environment was placed in landfills. The balance of the losses was widely dissipated in the environment from a variety of sources. The combination of fossil fuel combustion and mining losses accounted for 20% of total emissions for both years. Mercury lost from paints and chemicals were the major dissipative uses, but both have nearly been eliminated since 1990. The amount of mercury released from incineration, the only category to decrease, fell over 50% from 1989 to 1990.

Chlor-alkali manufacturing and batteries were the only end uses for which detailed data on losses were available.

According to the TRI, the chlor-alkali industry contributed only about 9% to total mercury emissions in each year of the study, with nearly all placed in landfills. Data on battery usage and disposal from the EPA show it to have been the largest source of mercury from consumer waste. Mercury contained in imported batteries was included in this study because of the magnitude of the contribution to total waste generated. In 1989 and 1990, mercury recovered from consumer batteries was negligible. However, from 1991 to 1993, the use of mercury in consumer batteries had decreased greatly in response to legislative action by several States to reduce the discharge of mercury in the environment, and the recycling rate has increased substantially.

From 1989 to 1992, domestic usage of mercury was reduced by one-half; mercury emissions decreased, though not commensurately. This is due to mercury emissions from sources such as fossil fuel combustion remaining steady, while manufacturing losses declined. Mercury mining ceased in the United States in 1990, removing another source of emissions. Mercury losses from chlor-alkali manufacture should decrease substantially and secondary

production increase owing to the ban on the disposal of high-mercury content wastewater and sludges and the phasing out of mercury cell plants. Still, the elimination of mercury from products has had a greater impact in

reducing mercury waste than have recycling programs. This trend toward elimination will result in less mercury being lost to the environment.

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APPENDIX

Emissions calculations - (1993 revision)

(Mt, unless otherwise noted)

Secondary production		
	1989	1990
Factor of 20 kg of Hg emitted for every mt produced:		
Industrial Production	137.00	108.00
Emissions of mercury	2.74	2.16
Chlor-alkali manufacture		
Total consumption	379.00	247.00
Releases (from TRI)	13.42	12.36
Transfers (from TRI)	62.79	62.85
Subtotal for chlor-alkali	76.21	75.21
Battery manufacture		
Factor of 5.6 kg emitted per mt used:		
Consumption	250.00	106.00
Emissions	1.40	0.59
Electric lighting		
Outdoor lighting (assume 50% of consumption)	15.50	16.50
33% lost per year	5.12	5.45
Indoor lighting (assume 50% of consumption)	15.50	16.50
22% lost per year	3.41	3.63
Subtotal for lighting	8.53	9.08
Portland cement production		
Production	73,869.87	73,795.23
Kiln emissions, factor, kg/mt	8.70e-05	8.70e-05
Emissions of mercury	6.43	6.42

NOTE.—Emissions factors are the U.S. EPA, Compilation of Air Pollution Emission Factors AP-42, 4th ed., Supplement B.

Average mercury content of coal and oil consumed in the United States

Year	Source	Consumption (mt)	Avg. Hg Content	Contained Hg (kg)	Hg emitted (25% emission control for coal)
1989	Coal	807,121,000	0.021%	169,495	127,122
	Distillate oil	3,477,626	0.006%	209	209
	Residual oil	33,009,550	0.040%	13,204	13,204
	Total mercury potentially emitted				140,534
					127,948
1990	Coal	812,366,000	0.021%	170,597	127,948
	Distillate oil	2,022,237	0	121	121
	Residual oil	24,724,557	0	9,890	9,890
	Total mercury potentially emitted				137,959

NOTE.—Energy and coal consumption data are from the Energy Information Administration, U.S. Dept. of Energy, Monthly Energy Review, Feb. 1993.