

Mercury in Our Environment

Thomas Barron, civil engineer

ABSTRACT

Mercury is a very useful metallic element that, while not particularly abundant in nature, can play an important role in the overall health of humans and animals. This article discusses the benefits and toxicological consequences of society's use of mercury. It also will focus upon the mining, processing, and uses of mercury in the United States, and then highlight the amounts of mercury that are released as wastes. Along the way, three important questions are addressed:

- How much mercury is released by human activities and by natural events?
- Do these releases pose a risk either to humans or to the environment in general?
- How does this information apply to dentistry?

Mercury • Hg¹

- Atomic Number: 80
- Atomic Weight: 200.59
- 68th most abundant element
- Typical Adult Body Load: 6 mg total
- Dietary Intake: 3µg/day (can be more with high fish diet)
- Typical uses: Switches, thermometers, dental amalgam, biocide, disinfectant, religious observance, batteries and laboratory reagents
- Toxic to humans and animals



Mercury has a number of chemical forms, with inorganic salts and other compounds being the most common. Mercury is usually mined from cinnabar, or mercuric sulfide, which may occur either by itself or in association with gold deposits.

Table 1 highlights three common forms of mercury, together with their relative solubilities in water and lipid fats. These solubilities are important because they determine how the mercury compounds move and accumulate within the body of a human who has been exposed.

Mercury Toxicology

Throughout history, humans have used mercury for a number of medical and religious purposes. Since the 1800s, these uses have expanded to include dental amalgam restorations, electrical

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switches, lamps, thermometers, paints, and process catalysts.

In contrast to its beneficial uses, mercury has the potential to harm animals and humans exposed to it. However, the risk of actual harm requires that three independent factors occur together:

Risk of Harm = Hazard + Exposure + Susceptibility

Hazard is the term for the inherent characteristics that mercury or any other chemical has and the way those characteristics interact with humans or animals. These hazards are different for elemental mercury and the various mercury compounds. Of particular concern is methylmercury, an organic compound with the structural formula $\text{CH}_3\text{-Hg}^+$ (e.g., dimethylmercury is: $\text{CH}_3\text{-Hg-CH}_3$). Methylmercury is toxic in very small amounts with neurologic or teratogenic effects starting when blood levels reach a fraction of a microgram of $\text{CH}_3\text{-Hg}$ per liter of blood serum ($\mu\text{g/l}$).

Exposure is a combination of dose (i.e., how much of the chemical is present), duration, and pathway. Three common exposure pathways for humans are: dental amalgam restorations, inhalations by industrial workers, and ingestion by people who eat fish.

Mercury bound in silver amalgam restorations is one obvious form of human exposure, but one that most studies to date suggest is relatively benign. For example, Litvak and her co-

Table 1

Common Mercury Compounds			
	Example Forms		
	Mercuric Sulfide (Cinnabar)	Mercuric Chloride (Calomel)	Mercuric Chloride Methylated
Formula	HgS	HgCl_2	CH_3HgCl
Structure	Hg - S	Cl - Hg - Cl	CH_3 - Hg - Cl
Water Solubility	Low	High	Low
Lipid Solubility	Med	Low	High

Sources: Goyer²; Emsley¹

workers recently reported that patients with modest numbers of mercury-containing amalgam restorations have an average total mercury level of only 1.7 $\mu\text{g/l}$ in their blood, and that this level does not produce detectable neurologic effects.³ The Environmental Protection Agency health guidelines suggest that serum mercury levels should be less than 5 $\mu\text{g/l}$ of total Hg for the average adult, and that the daily intake of mercury from all sources be less than 0.1 $\mu\text{g/Kg}$ of body weight.

However, other mercury compounds are volatile. Therefore, workers exposed for long periods to mercury vapor or airborne mercury particles may have more significant exposures. It is interesting to note that the Litvak study mentions observable diminishment of neurologic function in dental workers themselves. The blood mercury levels reported in these workers ranged up to 9 $\mu\text{g/l}$, nearly twice the EPA health guidelines.

