Global Assessment of Mercury and its Compounds

submitted by the Working Group member from Pakistan during the
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Introduction

Mercury is an element that occurs naturally in the earth's crust. Mercury is a metal that is commonly found in the environment in several forms, all of which are toxic. Mercury is mobile and widely dispersed in the biosphere and persists once released. Most people and wildlife can generally tolerate the extremely low levels of this naturally occurring substance. When mercury enters the body it becomes concentrated in tissue, an effect known as bioaccumulation. Since this element is toxic at very low concentrations, even slight increases in the minute concentrations naturally present in the environment can have serious effects on humans and wildlife.

Once mercury enters the water it can be converted to its most toxic form, methyl mercury, by bacteria or chemical reactions. Methyl mercury is absorbed by tiny aquatic organisms, which are then eaten by small fish. The chemical is stored in the fish tissue and is passed on at increasing concentrations to larger predator fish. People and wildlife at the top of the food chain are consequently exposed to elevated amounts of methyl mercury through the contaminated fish they consume.

Depending on its exact chemical form and the dose received, people or wildlife exposed to mercury can suffer serious adverse health effects. Mercury is a neurotoxin in low doses, affecting the functioning and development of the nervous system. Depending on the level of exposure, this toxin can have varied health effects ranging from mental retardation to death. Pregnant women need to be especially concerned about mercury contamination because direct exposure to the developing fetus through the mother's placenta could cause various health effects. Women of childbearing years, pregnant women, nursing mothers and children under the age of 15 should consume limited quantities of contaminated fish and space their fish meals appropriately. In addition, this sensitive population should not eat any swordfish or shark since these predators are known to have high levels of mercury in their tissues.

Incidents of human exposure have confirmed mercury's link to human health problems. In 1972, 6,500 Iraqi adults and children developed neurological problems and 459 people died after they ate grain coated with a fungicide containing methyl mercury. In another example that occurred in Minimata, Japan, 700 people died, 9,000 individuals experienced varying degrees of paralysis and brain damage, and 50,000 individuals experienced at least mild symptoms after being exposed to methyl mercury in seafood they consumed.

Airborne mercury is also a considerable threat to people and other organisms exposed through inhalation or bodily contact. Numerous cases of mercury poisoning, primarily through inhalation of the chemical, have also been documented in the workplace. In a survey conducted by the National Institute for Occupational Safety and Health, it was estimated that 70,000 American workers might be exposed to mercury vapors on the job, including nurses, lab technicians and others working in healthcare facilities (Anne Nadakavukaren, *Our Global Environment: A Health Perspective* - 1995). In addition, families of these workers were also identified to be at risk for exposure from mercury-contaminated work clothes brought home by workers. Despite these and countless other examples of the dangers of mercury, scientists still disagree about the levels at which this chemical is harmful to human health.

Studies have been conducted to determine the effects of mercury on wildlife that consume fish and other aquatic animals contaminated with the chemical. Current findings suggest that mercury has a neurotoxic effect on loons, eagles and osprey. One study found that loons with high levels of mercury in their brains (2 to 3 parts per million) reproduce less successfully than normal. These same levels could also hinder their speed and coordination, affecting their ability to catch prey and avoid predators.

In another study, researchers found geographical differences in mercury levels within loons. Those tested in eastern North America were found to have higher levels than those in the west. For example, loons in Alaska had low levels, only an average of 0.5 parts per million (ppm), while those in the Great Lakes region had an average of 1.1 ppm. New England loons were found to have an average of 2.3 ppm, and 3.1 ppm was the norm in the Canadian Maritime Provinces. Findings such as these provide evidence that the prevailing westerly winds in North America carry mercury to the east from pollution sources in the Midwest. Its ability to travel great distances once it becomes airborne makes mercury pollution a global issue, as well as a local and regional one.

Alkali and metal processing, incineration of coal, and medical and other waste, and mining of gold and mercury contribute greatly to mercury concentrations in some areas, but atmospheric deposition is the dominant source of mercury over most of the landscape. Once in the atmosphere, mercury is widely disseminated and can circulate for years, accounting for its wide-spread distribution. Natural sources of atmospheric mercury include volcanoes, geologic deposits of mercury, and volatilization from the ocean. Although all rocks, sediments, water, and soils naturally contain small but varying amounts of mercury, scientists have found some local mineral occurrences and thermal springs that are naturally high in mercury.

Mercury is a toxic metal that is of significant concern to the public. Naturally occurring mercury in our environment can be found in soil and rocks, including coal and copper ore. While trace amounts of mercury have always been present in the environment, concentrations of this chemical have been increasing to dangerous levels due to human activities such as coal burning.

Many of these activities are also largely responsible for creating local, regional and more widespread areas of contamination by redistributing the mercury found naturally in the environment. This redistribution creates significant potential for human and wildlife exposure. When coal is burned, for example, mercury is released into the air. Once it becomes airborne, it can be carried by winds and deposited locally within a couple of miles or kilometers from its source, or it can be carried for thousands of miles before being deposited on soil and bodies of water. Consequently, mercury that was not readily available to fish in a particular lake prior to redistribution may now be concentrating in their tissue. The likelihood of exposure to humans and wildlife that consume fish from this lake is now increased.

Included in the “combustion” category are Medical Waste Incinerators (MWIs), which burn medical waste. Hospitals, medical clinics, medical laboratories, nursing homes, others involved in medical and veterinary care and mortuaries use MWIs to rid biological waste of pathogens and to reduce the amounts of waste being sent to landfills. Mercury is released when debris containing the chemical, which could include anything from thermometers to antiseptics to CAT scan paper, is combusted at high temperatures.

Chapter No: 1

Chemistry of Mercury

Mercury is a naturally-occurring metal, traces of which occur in rocks of the earth's crust. Mercury has three possible "valence states", or conditions of electrical charge. The uncharged metallic or elemental mercury (Hg0), the form commonly used in thermometers, readily vaporizes from its liquid state, and is the most common form of mercury in the atmosphere. Long-range transport of mercury through the atmosphere consists primarily of mercury in the elemental form (Mitra, 1986). Limited amounts of elemental mercury may be found in soils and water. In soils and surface waters, mercury predominantly exists in the mercuric (Hg++- with a double positive electrical charge), and mercurous (Hg+- with a single positive charge) states, as ions with varying solubility. Mercuric chloride, a simple salt, is the predominant form in many surface waters (Mitra, 1986).

Mercury can form many stable complexes with organic (carbon-containing) compounds. Methyl mercury is a toxic, organic mercury compound that is fairly soluble in water. Dimethyl mercury, another organic mercury compound, is much less soluble. Inorganic mercury can be methylated by microorganisms indigenous to soils, sediments, fresh water, and salt water, to form organic mercury. Almost all of the mercury found in animal tissues is in the form of methyl mercury (WHO, 1989).

Name of mercury in Other Languages

- **Latin:** Hydrargyrum
- **Czech:** Rtut´
- **Croatian:** iva
- **French:** Mercure
- **German:** Quecksilber - e
- **Italian:** Mercurio
- **Norwegian:** Kvikksølv
- **Portuguese:** Mercúrio
- **Spanish:** Mercurio
- **Swedish:** Kvicksilver

Atomic Structure

- **Atomic Radius:** 1.76Å
- **Atomic Volume:** 14.82cm^3/mol

- **Covalent Radius:** 1.49Å
- **Cross Section:** 375barns ±5
- **Crystal Structure:** Rhombohedral
- **Electron Configuration:**
  $1s^2$ $2s^2p^6$ $3s^2p^6d^{10}$ $4s^2p^6d^{10}f^{14}$ $5s^2p^6d^{10}$ $6s^2$
- **Electrons per Energy Level:** 2,8,18,32,18,2

- **Ionic Radius:** 1.02Å
- **Filling Orbital:** $5d^{10}$
- **Number of Electrons (with no charge):** 80
- **Number of Neutrons (most common/stable nuclide):** 121
- **Number of Protons:** 80
- **Oxidation States:** **2**,1
- **Valance Electrons:** $6s^2$
  Electron Dot Model

Chemical Properties

- **Electrochemical Equivalent:** 3.742g/amp-hr
- **Electron Work Function:** 4.49eV
- **Electro negativity (Pauling):** 2
- **Heat of Fusion:** 2.295kJ/mol
- **Incompatiblities:**
  Acetylene, ammonia, chlorine dioxide, azides, calcium (amalgam formation), sodium carbide, lithium, rubidium, copper
- **Ionization Potential**
  First: 10.437
  Second: 18.759
  Third: 34.202
- **Valance Electron Potential (-eV):** 28.2

Physical Properties

- **Atomic Mass Average:** 200.59
- **Boiling Point:** 630K 357°C 675°F

- **Coefficient of lineal thermal expansion:**
- **Conductivity**
  Electrical: 0.0104 10^6/cm
  Thermal: 0.0834 W/cmK
- **Density:** 13.546g/cc @ 300K
- **Description:**
  Silver colored liquid transition metal.
- **Elastic Modulus:**
  Bulk: 25/GPa
- **Enthalpy of Atomization:** 61.5 kJ/mole @ 25°C
- **Enthalpy of Fusion:** 2.29 kJ/mole
- **Enthalpy of Vaporization:** 56.9 kJ/mole
- **Flammablity Class:** Noncombustible Liquid
- **Hardness Scale**
  Mohs: 1.5
- **Heat of Vaporization:** 59.229kJ/mol
- **Melting Point:** 234.28K -38.72°C -37.7°F
- **Molar Volume:** 14.81 cm^3/mole
- **Optical Reflectivity:** 73%
- **Optical Refractive Index:** 1.000933
- **Specific Heat:** 0.139J/gK
- **Standard State (at 20°C & 1atm):** Liquid
- **Vapor Pressure** = 0.0002Pa@-38.72°C

Regulatory / Health

- **CAS Number**
  7439-97-6
- **UN/NA ID and ERG Guide Number**
  2809 / 172
- **RTECS:** OV4550000
- **OSHA Permissible Exposure Limit (PEL)**
  Ceiling: 0.1 mg/m^3
- **OSHA PEL Vacated 1989**

TWA: 0.05 mg/m^3
Ceiling: 0.1 mg/m^3
Potential for skin absorption

- **NIOSH Recommended Exposure Limit (REL)**

  TWA: 0.05 mg/m^3
  Ceiling: 0.1 mg/m^3
  Potential for skin absorption
  IDLH: 10 mg/m^3

- **Routes of Exposure:** Inhalation; Skin absorption; Ingestion; Skin and/or eye contact

- **Target Organs:** Eyes, skin, respiratory system, central nervous system, kidneys

- **Name Origin:**

From the Greek god Mercury who was the messenger to the gods and was known for his speed; Hg from mercury's Latin name Hydrargyrum, which comes from the Greek word "hydrargyros" ("hydor" for water and "argyros" for silver).

MERCURY

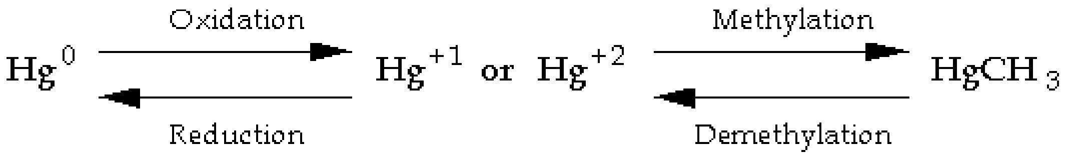
CHEMICAL SYMBOL: Hg

(based on its ancient name: Hydragyrum

Elemental Mercury	Hg 0
Inorganic Mercury	Hg $+^1$ or Hg $+^2$
Organic Mercury	Compounds such as: Methyl mercury - $HgCH_3$+ Dimethyl mercury - $Hg(CH_3)_2$

Mercury undergoes two predominant types of chemical transformations: 1) oxidation-reduction, and 2) methylation-demethylation. In oxidation, for example, mercury present in its uncharged form (Hg0) is converted to a higher valence state (e.g. $Hg+^1$). Reduction is the reverse of this process occurring through the addition of electrons. In methylation, elemental mercury adds an organic "methyl group" or hydrocarbon (CH_3) group, which is lost in demethylation. Both transformations can occur in either direction.