In addition, people who eat significant amounts of large fish (e.g., shark, halibut, and tuna) are reported to have serum mercury levels up to 90 $\mu\text{g/l}$, leading to the conclusion that the dietary pathway can be particularly significant.⁴

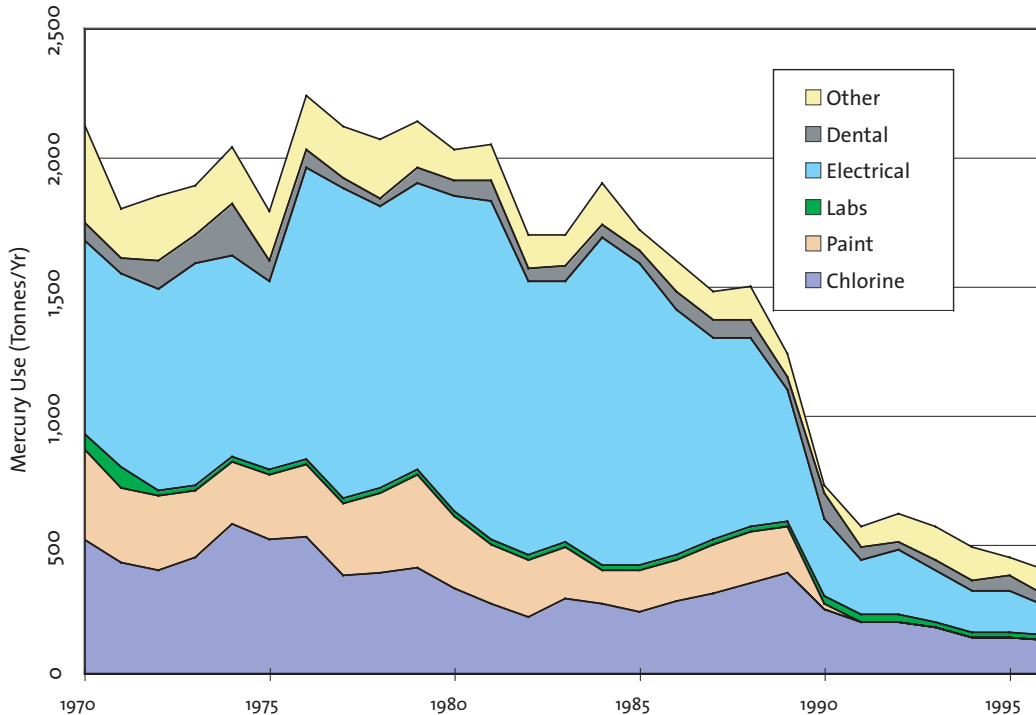
Susceptibility is the tendency of specific individuals or groups to experience the potential hazards presented by the chemicals to which they are exposed. As mentioned before, EPA health guidelines for adult daily intake of mercury from all sources is less than 0.1 $\mu\text{g/Kg}$ of body weight. However, pregnant women, a susceptible population, should work toward a somewhat lower daily intake. Hence, EPA issues fish advisories for Hg in most states.

Human Uses of Mercury

In 1997, about 400 metric tonnes of mercury were 'consumed' in the United

Table 2

U.S. Mercury Consumption (1970-1997)



Source: EPA⁵ and Sznoppek.⁶

States. Approximately one-third of this amount was imported, while the balance was produced by recycling or as a byproduct of gold mining. There are currently no active mercury mines in the United States.

Table 2, obtained from the EPA's 1997 Report to Congress,⁵ shows a downward trend in domestic mercury use since 1970. At the start of this period, annual mercury use in the U.S. totaled about 2,000 tonnes (2,200 tons), with the largest applications being batteries, chlorine production, and paints. By 1997, annual mercury use had decreased to just over 400 tonnes (440 tons), with dental amalgam, lighting, and switches each comprising about 10 percent of that total.

Dental Mercury Use

Recent studies published by the American Dental Association⁷ indicate there are about 165,000 dentists of all types actively practicing in the United States. General dentists make up the largest subgroup within this total, numbering approximately 120,000.