Common Mercury Transformations



Probably the best-known properties of elemental mercury are its low viscosity and its ability to form highly mobile droplets on surfaces. Low viscosity accounts for the way mercury droplets amalgamate into one when they collide. The high mobility of mercury may be the origin of its nickname, "quicksilver". Early Greek civilization recognized this metal's properties of quickness and embodied them in the messenger god Mercury, whom they elevated to the Pantheon. The planet Mercury, with its quick 88-day year and silver-white luster, epitomizes the reverence universally held for this element by ancient civilizations.

Mercury has a high surface tension, forming spherical droplets when the liquid is released. Though the mercury molecules within the droplets are stable, the molecules on the surface of the droplet are highly unstable, and readily vaporize. The boiling point of mercury is approximately 357°C (675°F). Essentially, all elemental mercury will exist as a vapor at temperatures above this level. Its high surface tension, uniform volume of expansion make mercury ideal for use in thermometers, barometers and other measuring devices.

PHYSICAL STATES OF MERCURY
(atomic number: 80, atomic weight: 200.6)

- Elemental mercury is a silver-white, heavy, mobile, liquid metal at ambient temperatures.
- Other forms of mercury such as mercuric acetate and mercuric chloride are white, heavy powders or crystal solids.

(US Dept. HHS, 1989)

Mercury is a relatively poor metallic conductor of electricity, yet it is often used in electronic devices such as switches and thermostats, when a liquid conductor is required and because its weight forms a positive seal. The ability of liquid mercury to conduct heat is responsible for the use of mercury as a coolant. The strongly toxic compounds of mercury have been exploited for bactericides, fungicides and insecticides, and its brilliant hues have lead to mercury use in paints (Mitra, 1986; ATSDR, 1994). It is also an excellent preservative and disinfectant, accounting for its presence in many chemical reagents and medical applications in forms such as Mercurochrome and Thimerosal.

Elemental Mercury is Insoluble

Thus, raindrops, running water and moisture are not good sinks for mercury vapor.

Mercury is Affected by Temperature

Mercury vaporizes more easily as temperature rises; at high temperatures essentially all mercury will exist as a vapor.

Chemical and Physical Properties of the Mercury

Atomic Number: 80
Group: 12
Period: 6
Series: Transition Metals
Molecular weight of mercury: 200.59.
Color: silver-white (liquid metal); tin-white (solid mercury)
Physical state: heavy, mobile, liquid metal; solid mercury is ductile, malleable mass, which may be cut with knife.
Melting point: -38.87 °C
Boiling point: 356.72 °C
Density at ° C: 13.534 g/cm^3 at 25 °C
Odor: Odorless
Solubility:
Water: 0.28μmoles/L at 25 ° C
Solubility:
Organic solvents: Soluble in H_2SO_4 upon boiling in lipids, readily soluble in HNO_3, insoluble in HCL; soluble in 2.77mg/L pentane
Partition coefficients:
Log K_{ow}: 5.95
Log K_{oc}: no data
Vapor pressure: 2x 10^{-3} mm Hg at 25 °C

Degradation reaction rate constant: Gas phase reaction with O_3 =1.7×10^{-18} cm^3/mol/s; 8×10^{-19} cm^3/mol/s
Auto ignition temperature: Not flammable
Flash point: Not flammable
Flammability limit in air: Not flammable
Conversion factors:
ppm (v/v) to mg/m^3 in air at 25 ° C:1ppm= 8.18mg/m^3
mg/m^3 to ppm (v/v) in air at 25 o C: 1mg/m^3=0.122ppm
Explosive limits: non-combustible
Valence states: +1, +2

Chapter no :2

Environmental Fate of Mercury: Cycling & Transformation in the Environment

All substances undergo cycling and transformations in the environment, but this is particularly so for mercury. Mercury's ability to exist in several physical states and chemical forms at commonly-encountered conditions of temperature and pressure, and propensity to undergo biological transformations, means that it is subject to complex and difficult-to-predict changes in concentration and form. Environmental monitoring studies thus must consider a variety of physical changes, geochemical reactions, and biochemical interactions in an attempt to understand the specific local conditions that contribute to mercury levels found in different environmental media and living things.

Mercury released into the environment can either stay close to its source for long periods, or be widely dispersed on a regional or even worldwide basis. Mercury concentrations in seawater, air and in human hair are higher in the northern hemisphere than the southern hemisphere (Mitra, 1986). The greater industrialization in the north is probably responsible for the higher levels; the stratospheric air circulation system leads to the re-deposition of pollutants from the mid-latitude industrial northern hemisphere in the same hemisphere.

Although the precise compositions will vary based on the locations sampled, in general, greater than 50% of the total amount of mercury in air exists in the elemental form, with a few percent attributable to particulate ore and the remaining percentage being comprised of a variety of other mercury compounds (Johnson and Braman, 1974). Atmospheric mercury concentrations have been measured in industrial, rural, residential, and aquatic areas. Levels are higher over industrial areas. Estimates of the residence times of various forms of mercury in the atmosphere vary from about five to ninety days (Airey, 1982; Mitra, 1986) to as long as three years (WHO, 1990). Atmospheric mercury concentrations over Greenland, polar regions and the open ocean exhibit little variation, indicating that anthropogenic, or human-caused, sources contribute to the higher levels found over the continental landmass areas (Mitra, 1986).

The vaporization rate of mercury approximately doubles for every 10 degrees Centigrade increase in temperature. The saturation level of mercury in air increases logarithmically with increasing temperature. Thus, seasonal, daily and latitudinal changes in ambient air levels occur (Mitra, 1986).

Evidence consisting of before-and-after measurements suggests that rain washes some mercury out of the atmosphere (Fogg and Fitzgerald, 1979). However, in industrial zones that use mercury or where mercury is a by-product of manufacturing, more mercury may be precipitated by dry fall-out than by rainfall (Dams et. al., 1970). Rain is more effective at removing particulate mercury than mercury vapor, because raindrops, running water and moisture are not good sinks, or storage media, for elemental mercury.

The presence of mercury in snow fields in Greenland indicates that snow also removes mercury from the atmosphere (Weiss et. al, 1971). Mercury enters soils by way of rain and snowfall, dry fallout from the atmosphere, the disposal of sewage sludge, improper disposal of mercuric hazardous wastes (formerly much more common than at present), landfilling of solid waste, and the agricultural use of mercury-containing pesticides.

Ionized forms of mercury are strongly adsorbed (held by surface particles) by soils and sediments and is desorbed (released) slowly (Mitra, 1986). Clay minerals adsorb mercury maximally at pH 6. Iron oxides also adsorb mercury in neutral soils. In acid soils, most mercury is adsorbed by organic matter. Microbial activity may then metabolize some part of the mercury, releasing it into the soil gas. When organic matter is not present, mercury becomes relatively more mobile in acid soils, and evaporation to the atmosphere or leaching of mercury to groundwater occurs (Mitra, 1986).

Once released to the atmosphere, mercury is distributed to the earth's surface including soils, wetlands, lakes, and oceans. It can then undergo chemical transformations including oxidation, reduction, methylation, and demethylation. Biological processes play an important part in these transformations; depending on local conditions, bacteria may ultimately convert some of the deposited mercury to methyl mercury, which is taken up by organisms through ingestion and absorption (Press & Siever, 1978).

METHYLATION OF MERCURY

- Methylation, the addition of ($-CH_3$) may occur in water, sediments or soil. Fish accumulate methyl mercury directly from the water in which they live or from prey.

- In water and sediments the amount of methylation is affected by:

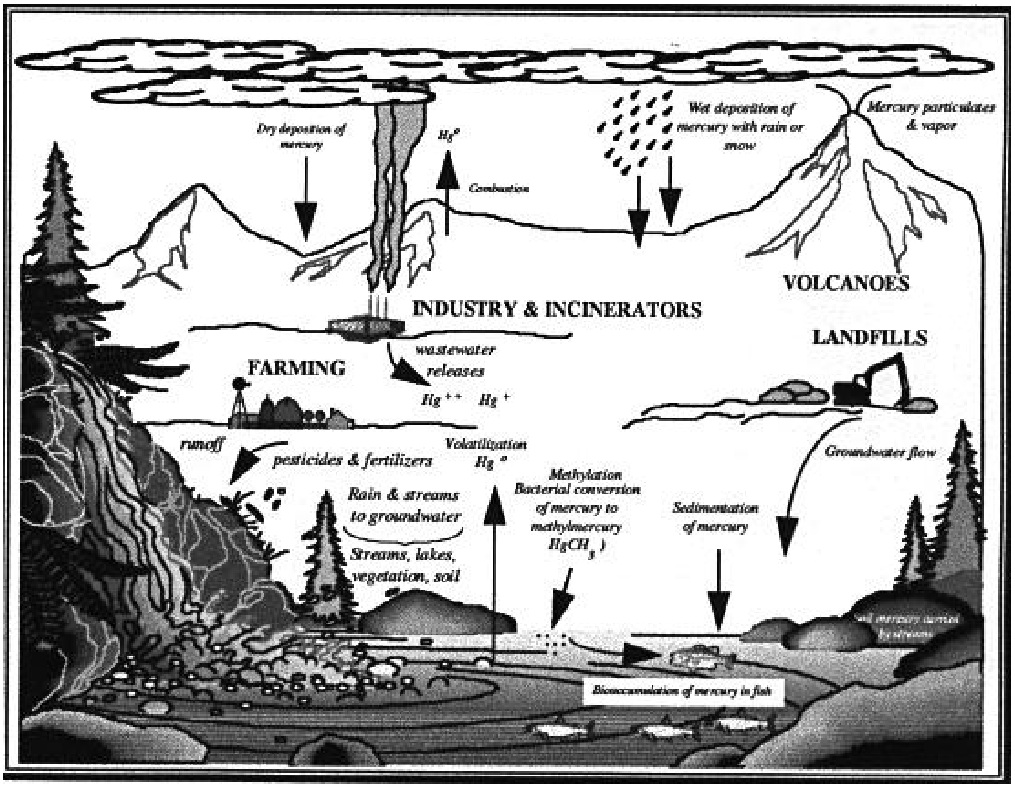
    1. the amount of dissolved oxygen present;
    2. the amount of sulfur present;
    3. the pH of the water or sediment; and,
    4. the presence of particles of clay or organic material.

- Where the amount of oxygen is limited, as in deeper layers of the surface water or sediments, more methyl mercury is formed. The presence of sulfur may be important because it is thought that sulfate-dependent bacteria are involved in the methylation process. Low pH is associated with an increase in methylation. (This means that methylation may occur more readily in water affected by acid rain.) If clay particles are present in the water, the mercury may attach to the particles, and may not be as available for methylation.

- Methyl mercury may also be formed in soil. As in lakes, rivers, or sediments, the oxygen and sulfur levels and the pH may affect the amount of methylation that occurs. Methyl mercury formed in the soil may be transported to surface water as runoff and ultimately enter lakes, ponds or the ocean.

The concentrations of different forms of mercury found in soil, water, or air, or in living things, is the result of the amount of releases, how they have been transported, and how the mercury is transformed. Figure 2-2 displays the overall process of cycling of mercury through the environment.

Cycling and Transformation of Mercury in the Environment



Erosion, rainfall and leaching transport mercury from land surfaces to streams, lakes and oceans. Streams that cut through mercury deposits contribute elevated amounts of mercury to the stream environment. Thermal springs and mine drainage also contains significant amounts.

While it circulates in the environment and changes its form, mercury is persistent and is not biodegradable. It tends to accumulate in sediments - in rivers, streams, lakes and the ocean. Mercury can even accumulate in sewer pipes which can lead to long-term releases of mercury to municipal wastewater that may continue even after the original source has been eliminated.

Mercury can thus be hard to control, once released. Furthermore, once present in a biological system, mercury can be passed up the food chain, "bioaccumulating" (increasing its concentrations) accordingly. Larger, older individuals build it up in their tissues with increasing age and thus the total concentration of mercury in a higher predator can be substantial. Because of mercury's combined qualities of potential toxicity, environmental persistence, and potential for bioaccumulation, this metal is a particularly insidious and difficult pollutant to manage.

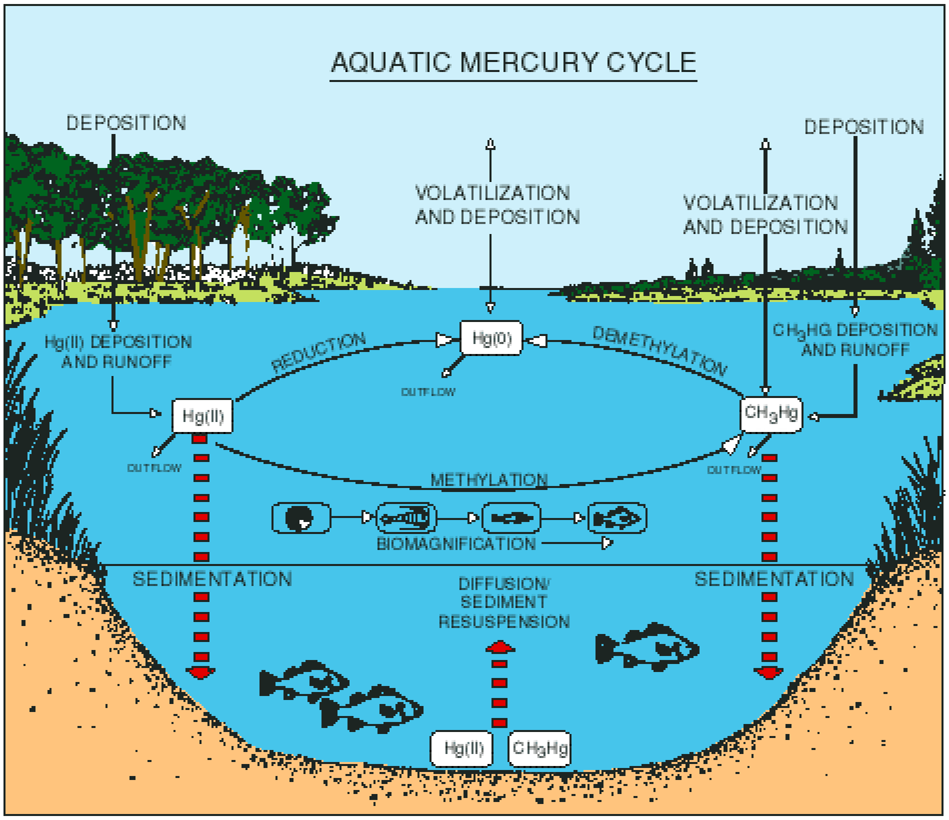


Figure 6. *Mercury cycling pathways in aquatic environments are very complex. The various forms of mercury can be converted from one to the next; most important is the conversion to methylmercury (CH_3Hg^+), the most toxic form. Ultimately, mercury ends up in the sediments, fish and wildlife, or evades back to the atmosphere by volatilization. Reprinted with permission from Mercury Pollution: Integration and Synthesis. Copyright Lewis Publishers, an imprint of CRC Press.*

Bioaccumulation:

Like many environmental contaminants, mercury undergoes bioaccumulation. Bioaccumulation is the process by which organisms (including humans) can take up contaminants more rapidly than their bodies can eliminate them, thus the amount of mercury in their body accumulates over time. If for a period of time an organism does not ingest mercury, its body burden of mercury will decline. If, however, an organism continually ingests mercury, its body burden can reach toxic levels. The rate of increase or decline in body burden is specific to each organism. For humans, about half the body burden of mercury can be eliminated in 70 days if no mercury is ingested during that time. Biomagnification is the incremental increase in concentration of a contaminant at each level of a food chain

Mercury (Hg) biomagnifies from the bottom to the top of the food chain. Even at very low input rates to aquatic ecosystems that are remote from point sources, Biomagnification effects can result in mercury levels of toxicological concern.

This phenomenon occurs because the food source for organisms higher on the food chain is progressively more concentrated in mercury and other contaminants, thus magnifying bioaccumulation rates at the top of the food chain. The bioaccumulation effect is generally compounded the longer an organism lives, so that larger predatory game fish will likely have the highest mercury levels. Adding to this problem is the fact that mercury concentrates in the muscle tissue of fish. So, unlike organic contaminants (for example PCBs and dioxins) which concentrate in the skin and fat, mercury cannot be filleted or cooked out of consumable game fish. Bioaccumulation

Mercury is accumulated by fish, invertebrates, mammals, and aquatic plants and the concentration tends to increase with increasing trophic level (mercury biomagnifies). Although inorganic mercury is the dominant form of mercury in the environment and is easily taken up, it is also depurated relatively quickly. Methylmercury accumulates quickly, depurates very slowly, and therefore biomagnifies in higher trophic species. The percentage of methylmercury, as compared to total mercury, also increases with age in both fish and invertebrates.

Uptake and depuration rates vary between tissues within an organism. Partitioning of mercury between tissues within aquatic organisms is influenced by the chemical form of mercury and route of exposure (ingestion or via the gills). Due to its preferential uptake, ability to be transferred among tissues, and slow depuration, most of the mercury in fish muscle tissue (Å99%) is methylmercury.

Marine mammal tissues have some of the highest concentrations of mercury found in all marine organisms, with the liver generally having the highest total mercury concentration. Although many juvenile and adult marine mammals primarily feed on fish, which contain high percentages of methylmercury, high concentrations of inorganic mercury are found in adult specimens. Apparently, adult marine mammals can mineralize methylmercury into inorganic mercury. Juvenile marine mammals have lower concentrations of total mercury than adults; but unlike fish and invertebrates, the percentage of methylmercury is higher in juvenile mammals.

Invertebrates generally have a lower percentage of methylmercury, as compared to total mercury, in their tissues than do fish and marine mammals. The percentage of methylmercury in invertebrates varies greatly and can range from one percent in deposit-feeding polychaetes, to close to 100% in crab.

Bioconcentration factors (BCFs) reflect uptake from water in laboratory experiments. BCFs for mercury are variable, with the highest factors determined for methylmercury. BCFs for methylmercury in brook trout range from 69,000 to 630,000, depending on the tissue analyzed. BCFs for inorganic mercury (mercuric chloride) in saltwater species range from 129 for adult lobster (Homarus Americanus) to 10,000 for oysters (Crassostrea virginica).

While sediment is usually the primary source of mercury in most aquatic systems, the food web is the main pathway for accumulation. High trophic level species tend to accumulate the highest concentrations of mercury, with concentrations highest in fish-eating predators. Mercury concentrations in higher trophic species often do not correlate with concentrations in environmental media. Correlations have been made between sediment and lower trophic species that typically have a high percentage of inorganic mercury, and between mercury concentrations in higher trophic species and their prey items. The best measure of bioavailability of mercury in any system can be obtained by analyzing mercury concentrations in the biota at the specific site

Chapter No: 3

Toxicity of Mercury

Human Health Effects

Mercury compounds are of concern because of their potential to act as poisons. A large amount of scientific data about mercury toxicity exists. Depending on the chemical form and the dose received, mercury can be toxic to both humans and wildlife. In people, toxic doses of mercury can cause developmental effects in the fetus, as well as effects on the kidney and the nervous system in children and adults (Stern, 1993; WHO, 1990; ATSDR, 1994). Wildlife such as bald eagles, kingfishers, otter and mink that feed on fish are particularly at risk because of the potential for methyl mercury to bioaccumulate in freshwater fish. Methyl mercury has a high bioconcentration factor which means that it will accumulate in living organisms such as fish.

Bioconcentration factors (BCFs) are simple ratios between the concentration of mercury in an organism and the concentration in the medium to which the organism was exposed (WHO, 1989). For methyl mercury , BCFs of from 10,000-100,000 have been reported.

In wildlife, mercury-related effects on the central nervous system and reproductive system have been reported (Heinz, 1976; Wobeser et al, 1976), effects consistent with those observed in humans.

The symptoms associated with mercury poisoning can be complex. In part, this is because mercury exists in a number of different chemical forms and the toxicity of each of these differs. Further complicating the picture is the fact that these forms can be converted from one to another in the environment and in the body. Thus, although the exact symptoms caused by mercury poisoning will depend on the precise chemical form involved, some overlap in symptoms can occur, especially at higher levels of exposure.

Mercury can be toxic when inhaled, eaten, or when placed on the skin. At low concentrations, it may seem to have no effect but signs of toxicity may develop later or become noticeable with continued exposure. Toxicity in humans is evidenced by loss of feeling or a burning sensation in arms and legs, psychological effects, loss of memory, loss of vision, loss of hearing, paralysis, congenital malformations, kidney toxicity, and death. Prenatal toxicity can result in a child with normal appearance at birth but who later exhibits a developmental delay in the ability to walk and/or talk. Because of the long latent period for observable effects, the need for treatment may be recognized too late.

The amount of mercury taken into the body largely determines whether health effects will occur following exposures. At very low exposure levels, such as those that might occur from mercury leaching from a modest number of amalgam dental fillings or from an exposure that might result from wiping up a spill from a small broken thermometer, no adverse effects are usually noted (note that vacuuming mercury can lead to more significant exposures; by breaking the mercury up into smaller droplets and increasing air flow over them, vacuuming can increase volatilization and dispersion of mercury and thus increase the potential for exposure).

At the other extreme, high-level exposures to mercury can cause serious effects or even be lethal. Several historical examples of epidemic mercury poisonings in other parts of the world, however, provide classic examples of investigative epidemiology and toxicology and serve to highlight the reasons why regulators are concerned about mercury.

For example, in a tragic episode in Iraq in 1971-1972, over 400 people died after ingesting large amounts of organic mercury in bread that was accidentally made with grain treated with a mercury-containing fungicide (Marsh et al, 1987; Bakir et al, 1973). In a second well known disaster which occurred from 1953-1960, many people living near Minamata Bay in Japan were severely poisoned by eating fish containing methylated mercury (Takeuchi, 1975; Tamashiro et al, 1985). In this case the bay was polluted by mercury from local industries, a practice now prevented by environmental regulations. Methyl mercury accumulated in marine organisms in the bay, including fish. These same fish were a primary source of food for many people in the area. In addition to many deaths, these exposures to mercury also caused a variety of other problems including neurological and developmental deficits in children exposed in the womb.

Effects on the brain and nervous system are frequently seen with high level exposures to mercury and can be quite severe. In the 18th century, mercury was used in the manufacture of fashionable felt hats. Workers involved in this trade handled mercury-laden skins and many were severely poisoned; while handling the furs, they would inadvertently inhale large amounts of mercury. These poisoned workers exhibited severe, and sometimes bizarre, psychological and behavioral symptoms. The term "mad as a hatter" was coined as a result of these poisonings.