Most general dentists, as well as an additional 10,000 specialists in pediatrics, prosthodontics, and endodontics, encounter and remove existing amalgam restorations in their patients. In 1999, these professionals are believed to have removed about 92 million amalgams. A somewhat smaller number of dental professionals, perhaps 100,000 in all, also placed new amalgam restorations. Berthold⁸ estimates that dentists

placed about 70 million amalgam restorations in 1999, compared to 100 million in 1990.

Table 3 summarizes the mercury content of these restorations.

Mercury Releases to the Environment

Our exposure to mercury arises in part from volcanic eruptions and other natural processes. The United Nations Global Mercury Assessment⁹ concludes that, once released by these processes, mercury is persistent and cycles globally:

"The most significant releases of mercury pollution are emissions to air, but mercury is also released from various sources directly to water and land. The largest man-made source of mer-

Table 3

Dental Amalgam Restorations in the United States (1999)

Amalgam Removals		Amalgam Placements	
No. of Dentists	130,000	No. of Dentists	100,000
Removals/Yr	710 per dentist 92 million total	Placements/Yr	700 per dentist 70 million total
Hg/Removal	300 mg each	Hg/Placement	450 mg each
Total Hg/Yr	27,600 Kg 30 tons	Total Hg/Yr	31,500 Kg 35 tons 8% of U.S. Total

Source: Interpreted by author (from ENVIRON⁷).

cury to the environment is the combustion of fossil fuels, which release Hg found within oil and coal. Once released, mercury persists in the environment where it circulates between air, water, sediments, soil and biota in various forms. Current emissions add to the global pool – mercury that is continuously mobilized, deposited on land and water, and remobilized.”

“The form of mercury released varies depending on source type and other factors. The majority of air emissions are in the form of gaseous elemental mercury, which is transported globally to regions far from the emissions source. The remaining emissions are in the form of gaseous inorganic ionic mercury forms, such as mercuric chloride, or bound to emitted particles. These forms have a shorter atmospheric lifetime and will deposit to land or waterbodies within roughly 100 to 1000 kilometers of their source.

Elemental mercury in the atmosphere can undergo transformation into ionic mercury, providing a significant pathway for deposition of emitted elemental mercury.”

“Once deposited, the mercury form can change, primarily by microbial metabolism, to methylmercury which

has the capacity to collect in organisms (bioaccumulate) and to concentrate up food chains (biomagnify), especially in the aquatic food chain (fish and marine mammals). Methylmercury is therefore the form of greatest concern. Nearly all of the mercury in fish is methylmercury.” [Source: UNEP⁹]

The transformations in nature of mercury from one form to another, for example conversions of ionic mercury into methylated mercury, are not fully understood. Nancy Beckvar summarized what is known about these chemical dynamics in the final report of her research project sponsored by the National Oceans and Atmospheric Administration:¹⁰

“In both freshwater and saltwater environments, mercury is converted from inorganic bivalent mercury (Hg[II]) to methylmercury primarily by microorganisms, although chemical methylation also occurs. Methylmercury production depends on both the availability of Hg[II] for methylation and microbial activity.”

“Methylation is usually greatest at the sediment/water interface, but also occurs in the water column. Net methylmercury production is a function of both the rate of methylation and the rate of demethylation. Methylmercury is

not readily decomposed so the methylation rate is usually higher than the demethylation rate. Degradation of methylmercury is also primarily a microbial process.”

“Methylation is influenced by the availability of Hg[II], oxygen concentration, pH, redox potential (Eh), presence of sulfate and sulfide, type and concentrations of complexing inorganic and organic agents, salinity, and organic carbon.” [Source: Beckvar¹⁰]

Mercury is typically found as an ore, such as cinnabar (HgS), or as a trace ingredient in coal and other hydrocarbons. Processing the ore in a heated retort, using the recovered mercury, and burning fossil fuels are examples of human activities that release this mercury into the air and water around us. In 1995, human-related mercury releases in the United States totaled an estimated 585 tons, with the majority coming from coal-fired boilers and waste incinerators.⁶