Fortunately, exposures to mercury in the developed world in general, are well below those associated with such acute, severe effects. None-the-less, longer-term exposures to more modest levels of mercury can present unacceptable risks to susceptible groups including infants and fetuses.

In the United States a potentially significant route of exposure to mercury is from consumption of freshwater fish, which bioaccumulate methyl mercury, caught from contaminated waterbodies (certain larger predatory saltwater species such as shark may also contain elevated levels of mercury). Depending on how many contaminated fish one consumes, mercury exposures via this pathway can present a significant risk.

In contrast, inhalation exposures to mercury are generally not of concern since ambient air concentrations are typically low, ranging from 2 to 20 ng/m3 (ATSDR, 1993).

It is important to note that other potentially significant exposures to mercury can occur which is not related to environmental contamination. For example, exposures can occur in the home following accidental release of mercury or its intentional dispersion, as occurs during reported ceremonial/religious uses of this metal by certain groups of Caribbean descent including, for example, practitioners of Santeria and Espiritisimo, who may sprinkle elemental mercury around a dwelling or in an automobile to ward off evil spirits or to enhance positive forces. Some groups may also use mercury as a home remedy to treat certain ailments (Connecticut Department of Public Health, Division of Environmental Epidemiology and Occupational Health, personal communication).

ORGANIC MERCURY POISONING- CASES OF CONTAMINATION OF FOOD WITH HIGH LEVELS OF METHYL MERCURY

Descriptions and analyses of symptoms are found in reports of several poisoning episodes where foods became inadvertently contaminated with high levels of methyl mercury.

- In **Iraq**, seed grain treated with a methyl mercury pesticide was mistakenly used to make bread that was a major source of food. Methyl mercury concentrations in the bread were estimated to average approximately 9 milligrams per kilogram (mg/kg) or 9 ppm.

- In **Japan**, fish containing high levels of methyl mercury were a major food source. In Minamata Bay, Japan, estimated concentrations of methyl mercury in marine products ranged from 5.6 ppm to 35.7 ppm.
- In **the United States**, in Alamogordo, New Mexico, a farm family was poisoned by eating meat from a pig that had been fed grain treated with methyl mercury fungicide. Exposure in this case was likely to have been very high.

Adverse effects have been found to be persistent in survivors of all major epidemics of methyl mercury poisoning. Effects often developed long after the exposure had ceased.

In the Iraq epidemic and in the United States family exposed by eating pork, follow-up studies showed that serious effects (quadriplegia, mental defect, loss of vision, etc.) persisted for the duration of follow-up or until death. Mercury remained in the brain over this period of time as well.

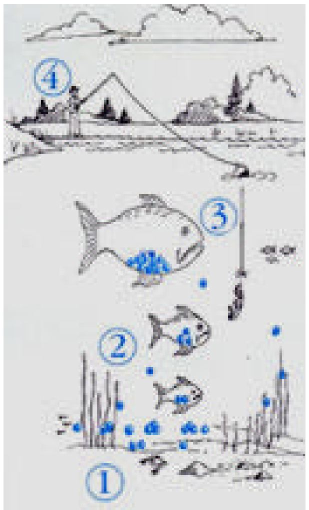
In both situations, methyl mercury had been ingested for as little as 3 months (at high levels). Medical attention, including chelation therapy, had been provided to the family in the United States.

In general, consumption of larger sized predatory fish from species such as largemouth bass will pose greater risks- because these fish are both older and at the top of the food chain they will have accumulated more methyl mercury than younger, smaller fish.

The exact mechanisms by which mercury enters the food chain remain largely unknown and may vary among ecosystems. Certain bacteria play an important early role. Bacteria that process sulfate (SO_4=) in the environment take up mercury in its inorganic form and convert it to methylmercury through metabolic processes. The conversion of inorganic mercury to methylmercury is important because its toxicity is greater and because organisms require considerably longer to eliminate methylmercury. These methylmercury-containing bacteria may be consumed by the next higher level in the food chain, or the bacteria may excrete the methylmercury to the water where it can quickly adsorb to plankton, which are also consumed by the next level in the food chain. Because animals accumulate methylmercury faster than they eliminate it, animals consume higher concentrations of mercury at each successive level of the food chain. Small environmental concentrations of methy-lmercury can thus readily accumulate to potentially harmful concentrations in fish, fish-eating wildlife and people. Even at very low atmospheric deposition rates in locations remote from point sources, mercury biomagnification can result in toxic effects in consumers at the top of these aquatic food chains.

The cycle of mercury in nature is complex. This illustration summarizes how methylmercury accumulates at the higher levels of the food chain and becomes concentrated in fish and animals that eat fish.

1. Methylmercury in the water and sediment is taken up by tiny animals and plants known as plankton.



2. Minnows and juvenile fish eat large quantities of plankton over time.
3. Larger predatory fish consume many smaller fish, accumulating methylmercury in their tissues. The older and larger the fish, the greater the potential for high mercury levels in their bodies.
4. Fish are caught and eaten by humans and animals, causing methylmercury to accumulate in human tissues.

The health risks of mercury at low levels of exposure remain uncertain and this is an area of considerable ongoing scientific investigation and debate (ATSDR, 1994; Stern, 1993; Marsh, et al 1995a; 1995b; Weiss, 1995). Fetuses, infants and small children, however, appear to be particularly sensitive to mercury. For prenatal exposures, effects may not be apparent at birth but may only reveal themselves later in childhood as delays or deficits in language, cognitive and motor skill development. Current research suggests that potentially important neurological and behavioral effects may be caused by exposures of a fetus to methyl mercury during pregnancy (ATSDR, 1994; Stern, 1993; WHO, 1990).

However, it is important to re-emphasize that the precise level at which demonstrably adverse effects occur remains highly uncertain. Two recent studies of children exposed to mercury via fish consumption have yielded conflicting results regarding the hazard posed by mercury in fish. In both studies, children living on islands where fish are regularly eaten were studied. No clearly adverse effects were reported among approximately 1,500 Seychelles islander children who were studied to the age of 5.5 years (NeuroToxicology, V16, 1995). In publications on this study, the mercury concentrations of the fish consumed were not specifically given but they are reported to have been generally below levels deemed to be of concern by the USFDA (presented at the Boston Risk Assessment Group (BRAG) seminar on May 8, 1996 by Dr. Philip Davidson one of the lead authors of the Seychelles Island mercury study). In any case, although reassuring in that clearly adverse effects were not seen, the reported results of this study must be interpreted cautiously. First of all, new analyses of the data suggest potentially deleterious effects may have occurred among some children (Dr. Philip Davidson, BRAG seminar, 1996). Secondly, the study has yet to be completed; additional assessments of the children, including tests that are more sensitive indicators of neurological effects, remain to be analyzed and/or completed. Further complicating this issue is a second study soon to be published, which has been reported to have detected significant effects in 1,000 children exposed to mercury and, potentially, other contaminants in the Faroe Islands.

Ecological Effects of Mercury

Many more studies have been published on the effects of mercury on human health than on its effects on ecosystems. Ecosystems encompass the functional relationships between organisms and their physical environment. They include energy flow through food chains, and pathways through which chemical elements essential to life move through a complex network (Ehrlich & Ehrlich, 1970). Groups of living organisms interact within an ecosystem, giving it a certain amount of resilience to stress. If, for example, mercury is present in an ecosystem at high enough levels to cause the local extinction of eagles that live on fish, another predator species may assume the eagles' place on the food chain. The ecosystem persists, but the populations within it are less diverse, and possibly less specialized. Contaminants with a global distribution like mercury may cause impacts over a widespread geographic area.

The study of ecosystem effects of mercury typically has been reduced to studying its effects on individual species. Published studies generally fall into two categories: laboratory investigations and field studies. Laboratory studies tend to focus on individual species and show that organisms can absorb mercury compounds from their food as well as directly from the water, soil or sediments in which they live. Aquatic invertebrates bioconcentrate mercury at a much higher rate than fish, and plants have variable rates of bioconcentration depending on the species.

Effects of mercury on organisms in the laboratory do not directly correspond to field effects. Natural conditions introduce many variables that confound results. For instance, sediments can partition mercury from the water, lessening exposure to organisms in the water column. Changing temperatures and pH levels affect bioconcentration as well. The spectrum of other chemicals that occur in nature affect mercury interactions with sediments, water and organisms (WHO, 1989). In spite of these limitations, such studies do, however, provide insight into the types of effects mercury may cause in wildlife and their potential magnitude.

Mercury is accumulated by aquatic organisms of all types and, in its methylated form, is the most common contaminant in freshwater fish (ATSDR, 1994; USEPA, 1992). Fish kills have occurred in cases of severe mercury contamination, such as occurred in Minamata Bay in Japan. Freshwater microorganisms can also be very sensitive to mercury contamination.

Field studies indicate that tissue concentrations of mercury in marine and freshwater fish increase with size. Monitoring of winter flounder, lobster and bivalves from coastal Massachusetts shows that mercury levels in these marine species are lower than concentrations in freshwater fish (Schwartz, et. al. 1995). Marine predators, particularly those that grow to large sizes, such as sharks, have been found to exhibit high mercury levels. Marine species that do not grow to large sizes and have short lives (e.g. many flounder) are generally lower in mercury than predatory freshwater species.

The long-term ecological effects of elevated mercury in fish are not presently known. In theory, the effects could be critical to the survival of species whose diet consists mainly of other fish.

Fish-eating birds have higher concentrations of mercury than other birds. Studies of mercury in feathers from Maine eagles, conducted by the United States Fish and Wildlife Service (USFWS) show that coastal eagles have a lower body burden of mercury than eagles that live inland and feed on freshwater fish. In areas where methyl mercury fungicides are used, seed-eating birds and small mammals and their predators can have high mercury concentrations (WHO, 1989).

Environmental Monitoring of Biological Effects

Extensive studies of mercury in the aquatic environment are underway at colleges and universities throughout the world. In the United States, a large number of studies are also supported by private industries and conducted by environmental consultants. State and federal environmental agencies support and conduct environmental monitoring studies. Many large ecosystems are presently being studied. For example, the Great Waters Study represents a concerted effort led by USEPA to assess the quality of large water bodies in the United States; mercury is one of several chemicals being considered. The International Toxics Monitoring Program investigates mercury in waterbodies in eastern Canada and New England. The Everglades, the Great Lakes, Lake Champlain, the Chesapeake Bay, large areas in Alaska, the Rocky Mountains and the Canadian Shield are additional examples of places where ecosystem-scale mercury monitoring projects have been initiated. Government agencies on the federal and state levels, scientists, and students from colleges and universities often join forces to perform these studies.

Tissue concentrations of mercury in fish and invertebrates are extensively available in the literature. Associated sediment and water quality data are also often available. Assessment of trophic pathways by means of radioisotope tagging is a recent trend in monitoring strategies. Aquatic studies are well-developed due in part to human exploitation of fish as a food supply. The National Study of Chemical Residues in Fish, published by USEPA's Office of Science and Technology, reports mercury detection in fish tissue at 92% of the 388 test locations. Measured concentrations ranged up to 1.77 parts per million, with 2% of the sites greater than 1 part per million. Most of the higher concentrations were in the Northeast (USEPA, 1992).

Terrestrial studies of mercury in the environment include studies of birds, mammals, invertebrates, soil microorganisms, plants, air and soils. A multitude of terrestrial investigations have been conducted on mercury in birds. Tissue mercury concentrations, often organ-specific, are widely available. Feathers are often used to measure mercury levels, thereby sparing the bird; evidence shows that significant adverse effects may occur at levels as low as 13 parts per million (WHO, 1976).