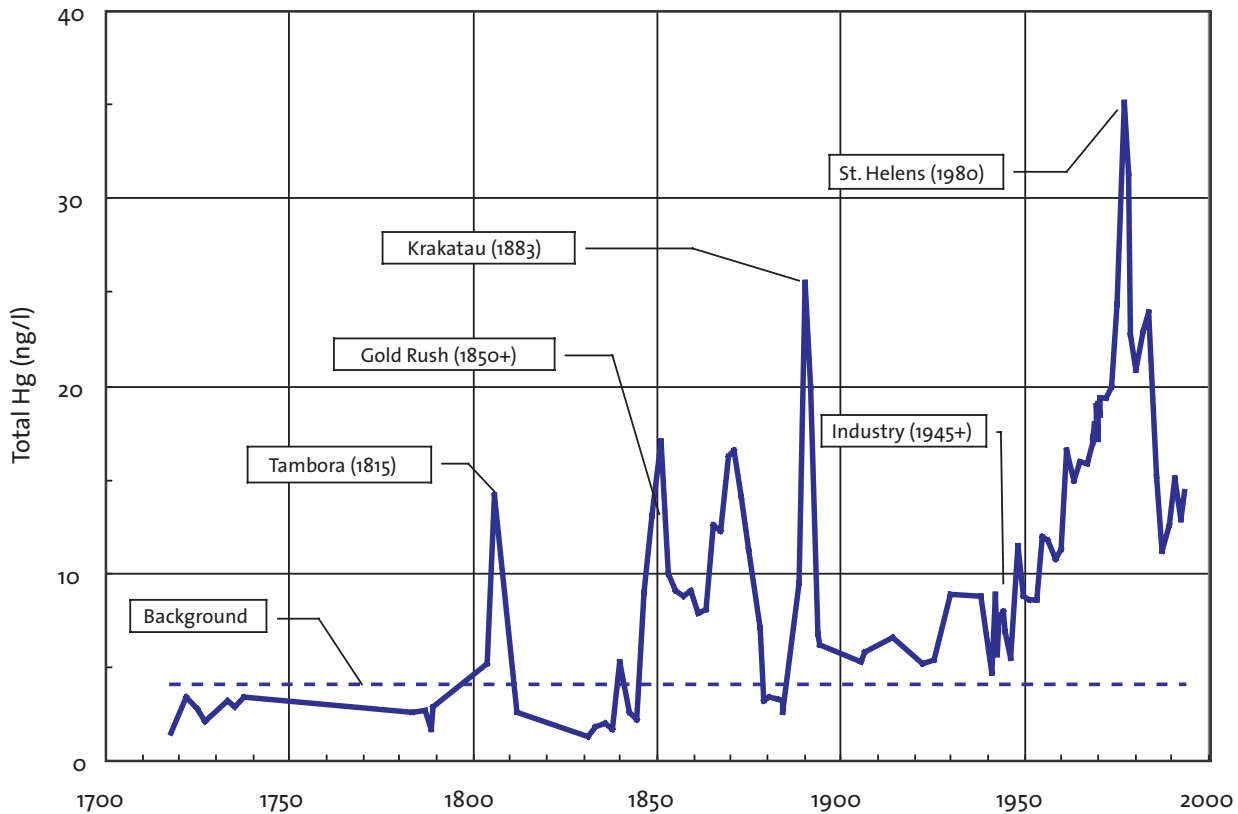
Amounts released to the air can be carried great distances. Therefore, some of our stack emissions reach Europe, while we in turn receive airborne mercury from Asia. The United Nations Environmental Programme estimates that annual worldwide mercury emissions to the air are 2,000 tonnes (2,200 tons), with stationary coal combustors in Asia contributing 40 percent of this total and being by far the largest sources.⁹

Volcanoes, hot springs, and forest fires are natural processes that also release large but not precisely known amounts of mercury. Geophysicists are starting to develop detailed estimates of this natural release. Initial results suggest that mercury released from human activities exceeds that from nature, except for during short-lived natural events such as the 1980 eruption of Mt. Saint Helens in Washington state.

Work by Paul Schuster and other researchers with the U.S. Geological

Table 4

Glacial Ice Mercury Concentrations (1700-2000)



Source: Schuster¹³

Survey give an interesting picture of the relative amounts of mercury released from human and natural sources.^{11,12}

Table 4 is a chart of mercury concentrations that Schuster's team measured in boreholes drilled into a glacier in Wyoming. This particular ice deposit has been steadily increasing for about 300 years, making it possible to assign dates to samples obtained from various depths below the surface. These dates appear along the horizontal axis of **Table 4**.

The Wyoming ice deposit reveals that during the past three centuries, sufficient mercury particles landed upon

the glacier's surface to leave a background residue of mercury in the ice of about 3.5 nanograms to 4 nanograms per liter (ng/l). Large volcanic eruptions, three of which are noted on the chart, caused yearlong peaks in the mercury concentration that are up to 20 ng/l above this background.

From 1850 to 1880, Schuster's glacier observations show that these natural processes were over-shadowed by the mining and retorting of mercury for the California gold rush and other western mining operations. These historical events added an average of perhaps 5 to 10 ng/l of mercury to the glacial ice that

Schuster's team studied, or about twice the natural background. Sediment samples from California rivers and bays show similar peak accumulations of gold rush mercury working its way downstream toward the Pacific Ocean.¹⁴

The 20th century saw significant industrialization take place in Asia and the western U.S., i.e., upwind of the Wyoming glacier. Power plants, waste boilers, and other industrial processes added from 5 ng/l to 15 ng/l of mercury to the glacial ice from about 1940 onward.

Also significant are the as-yet unexplained decreases that Schuster's chart

Table 5

Estimated Dental Office Mercury Releases to Environment

	Typical Mercury Releases		
	Solid Waste [2]	Sewer Waste [3]	Airborne Waste
Remove One Restoration [1]	210 mg	90 mg	
Place One Restoration [4]	30 mg	15 mg	
Daily Total per Dentist [5]	0.85 g	0.38 g	
Annual Total per Dentist [5]	170 g	75 g	Unknown
Annual Total for United States	20,000± Kg Total [6]	9,000± Kg lost	5,000± Kg lost

[1] One procedure involving a restoration that contains 0.3 grams of Hg.

[2] Optimally sent to a certified mercury recycler.

[3] Sewer waste = amounts swallowed by patient plus amounts discharged via office vacuum system. Vacuum system assumed to not have an amalgam separator unit installed.

[4] Most of the triturated amalgam ends up in the restoration. These estimates are the unused excess plus the amount carved during placement.

[5] Assumes 200 work days per year.

[6] An estimated 75 percent of this total is recycled. The remaining 5,000± Kg/yr is released via the trash or from incinerated medical waste.

Source: Barron¹⁸; also see **Table 3**; ENVIRON⁷, and Sznopke.⁶

reveals in the glacier's mercury levels from about 1990 onward. The author speculates that this downward trend may be from diversion of batteries, lights, thermometers, dental amalgam, and other mercury-containing wastes from municipal and medical incinerators. Alternatively, the decreases are perhaps from air pollution control measures recently installed at coal-fired power plants in states just west of the Wyoming glacier.

Conclusions

How much mercury is released to the environment by human activities and by natural events?

Dental Offices

Table 5 summarizes the author's estimate that 13 tonnes per year of mercury are released by dental offices that remove or place amalgam restorations.

Careful attention to collecting this waste amalgam and shipping it to certified mercury recyclers are important steps dental offices should take to mitigate these releases. Details of these mitigating measures are discussed in other articles in this *Journal* (Johnson and Pichay¹⁵) and in fact sheets issued by the ADA (McManus¹⁶) and various local governmental agencies (CCSF¹⁷).

Other Releases

Table 6 shows the author's estimate that 1,350 tonnes of mercury are released each year in the United States from both natural sources and human activities. Worldwide amounts are thought to be perhaps 10 times these domestic levels. Circulation of mercury in the atmosphere is such that part of the releases in Asia reach across the Pacific to the United States, while some fraction of our domestic releases

migrate eastward toward Europe.