Studies of mercury levels in Maine eagles have been conducted by the US Fish and Wildlife Service. Data from these studies (Linda Welch, US Fish and Wildlife Service, personal communication) indicate that inland eagles have high levels of mercury in their feathers (an average of 20 parts per million, and as high as 37 parts per million in six to eight week-old fledgling eagles). The 'background" level in feathers is estimated to range from 2 to 3 parts per million. Mercury in eggs was greater than 0.5 parts per million in some cases. More than 0.5 parts per million of mercury in eggs is considered sufficient to prevent hatching. Freshwater fish make up 75% of the diet of inland eagles. Coastal eagles show much lower levels of mercury in feathers and eggs, suggesting that their prey along the coast of Maine contain lower concentrations of methyl mercury.

Testing Massachusetts eagles for mercury is underway in conjunction with the highly successful program to reestablish these raptors in the Quabbin Reservoir area, conducted by the Massachusetts Division of Fisheries and Wildlife. No effects of mercury have been observed, but mercury sampling is not far enough along to offer insights into possible effects on the health and fitness of eagle populations (Bill Davis, MA Division of Fisheries and Wildlife, personal communication). The population of eagles in Massachusetts is young, so perhaps the birds have not lived long enough to bioaccumulate significant levels of mercury.

One of the leading causes of death in eagles is collisions with buildings, cars, power lines, and the like. It has been proposed that an excess of mercury, which can lead to neurological impairment, may have contributed to an observed increase in eagle collisions in recent years, although other factors such as an increase in the absolute numbers of eagles in more highly developed regions of the country are also likely to be involved (Kenneth Carr, US Fish and Wildlife Service, personal communication).

Small mammal studies in the laboratory and in field situations demonstrate that mammals are particularly vulnerable to mercury, probably due to its neurotoxic effects and the high trophic position of mammals in the food chain. Mink show sublethal effects on a diet containing 5 to 10 ppm mercury, including loss of balance and coordination, anorexia, and weight loss (Wren et. al., 1987). Some of the test animals died. Small mammals sampled from fields sown with mercury-treated grain also died. Mercury poisoning was suspected as the possible cause of death of at least one Florida panther, and environmental mercury may have contributed to the severe population decline experienced by this endangered wild cat (Roelke, 1990).

Plants have also been studied for mercury accumulation. Sensitivities were species-specific, but in general, plants accumulate mercury as readily as other organisms. Aquatic plants are more efficient accumulators than terrestrial plants (John, 1972; WHO, 1989).

Terrestrial invertebrates also concentrate mercury. This observation has led to the suggestion that earthworms be used as a means to bioremediate soils contaminated with mercury (WHO, 1989).

Assessing the amount of the risk to human and ecological health from exposure to mercury, especially where organisms such as large fish and other species high on the food chain concentrate mercury, is central to determining the needed level of control of mercury emissions.

Toxicokinetics of Mercury

Exposure to mercury can occur through inhalation, ingestion or dermal absorption. the amount of mercury absorbed by the body -and thus the degree of toxicity - is dependent upon the chemical form of mercury. For instance, ingested elemental mercury is only 0.01% absorbed, but methyl mercury is nearly 100% absorbed from the gastrointestinal tract. The biological half-life of mercury is 60 days. Thus, even though exposure is reduced, the body burden will remain for at least a few months. Elemental mercury is most hazardous when inhaled. Only about 25% of an inhaled dose is exhaled. Skin absorption of mercury vapor occurs, but at low levels (ex. 2.2% of the total dose). Dermal contact with liquid mercury can significantly increase biological levels. The primary focus of this article is elemental mercury, since that is the form of exposure to health care workers involved with mercury-containing instrument accidents.

In the human body, mercury accumulates in the liver, kidney, brain, and blood. Mercury may cause acute or chronic health effects. Acute exposure (i.e., short term, high dose) is not as common today due to greater precautions and decreased handling. However, severe acute effects may include severe gastrointestinal damage, cardiovascular collapse, or kidney failure, all of which could be fatal. Inhalation of 1-3 mg/m3 for 2-5 hours may cause headaches, salivation, and metallic taste in the mouth, chills, cough, fever, tremors, abdominal cramps, diarrhea, nausea, vomiting, tightness in the chest, difficulty breathing, fatigue, or lung irritation. Symptoms may be delayed in onset for a number of hours.

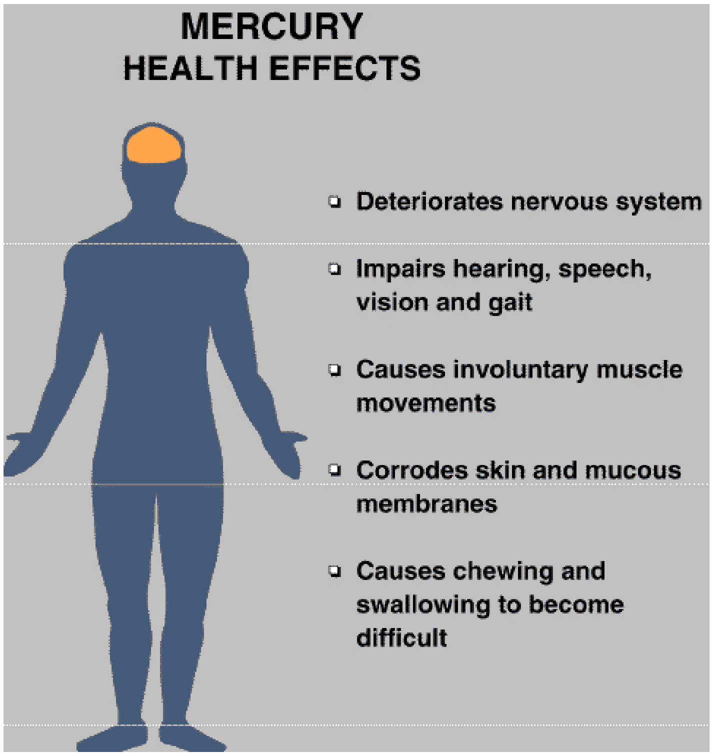
Chronic effects include central nervous system effects, kidney damage and birth defects. Genetic damage is also suspected.

***Nervous system effects*:** These are the most critical effects of chronic mercury exposure from adult exposure as they are consistent and pronounced. some elemental mercury is dissolved in the blood and may be transported across the blood/brain barrier, oxidized and retained in brain tissue. Elimination from the brain is slow, resulting in nerve tissue accumulation. Symptoms of chronic mercury exposure on the nervous system include: Increased excitability, mental instability, tendency to weep, fine tremors of the hands and feet, and personality changes. The term "Mad as a Hatter" came from these symptoms which were a result of mercury exposure in workers manufacturing felt hats using a mercury-containing process.

***Kidney effects*:** Kidney damage includes increased protein in the urine and may result in kidney failure at high dose exposure.

Birth defects: Neurologic damage from methyl mercury. The manifestations of mild exposure include delayed developmental milestones, altered muscle tone and tendon reflexes, and depressed intelligence.

Mercury exposure in children can cause a severe form of poisoning termed acrodynia. Acrodynia is evidenced by pain in the extremities, pinkness and peeling of the hands, feet and nose, irritability, sweating, rapid heartbeat and loss of mobility.



The most prevalent effects observed after human exposures to mercury in its three most prevalent forms:

- Metallic mercury
- Inorganic mercury
- Organic (containing carbon) mercury compounds.

The mode of entry of these forms of mercury into the body, their distribution within the body, and the conversion of one form to another by metabolic processes in the body all influence the type and extent of toxicity observed. These factors are discussed below.

Fate of Mercury after Contact

The toxicity of a chemical is determined by the dose or amount taken into the body. The specific effects further depend on the amount or concentration that reaches specific organs, such as the brain or kidneys that are sensitive to poisoning by the chemical. Factors that affect the amount of mercury reaching an organ are the rate at which it enters the bloodstream (its absorption efficiency) through the skin, the lungs or the gastrointestinal system; the rate at which it is distributed to the different body organs; and changes in its chemical structure that may occur in the different organs due to metabolism.

Mercury can exist in several different forms: metallic mercury, the type found in many thermometers, has no electrical charge (it is neutral); inorganic mercury is positively charged at a level of either +1 or +2; organic mercury is a complex of mercury with carbon containing compounds. Both the charge and chemical form of mercury affect how it is absorbed and transported in the body. Uncharged mercury can move into cells readily; mercury that has a charge is largely prevented from passing across barrier membranes such as the blood brain barrier and the placenta, unless it is carried through as part of another molecule. Organic mercury compounds can accumulate in living organisms such as fish.

The distribution and toxicity of mercury in the body is complex since any one of the three chemical forms can be changed to all of the others.

- Metallic mercury (Hg+0) can be changed to positively charged inorganic forms ($Hg+^1$ ands $Hg+^2$) as a result of a chemical process known as oxidation.
- Inorganic forms of mercury can be changed to metallic mercury by a process called reduction or can be combined with a carbon atom (as the carbon in a methyl group $-CH_3$) to form organic mercury compounds.
- Organic mercury compounds can themselves be metabolized so that the carbon is removed from the mercury.

In the body, conversion to the charged, inorganic form predominates but other transformations can occur.

Each chemical form of mercury produces a specific set of toxic symptoms. Complex patterns of effects may be observed, however, due to conversions of the initial form into the others in the body. For example, inorganic mercury (positively charged form) is highly toxic to the kidney. Since it is charged it does not readily pass through the blood brain barrier and thus is less toxic to the brain. Inorganic mercury is itself not readily transformed into the uncharged forms in the body. In contrast, metallic and organic mercury can more readily cause brain damage since they can pass through the protective blood-brain barrier. At high exposure levels the favored conversion of these forms of mercury to the inorganic form cannot sufficiently minimize the toxic accumulation of mercury in the brain. These compounds can also cause kidney toxicity in part because they are readily transformed to inorganic mercury in the body. Thus, exposure to all three forms of mercury can result in kidney toxicity while brain toxicity is not commonly seen following exposures to inorganic mercury.

Extent of absorption of mercury after contact by different routes

Form of Mercury	***Extent of Absorption by Route of Contact***		
	Ingestion	**Dermal Contact**	**Inhalation**
Metallic (e.g. the form in thermometers)	Very low for liquid form	Moderate for vaporized form	High for vaporized form
Inorganic (e.g. sometimes used in health and beauty products)	Low to moderate (higher in infants and children)	Low to moderate	Low to moderate
Organic (e.g. methyl Hg; the predominant form found in fish)	High	Low to moderate	High

Fate of Mercury in the Body

Fate of mercury in the body

Form of Mercury	**Mercury Retained in:**	**Transformed to other forms:**	**Whole body half-life *(months)***	**Excreted primarily in:**
Metallic	Kidney *(most)* Brain Fetus Liver	Inorganic *(generally favored)*	1 to 2	Feces *(most)* Breath Urine
Inorganic	Kidney *(most)* Liver (Brain if high intake results in large amounts being transformed)	Metallic and Organic (generally less favored)	1.5 to 2	Urine *(most)* Feces Hair Milk
Organic *(methyl compounds)*	Kidney *(most)* Brain Fetus Liver Muscle	Inorganic (generally favored)	2 or 4	Feces *(most)* Urine Hair Milk

Metallic mercury

Exposure to metallic mercury is primarily to vaporized mercury in industrial settings with some exposure to vaporized dental amalgam and to liquid mercury from spillage in the home. Spillage at home may occur if a mercury containing thermometer or thermostat is broken; the silvery metallic mercury will evaporate. As a vapor, it is well-absorbed into the blood and highly toxic when either inhaled or in contact with skin.

In the blood, metallic mercury may remain in plasma where it can be transported to organs such as the brain. It may also enter red blood cells, where it is readily transformed to the inorganic form. Inorganic mercury can either return to the blood plasma and combine with carrier proteins there or remain in the red blood cell.