Do these mercury releases pose a risk either to humans or to the environment in general?

Studies to date show that people in general, including those with modest numbers of amalgam restorations, have blood mercury levels that are below EPA health risk guidelines. However, dental workers and people who eat significant amounts of fish may have much higher levels.⁴ Some researchers also report that they see a connection between these high mercury levels and decreased neurologic function.³

Regulatory agencies that focus upon water quality issues have determined that human releases of mercury (from both current and historical activities) can pose a significant risk to fish and¹⁹ invertebrates, as well as to birds that feed upon them. These agencies are setting lower regulatory limits upon the

Table 6

Estimated Total Mercury Releases to Environment (1990s)

Source	Tonnes/yr
Power Plants & Other	160 (1)
Mining & Processing Losses	80 (2)
Dental Restorations — Solid/Medical Waste	5 (3)
— Lost to Sewer	9 (4)
Other Industrial Processes	340 (5)
	<hr/> 594
Natural Processes	750 (6)
Total Released	<hr/> 1,344

Notes

- (1) Releases in the United States only. Sznoppek,⁶ Figure 6.
- (2) Sznoppek,⁶ Figure 7.
- (3) Loses to either medical or municipal wastes, excluding recycled amounts. Barron;¹⁸ Sznoppek,⁶ Figure 7.
- (4) See Exhibit 5.
- (5) Sznoppek,⁶ Figure 7.
- (6) Author's estimate based upon Sznoppek,⁶ Figure 7, which estimates 1,000 and implication of Schuster,¹² Figure 3, that shows natural Hg is about 40 percent of total airborne Hg.

levels of mercury that businesses, industries, and sewage treatment plants may release into the environment.

In the Great Lakes area, many municipal wastewater treatment plants have received mercury discharge limits in the single parts-per-trillion (ppt) range. These limits are forcing municipalities to review their options for additional controls on all incoming mercury sources.

How Does this Information Apply to Dentistry?

It is suggested that dental professionals follow the various ongoing studies that focus upon potential health impacts of amalgam in patients. So far, the results of published studies appear to be negative. However, as with any area of public concern, it is better to be knowledgeable on the latest developments and prepared for questions that arise.^{20,21}

Another issue that deserves careful review is the potential exposure of dental workers to amalgam dust. It is suggested that a close reading be made of both the referenced Litvak study,³ and other reports of potential mercury impacts upon dental occupational health.

Another important issue relates to the management of amalgam waste materials in the dental office. In California, state regulations designate solid amalgam as a hazardous waste unless it is recycled for the metals that it contains. This regulation applies to all forms of waste amalgam, including non-contact scrap, as well as the residual found in empty capsules, chairside traps, and vacuum system screens. The ADA has published a set of recommended best management practices (BMPs) for managing these materials. These BMPs are intended to keep amalgam waste out of the medical waste and

Web sites of interest

City of San Francisco Dental Amalgam Program
 <http://sfwater.org/main.cfm/MC_ID/4/MSD_ID/85>

Palo Alto Regional Water Quality Control Plant
 <<http://www.city.palo-alto.ca.us/cleanbay/dental.html>>

United Nations Environmental Programme
 <<http://www.chem.unep.ch/mercury>>

Water quality limits on mercury discharges
 <<http://www.swrcb.ca.gov/rwqcb2/sfbaymercury.tmdl.htm>>

solid waste streams where incineration can release and redistribute mercury great distances.

At the local level, additional regulations are emerging for the closer control of amalgam waste contained in dental office sewer discharges. Restricted by tighter limits at their own outfall, local sewer agencies are asking dental offices to implement amalgam BMPs, and in some cases are requiring offices to install amalgam removal equipment on their vacuum systems. An example of such a program is described on the Web site set up by the City of San Francisco.¹⁷

CDA

References / Most of these references can be downloaded from the Internet. It may be helpful to correspond directly with the authors of each reference and ask for other recommended studies. In addition, the American Dental Association has specialists who focus on the subject of mercury, its beneficial uses in dentistry, and patient or regulatory concerns about these uses.

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