Inorganic mercury does not readily enter or pass out of the brain nor do appreciable amounts pass between a pregnant woman's blood and blood of the fetus. Thus, metallic mercury that is transformed to inorganic mercury in either the brain or the fetus accumulates there. Mercury may also accumulate in the kidney as a result of its binding to sensitive tissue sites.

Other chemicals in the body can alter the rate of transformation from metallic mercury to inorganic mercury and the distribution to different body organs. Ethanol inhibits the conversion and seems to be protective against the accumulation of inorganic mercury in the brain. Results of studies on exposed human populations which use alcohol cannot be used to predict tolerable exposure levels for populations which have little or no alcohol intake (such as young children).

After absorption, the vaporized metallic mercury is excreted in the breath with trace amounts going to urine and feces. Once transformed to inorganic mercury, excretion is through urine and feces. After it is absorbed into the body the amount of metallic mercury present is reduced by half every 1-2 months (half-life). Larger amounts of mercury in the body (body burdens) take longer to be removed than smaller amounts. Different organs release accumulated mercury at different rates; brain and kidney have been found to retain mercury for a lifetime.

Inorganic mercury

Inorganic mercury can occur at two charge levels: mercuric ($Hg+^2$) and mercurous ($Hg+^1$). Both are toxic to humans, but effects of the doubly charged form tend to be more severe.

Absorption after ingestion is appreciable for both forms; ingestion and entry through the skin are the main ways inorganic mercury enters the body. Accidental poisoning from ingestion and skin application has been reported as a result of long-term use of mercurous compounds sometimes found in health and beauty preparations including some laxatives, skin-lightening creams, and baby teething powders.

Once absorbed into the bloodstream, inorganic mercury combines with proteins in the plasma or enters the red blood cells. It does not readily pass into the brain or fetus but may enter into other body organs. The liver is a major site of metabolism for mercury, and all mercury absorbed from the stomach and intestine is carried in blood directly to the liver. Inorganic mercury is transformed at a relatively low rate to both metallic and organic forms, allowing for the possibility of toxic effects from these forms following high level exposures to inorganic mercury. Some of the inorganic mercury may also be combined with other chemicals in liver bile; it is then carried in bile to the intestine and excreted in feces. If it leaves the liver in the bloodstream, it can then go to other organs, including the kidney. In the kidney, much of the plasma mercury is quickly absorbed into the kidney and excreted in urine. However, some may bind to cells in the kidney, persisting there for even a lifetime. Mercury in blood may also be transferred to breast milk or deposited in hair.

The concentration of inorganic mercury in the kidney is directly related to the amount taken in. The concentration of mercury in urine is usually measured to estimate the extent of a recent exposure.

While as much as 90% of ingested inorganic mercury can be unabsorbed and thus excreted within a few days of exposure, the half-life of the portion that is absorbed is approximately 2 months.

Organic mercury

Organic forms of mercury used, as pesticides have been previous sources of widespread exposure of both humans and wildlife. Presently, human exposure is primarily due to eating foods containing methyl mercury, such as fish and shellfish. Human consumption of fish eating predators (some bird species, raccoons, and aquatic mammals such as seals and whales) results in a higher exposure rate since mercury is concentrated in their tissue after they eat contaminated fish and shellfish.

Methyl mercury in food is almost completely absorbed into blood. Once absorbed, most methyl mercury is transferred to the red blood cells; the rest is bound by carrier molecules in the plasma. This distribution is relatively stable so the concentration in blood is a useful indicator of the extent of a recent or ongoing exposure.

Because of the retention in red blood cells, methyl mercury in blood is slowly transferred to other organs; this transfer continues even after ingestion of contaminated food ends. Mercury absorbed into the bloodstream from the stomach and intestine goes to the liver, where it may be metabolized to inorganic mercury (and subsequently excreted as described above); combined with bile chemicals directly and excreted; or, combined with bile chemicals and reabsorbed from the intestine. This recirculation between intestine and liver continues until the organic mercury is excreted or released from the liver into the bloodstream.

Methyl mercury in the bloodstream can enter the brain and cross the placenta. Once in these and other organs, methyl mercury can be metabolized to other inorganic forms that become concentrated in the brain or fetus. Thus, even when blood mercury levels are decreasing, concentrations in the brain and fetus may still be high or even be increasing. Methyl mercury also persists in muscle tissue; because of this, ingestion of animals which have taken in methyl mercury can result in methyl mercury poisoning.

Methyl mercury is also transferred from blood to milk and hair. The concentration of mercury in milk is lower than in the mother's plasma, and most of the mercury in milk is in the inorganic form. In contrast, mercury is concentrated in hair, the ratio of hair methyl mercury to blood methyl mercury ranging from 200 to 1 to 300 to 1. The hair concentration can be used as an indicator of previous mercury exposures, for example during pregnancy, even if there were no obvious signs of exposure at the time of occurrence.

For most people, a period of approximately two months is required to clear half of an absorbed quantity of methyl mercury from the body. However, this may require about 4 months in some people, possibly because of genetic differences. This prolonged retention could put these people and their fetuses at greater risk of toxic effects.

Treatment of mercury poisoning by modifying its fate in the body

The chemical form, extent of exposure and entry into the body, the rate of change from one form to another, and the rate of removal from the body all affect the type and severity of symptoms seen after mercury poisoning. In general, medical treatment immediately after exposure involves the removal of mercury from blood by the administration of substances which will bind mercury and carry it out of the body. This form of treatment is know as chelation therapy. If treatment is delayed until mercury is concentrated or trapped in sensitive organs (e.g., the brain and the fetus), attempts to remove it will not be successful.

This type of treatment may not be protective in those who are exposed to high concentrations of mercury since it could cause release of mercury from less sensitive organs to blood; once in blood, there is a risk of mercury being transported to more sensitive tissues such as the brain.

Other therapeutic approaches utilize substances that bind mercury in the intestine so that it does not enter (or re-enter) the blood. This may be useful in speeding the removal of methyl mercury which is cycling between the liver and the intestine. Mercury in the brain is not appreciably removed by either approach.

Toxic Effects of Mercury

Mercury can be toxic when inhaled, eaten, or when placed on the skin. At low concentrations, it may seem to have no effect but signs of toxicity may develop later or become noticeable with continued exposure. Toxicity in humans is evidenced by loss of feeling or a burning sensation in arms and legs, psychological effects, loss of memory, loss of vision, loss of hearing, paralysis, congenital malformations, kidney toxicity, and death. Prenatal toxicity can result in a child with normal appearance at birth but who later exhibits a developmental delay in the ability to walk and/or talk. Because of the long latent period for observable effects, the need for treatment may be recognized too late.

With respect to the potential for mercury compounds to cause cancer considerable uncertainty exists. In spite of the large numbers of people exposed to mercury epidemiological studies addressing the carcinogenicity of mercury are relatively few and are limited in their ability to detect an effect due the small numbers of people actually studied in any one investigation; possible exposures to other carcinogens and poor mercury exposure information also limit the confidence in these studies. Overall these human studies have not demonstrated a clear association between mercury and cancer. Additional research in this area is clearly needed. In addition to a sparse database on humans, relatively few cancer studies have been performed under standard laboratory procedures. Those studies which have been completed suggest that exposure to inorganic forms of mercury might increase kidney, fore stomach, thyroid, and lymphoid tissue tumors in some rodents. Animal studies also suggest that organic mercury compounds may cause kidney tumors at high levels of exposure where significant kidney toxicity occurs.

At this time the USEPA has proposed to classify methyl mercury and inorganic mercury as EPA Group C compounds (possible human carcinogens). Metallic mercury was deemed to be not classifiable due to insufficient data (EPA Group D). These classifications are currently under review.

Limited evidence suggests that mercury may decrease the body's defenses against cancer cells and infectious agents by depressing the immune system. Other studies have demonstrated the ability of mercury to cause chromosomal effects, an outcome that is frequently associated with transformation of normal cells to cancer cells. Further work on this aspect of mercury toxicity is needed.

When exposure is limited to one form of mercury, a characteristic set of toxic effects usually appears. However, as each chemical form can be metabolized to the others, a subset of clinical signs related to other forms can appear if high enough concentrations in the body are reached.

Toxicity of Metallic mercury

Metallic mercury toxicity is most usually a result of exposure to the vaporized form. A brief exposure to a high concentration in air results in toxicity to the lung--chest pain, bronchitis, pneumonitis. If the air concentration is lower, there may be no early signs of toxic effects because the vaporized mercury is cleared from the lungs to the blood or by exhaling. Poisoning from inhaled metallic mercury can also occur after a chronic low level exposure. Three cardinal signs of this type of exposure are excitability (erethism), tremors, and gingivitis.

Excitability and tremors are results of the deposition of mercury in the nervous system. There is a rapid transfer of the vaporized form from blood to the brain; transformation of metallic mercury to the inorganic form in the brain results in accumulation. Both forms may be toxic while in the brain. Unsteadiness and tremor when trying to move or to hold objects (intention tremor) and various manifestations of excitability can develop after a long latent period.

Organs and functions affected after exposure to various forms of mercury

Toxic effects	**Vaporized Metallic Mercury**	**Inorganic Mercury**	**Organic Mercury (Methylated)**
Prenatal exposure effects in nervous system	Yes (limited data from animals)	Yes *(animals)*	Yes
Postnatal exposure effects:			
Nervous system	Yes	Yes	Yes
Kidney	Yes	Yes	Yes
Cardiovascular system	Yes	Yes *(animals)*	Yes *(animals))*
Gastrointestinal system	Yes	Yes	Yes
Lungs	Yes		
Muscle	Yes		Yes
Liver	Yes		
Blood cell count	Yes		
Skin and eyes	Yes	Yes	Yes
Fertility	Yes	Yes	Yes
Immune system	Yes	Yes (animals)	Yes (animals)
Genetic	Yes	Yes	Yes
Pancreas			Yes (extensive data from Japan populations)
Thyroid	Yes (limited data)		
Cancer		Yes (limited data from animals)	Yes (limited data from animals)

The unsteadiness is seen most dramatically when the patient is asked in the clinic to hold both arms out to the side for three minutes. The patient is unable to do so, and will begin to flap the arms to relieve the stress (seagull sign). The psychological signs include insomnia, loss of appetite, shyness, emotional instability, and memory loss. Some reversal of these effects may occur upon removal from contact with mercury. With continued exposure, more severe tremor and muscle spasms as well as death may result.

Literature reports of incidents of mercury vapor toxicity include another type seen mainly in children--acrodynia (also known as Swift's disease or pink disease). In this disease, which occurs infrequently even among children exposed there is weight loss, loss of appetite, irritability, muscle weakness, learning disorders, and redness (hence "pink") and peeling of skin on fingers and toes. Children have most frequently shown these symptoms when calomel (a substance containing inorganic mercury) was used as a soothing agent on their teething rings. The same symptoms have been seen in children exposed to mercury vapor from contaminated floors or carpeting. Since the symptoms from inhaled mercury were accompanied by high urinary excretion rates and were the same symptoms as seen after calomel exposure, it may be that they were related to the transformation of metallic mercury to the inorganic form. It is thought that these signs may be the result of an autoimmune reaction against tissue containing mercury.

Studies of workers exposed to mercury have found that tremors and an abnormal walking gait occurred after chronic (1-5 years) exposure to 0.076 mg vaporized mercury per cubic meter of air. Mild tremors occurred at 0.026 mg/cu.m. Immune deficiency occurred in those exposed to as little as 0.106 mg/cu.m. (effects summarized by ATSDR). These numbers indicate that the toxic effects of inhaled mercury can occur at low concentrations.

A current epidemic of metallic mercury poisoning is going on now in the Amazon Rain Forest (described in Branches et al., 1993) among native people employed as gold miners. In Brazil alone, over a million miners are directly exposed to mercury vapors in the gold extraction process. Many others are exposed in the refinement and working of gold contaminated with mercury. Both sets of workers display signs of metallic mercury toxicity and excrete mercury in urine, but the gold shop workers have higher blood levels. Medical investigators studying these workers suggest that they may suffer increased levels of exposure resulting from vaporization of mercury as the contaminated gold is heated indoors.

The exposed miners and gold workers studied to date have all been adult men. No instances of exposed pregnant women have been described. In one case an individual studied, who did not work with gold at all, was found to have had a high blood mercury level. It was subsequently discovered that he lived above a gold shop and was almost certainly poisoned by mercury vapors from that source. Since these residents are also part of the exposed population and could include pregnant women, future investigations may extend to these families.

Toxicity of Inorganic Mercury

Inorganic mercury toxicity can result from ingestion or direct skin contact with inorganic mercury or it can occur as a result of transformation of metallic mercury to inorganic mercury in the body. Poisoning has also resulted in the past when mercury containing calomel was used on teething rings; when mercury soaps and creams were applied as skin lighteners; or when laxatives containing inorganic mercury were taken chronically. Somewhat different signs of toxicity result depending on whether the mercury is in the mercuric ($+^2$) or mercurous ($+^1$) form.

Taken in a high dose (over 10 percent in water), mercuric chloride produces severe abdominal cramps, bloody diarrhea, and suppression of urine. Death of important tubule cells in the kidney also occurs after exposure to this form of mercury. Loss of these cells results in kidney malfunction including release of essential plasma proteins into urine (albuminuria) and excessive retention of water in the body tissues (edema). Death can result from shock and kidney failure within 24 hours, but if the patient is otherwise stabilized and placed on dialysis, the kidney may eventually repair itself using the surviving cells.

Ingestion of lower concentrations of mercuric chloride in water or food can result in an autoimmune reaction to kidney cells altered by exposure to mercury. The first signs are an inflammation of the glomerulus (the location where plasma fluids are filtered to the urinary tract); the body then further reacts immunologically to the degraded cells, causing further damage.

Mercurous compounds are less toxic than mercuric compounds. Calomel (mercurous chloride) was used in medicine; placed on gums of teething children to reduce pain; and was used as a skin lotion. Adverse responses to this form of mercury is thought to result from an immune reaction in the skin. Symptoms include a reddish skin and rash (leading to the common name of "pink disease"), fever, swollen lymph nodes and spleen, and peeling hands and feet. Mercurous compounds have also been used in the treatment of syphilis, as purgatives, and as both internal and external disinfectants. Toxicity and even death, generally as a result of kidney failure, have resulted from long-term use or misuse of these substances. Current regulations on prescription drugs and consumer products have decreased this type of exposure.

Toxicity of Organic Mercury

Poisonings by organic mercury have occurred primarily as the result of contamination of food with methyl mercury. Extensive descriptions and analyses of symptoms have been described in reports on several widespread poisoning episodes where foods became inadvertently contaminated with high levels of methyl mercury. Studies have also been made of people exposed to more modest levels of methyl mercury in food. Some of the more extensive documentation of mercury effects in people include studies on populations in the following regions:

- Iraq (Bakir, et al., 1973), where grain treated with a methyl mercury pesticide was mistakenly used to make bread that was a major source of food;

- Japan (Takeuchi, 1975), Canada (McKeown-Eyssen et al., 1983 reports) and New Zealand (Kjellstrom, et al. 1986, 1989) where fish containing methyl mercury was a major food source;

- The Faroe Islands (Grandjean et al., 1992; Dalgard, 1994), where mercury containing fish and whale meat are important sources of food;

- The Mediterranean Basin (Franchie et al., 1994) where fishermen and their families are exposed to varying amounts of mercury from fish;

- The United States (Davis et al., 1994) where a farm family was seriously affected by eating meat from a pig that had been fed methyl mercury treated grain.

In all cases, the severity of symptoms was increased when the food was either more highly contaminated or eaten in larger quantities. In adults, the first signs of toxicity included abnormal sensation (tingling or numbness) in arms and legs. This effect was correlated with a cumulative intake of 25-40 mg methyl mercury and 5 ug of mercury in a gram of hair (hair to blood ratio of approximately 250 to 1). An average daily intake of 3-7 ug methyl mercury per kilogram body weight could be expected to produce such effects. Other early effects included blurred vision and a general feeling of malaise.

At higher mercury exposure levels and correspondingly higher body burdens, additional symptoms appeared. These included: loss of coordination of gait (ataxia); slurred speech (dysarthria); loss of peripheral vision; loss of hearing; coma; kidney failure; loss of memory; abnormal blood sugar; and quadriplegia. Symptoms were due to toxic effects on the brain, peripheral nerves, pancreas, immune system, and kidneys. In addition, in some people, genetic changes were observed in lymphocytes, suggesting that such changes could also occur in other tissues, including the reproductive organs.

The evidence from numerous epidemiological studies indicates that the fetus is very sensitive to mercury. The children of women exposed to methyl mercury during pregnancy may show signs of toxic effects either at birth or later in childhood. Some mothers who had a hair concentration of 6 ug of mercury per gram of hair (6 ug Hg/g hair) or higher during pregnancy had children who, compared to those not so exposed to mercury, started walking and talking later in life and who scored lower in tests designed to measure other physical and mental development. Children whose mothers had even higher maternal exposure levels (hair mercury concentrations of up to 400 ug/g), were affected with a greater frequency and suffered more severe symptoms. These included mental retardation, cerebral palsy and a high degree of irritability and sensitivity to touch.

Comparison of the doses needed for adult toxicity and fetal toxicity is difficult since the fetus preferentially accumulates methyl mercury; the ratio of mercury in fetal blood to maternal blood is about 5:1. Thus, the fetus is exposed to a greater overall concentration of methyl mercury than the mother. Additionally, there may also be a greater rate of transfer of mercury to the brain in the fetus. Pregnant women may there for show little if any adverse effect following mercury exposure but still have an affected child.

Because methyl mercury is secreted into breast milk, nursing infants of mothers exposed to mercury only after pregnancy can also be exposed to methyl mercury. Children exposed in this way have been shown to have methyl mercury in their blood; since few children were observed in these studies, and none followed through full development to adults, it is not possible to determine the effects of this type of exposure. Available data, however, suggest that effects of exposure after birth are less severe than effects from a prenatal exposure.

Adverse effects have been found to be persistent in survivors of all major epidemics of methyl mercury poisoning. In the Iraq epidemic and in the United States family exposed by eating pork, follow-up studies showed that serious effects (quadriplegia, mental defect, loss of vision, etc.) persisted for the duration of follow-up or until death; mercury remained in the brain over this period of time as well. In both situations, methyl mercury had been ingested for as little as 3 months (at high levels); medical attention, including chelation therapy, had been provided to the family in the United States.

Because of the seriousness of the effects associated with methyl mercury poisoning, their insidious onset, and the persistence of symptoms, environmental and public health professionals have focused their efforts on preventing exposures, especially of the fetus. As early as 1976, the World Health Organization (WHO, 1976) recommended that no more than 0.3 mg total methyl mercury be ingested per week. Other agencies have recommended limits for allowable daily intakes of mercury in its various forms or have set limits for concentrations in air, water, food, and other environmental media. A recent evaluation of data on methyl mercury resulted in the suggestion that the reference dose (the daily dose likely to be without significant adverse effects) for a chronic (long-term) exposure to this organo-metal should be somewhat lower than the previous value recommended by the USEPA (Stern, 1993). This and other data on mercury intake were evaluated by USEPA which recently lowered its recommended reference dose to 0.1 ug/kg/day from its earlier value of 0.3 ug/kg/day.

It is important to note, however, that the hazard of low doses of mercury, especially attributable to fish containing methyl mercury, is a matter of considerable controversy.

Chapter No: 4

Natural and Anthropogenic Sources of Mercury

There are many sources of mercury inputs to the biosphere. Natural sources are significant contributors, clearly greater than man-made inputs in some areas, especially those where high concentrations of mercury exist in surficial ores. The contribution of mercury to the biosphere associated with human activities is a matter of great debate. In part, this is because it is difficult to separate mercury that was originally derived from past human releases from new natural inputs. In any case, many scientists believe that the flux of human-derived mercury into the atmosphere is at least on par with, and probably exceeds, by up to two- to four-fold, natural sources of this metal (Terry Haines, University of Maine; USEPA, 1991; Hovart, 1993; USEPA, 1995). Reports that the typical mercury content of lakes has increased by two- to seven times since industrialization (Nriagu, 1979; Swedish, EPA, 1991), and that the deposition of mercury has increased significantly in the mid-continental United States (Swain et. al. 1992) support this contention.

Natural Sources of Mercury

Mercury is a naturally occurring element that is present in trace amounts throughout the environment. Much of it is isolated in coal and other geological deposits.Mercury is one of the natural elements that make up our solar system. It is present in the sun, solar winds and solar flares and has been detected in meteorites and moon rocks (Mitra, 1986). On the earth, naturally occurring mercury deposits are generally found as Cinnabar (HgS) and this is the most important mercury ore. The mercury content of cinnabar exceeds is 86% this vermilion-red sulfide mineral ore occurs in quantity at relatively few locations (Mitra, 1986). Its associations with recent volcanic rocks and hot springs suggest a deep crustal or mantle source.

CINNABAR (Mercury Ore) DEPOSITS

Important mining localities include:
Almaden, Spain; Idria, Yugoslavia; Huancavelica, southern Peru

In the United States, large deposits occur in:
New Almaden, California New Idria, California.

Minable quantities of cinnabar are found in:
Nevada; Utah; Oregon; Arkansas; Idaho; Texas

No deposits of cinnabar have been identified in Massachusetts. (Hurlbut & Klein, 1977). However certain shales and granite that are found have higher than average levels of mercury.

Inorganic mercury occurs in small amounts in many rocks. Granite contains about 0.2 parts per million (ppm) mercury (Press and Siever, 1978). Other crustal rocks generally contain less than half that amount. The mercury in rocks steadily contributes small amounts of this metal to the atmosphere and natural waters by ordinary weathering processes. Volcanic sources also disperse mercury vapor into the atmosphere. Atmospheric mercury levels measured at Kilauea and Mauna Loa volcanoes in Hawaii commonly show the same order of magnitude as Icelandic volcanoes, between 10 and 25 micrograms per cubic meter (µg/m3). Normal values in air (Mitra, 1986) are about 3 nanograms per cubic meter (ng/m3).

Soils and sediments may also contain mercury. The mercury content of sedimentary rocks such as shale, which were deposited long before humans existed, signifies that at least some of the mercury in modern sediments is natural in origin. More recent sediments will also contain mercury derived from manmade sources.

Mercury leaches into surface and groundwater from natural sources, and it is distributed into the oceans through the mid-oceanic ridges and rift systems. Most natural waters contain a few parts per billion (ppb) mercury. Freshwater concentrations have been reported as high as 0.07 ppm (Hem, 1970). Some fraction of the mercury in natural waters may be converted to an organic form, methyl mercury which is the form most harmful to higher organisms (WHO, 1989).

MEASUREMENT OF CONCENTRATIONS IN AIR

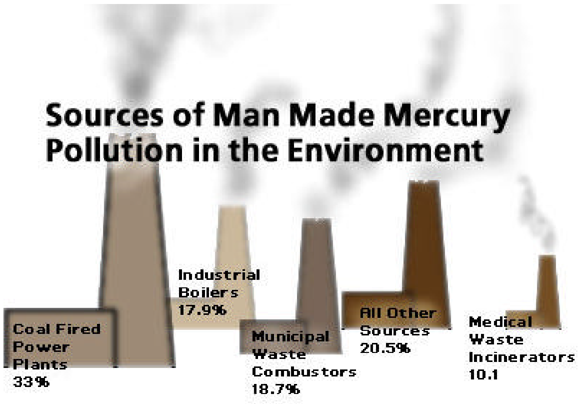
Concentrations of chemicals in air are measured in units of:

The mass of chemical (milligrams, micrograms, nanograms, or picograms) per volume of air (cubic meters).

1 milligram (mg) = 1/1,000 gram
1 microgram (µg) = 1/1,000,000 gram
1 nanogram (ng) = 1/1,000,000,000 gram
1 picogram (pg) = 1/1,000,000,000,000 gram

One cubic meter (m3) = 35.31 cubic feet.

Forest fires: can heat fuels from biomass that harbors concentrations of mercury from the biosphere to temperatures well above the boiling point of mercury (357 degrees C). The mercury can then be released into the atmosphere or decomposed. *Oceanic releases*: through the evaporation of elemental mercury from the ocean's surface.



Anthropogenic Sources of Mercury

The unique properties of mercury have resulted in a long history of use by the enterprising human race. The mercury ore cinnabar has been found smeared on Neolithic skulls. In about 2000 BC, mercury pigment was used on a tomb which was discovered on an island in the Mediterranean (Mitra, 1986). Today, its presence in batteries and thermometers establishes a place for mercury in every household.

Many thousands of tons of mercury have been mined during the past 50 years for use in electrical equipment, chemical processing plants, chlor-alkali plants, and pesticides. Mining essentially results in an accelerated weathering process, by which much more mercury than normal is released from rocks. Much of the mercury used in manufacturing subsequently escapes into natural waters and the atmosphere.

Mercury is used in a number of consumer and commercial products. Some of these products are more commonly recognized as containing mercury than others. Mercury is found in varying amounts in batteries, fluorescent and high intensity light bulbs, thermometers, thermostats, and light switches. Mercury is also used to make chlorine and caustic soda and certain types of dental fillings. Some paints and pesticides made in the United States used to contain mercury (as a preservative and fungicide) but no longer do as a result of voluntary and required bans. Thus, citizens, hospitals, dental offices, farmers, builders, and certain types of manufacturing operations all use and eventually discard products containing mercury into the municipal solid waste stream. Following disposal the mercury in these items may ultimately be released into a landfill or the atmosphere following combustion in a waste combustor .

The most obvious sources of mercury in biomedical research facilities are thermometers, blood pressure gauges, clinical reagents and laboratory chemicals. Mercury is used or present in many other items that may be less obvious such as drugs and biologics, fluorescent light tubes, switches and other electrical devices. It is also present as an unintended contaminant in a wide variety of commercial products such as animal bedding and bleach and may concentrate in plumbing. Dental amalgams may be another significant source of mercury in the environment

In addition to mercury emissions associated with disposal and incineration of municipal wastes, mercury is also released into the atmosphere by the burning of fossil fuels such as coal and oil, medical wastes, and wood. Releases also occur:

1. When products containing mercury, such as fluorescent lights, are broken;
2. From volatilization during laboratory and industrial uses;
3. During cremation of human bodies, due to mercury use in amalgam fillings; and,
4. In the purification, or roasting, of ores.

In addition to industrial activities, worldwide agriculture and mining have also contributed major amounts of mercury to soils, water and air.

Mercury often collects in plumbing systems in healthcare facilities and laboratories. Sometimes this occurs if mercury is poured down the sink (no mercury-containing waste should ever be disposed of in drains). However, more often it builds up in plumbing by slowly concentrating in biological films, sludges and other solids from the trace levels of mercury that are often present in wastewater. When these solids are dislodged, excessive levels of mercury may be discharged, violating local pollution control limits.

Air monitoring and deposition studies for mercury have been performed primarily in rural locations. These generally show vapor phase mercury to be in the 1 to 10 ng/m3 and particulate mercury to be 10 to 100 picograms per cubic meter (pg/m3). This indicates that, in rural areas, vapor phase mercury is likely to constitute from 95 to 99% of the total with the remainder being particulate phase mercury. A study being conducted in the Lake Champlain Basin, Vermont, has estimated an annual wet deposition of 15 micrograms per square meter (µg/m2).

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Sources of Mercury

Intentional Use			**Incidental Release**	
Producing or Supplying Mercury	**Use in Manufacturing*** (products contain mercury or processes use mercury)	**Waste Disposal** (mercury- containing products or wastestreams)	**Manufacturing Processes** (raw materials contain mercury)	**Energy Production** (fuel source contains mercury)
Primary Mercury Production (by-product of gold mining) **Secondary Hg production** (mercury recovery) **Mercury Compound Production** **Government Stocks** • National Defense	**Chemical and Allied Products** Chlorine/Caustic Soda Lab Uses Paint **Other Chemical and Allied Products** Catalysts Pesticides Pharmaceuticals **Electric and Electronic Uses** Electric Lighting Wiring Devices & Switches Battery	Municipal Waste Incinerators Commercial/Industrial Waste Incinerators Sewage Sludge Driers & Incinerators Wastewater Treatment (POTWs) Hazardous Waste Incinerators Landfills Ash disposal facilities Auto salvage/scrapyards	Carbon Black Production Carbon Black Production Coke Production Petroleum Refining Lime Manufacturing Portland Cement Manufacturing Phosphate-based fertilizer production	Utility Boilers Commercial & Industrial Boilers Residential Boilers and wood stoves

Stockpile (primary mercury) • Dept. of Energy stocks (secondary mercury) **Imports**	Manufacturing **Instruments and Related Products** Measuring & Control Instruments Dental Equipment & Supplies Hospitals, Dentists	Crematories		production Copper Smelting & Refining Non-ferrous Metals Smelting	

The Anthropogenic Sources of Mercury

Industrial products: mercury is used in more than 2000 industries and products. These include: thermometers, fluorescent lamps, mirrors, gold/silver extraction, batteries, dental amalgams, lubricants, dyes,floor wax, fabric softeners, chlorine bleach, etc. that leach into the soil and ultimately reach groundwater aquifers.

***Coal-fired Power plants*: ** Mercury is oxidized (as the flue gas cools & exits the plant) to its water soluble ionic form.Incinerators and coal-fired plants emit more mercury than any other point source of unregulated mercury emissions in the U.S.

***Gasoline and Oil combustion*: ** Mercury is vaporized through the combustion of crude oil. Vehicles release the greatest amount of mercury this way.

***Smelting*: ** Mercury is released into the atmosphere in the smelting of ores to yield pure metals.

Chlor-Alkali Plants: Elemental mercury is used as the electrode in electrochemical production of chlorine gas and caustic soda.

Mildew Suppression, Laundry facilities: Mercury is used to suppress mildew by laundry facilities. However, this source should become less problematic due to the US EPA ban of mercury used as a fungicide in interior latex paints.

Sewage Treatment: Mercury is concentrated in sewage sludge. Secondary treatment of water does not fully treat/remove inorganic dissolved contaminants, thus it can be released into the soil and/or into the atmosphere if it is dried up.

Mercury dumping from naval vessels: Mercury is used as ballast in its subsurface vessel fleet, and during inter-ship ballast transfer operations, elemental mercury is occasionally spilled into marine waters. This can result in the contamination of both sediment and water.

Overall, the pH and the alkalinity of water can affect the concentrations of mercury in a water body. Methyl mercury is produced, transported and accumulated by aquatic organisms significantly more efficiently at low alkalinity and pH.

Salinity can also impact mercury concentrations. For example, as runoff into the SF bay increases and the salinity decreases, the concentration of dissolved mercury increases. In addition, sulfate concentrations in water can impact microbial methylation of mercury. There is a window of sulfate concentration that promotes the highest mercury methlation rate (opt. Hg by SRB in sediments is at 200-500 mM.).

In **aquatic sediments**, mercury and other metal contamination is most strongly correlated with the proportion of fine particles. Aerobic and Anaerobic micro environments can affect oxygen metabolism and sulfur metabolism. Oxygen rich environment. (upper sed) can favor O2 metabolism and oxygen poor environment. lower sed) can favor sulfur metabolism, producing Hgs and CH_3Hgs

Uses of mercury

Desirable properties such as the ability to alloy with most metals, liquidity at room temperature, ease of vaporizing and freezing, and electrical conductivity make mercury an important industrial metal. In 1973, U.S. consumption of mercury was 1900 metric tons. Primary among its over 3000 industrial uses are battery manufacturing and chlorine-alkali production. Paints and industrial instruments have also been among the major uses. Until paint manufacturers agreed to eliminate the use of mercury in interior paints, 480,000 pounds of mercury in paints and coatings were produced each year.

Some Common uses of mercury:

- Barometers
- Catalysts And Pigments
- Cells for Caustic Soda and Chlorine Production
- Dental Amalgams
- Electrical Instruments
- Fungicides/Preservatives (most uses now banned)
- Investment Casting

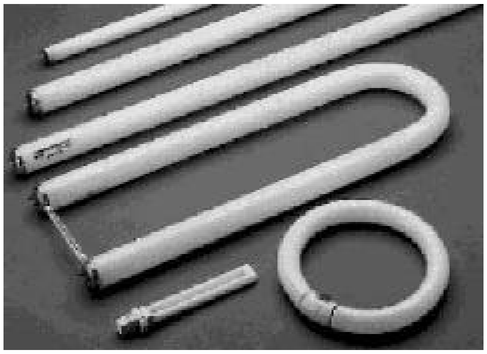
- Laboratory Reagent
- Manometers
- Medicines
- Mercury Vapor Lamps
- Metal Plating
- Photography
- Synthetic Silk
- Solder
- Tanning and Dyeing
- Textile Production
- Thermometers
- Use In Boilers/Turbines For Electricity Generation

HISTORICAL USES

- Felt Hat Manufacturing
- Paints
- Pesticides

Mercury has many applications in the industry due to its unique properties, such as its fluidity, its uniform volume expansion over the entire liquid temperature range, its high surface tension, and its ability to alloy with other metals. However domestic consumption of mercury has shown a downward trend since 1970's. In 1995, consumption was 463 metric tons, down 10% from 1994. The largest commercial use of mercury in the U.S was for electrolytic production of chlorine and caustic soda in mercury cells, accounting for 35% in domestic consumption. Manufacture of wiring devices and switches account for 19% domestic consumption. Manufacture of wiring devices and switches accounted for 19% and dental equipment and supplies used 7% (USGS1997). Due to the high toxicity of mercury in most of its forms, many applications have been canceled as a result of attempts to limit the amount of exposure to mercury waste.

Electrical Applications:



Mercury is a critical element in alkaline batteries. In the past, excess amounts of mercury were used in batteries; however, alkaline battery manufactures in Europe, Japan, and the United states are now reducing the mercury load from 0.1% - 0.0125% of battery content. This reduction will ultimately limit the amount of mercury needed in the battery industry to below 4 metric tons per year (Cole et al. 1992; Reese 1990). Mercuric oxide has become increasingly important commercially in the production of galvanic cells with mercuric oxide anodes in combination with Zinc or Cadmium cathodes. The voltage for these small, button-shaped batteries remains constant during discharge. The batteries are used in hearing devices, digital watches, exposure meters, pocket calculators, and security installations (IARC 1993). Some electrical lamps are efficient, long- lasting, and produce more lumens per watt than most other industrial lamps (Drake 1981). Wiring and switching devices, such as thermostats and cathode tubes, use mercury because of its predictable contact resistance, thermal conductivity, and quiet operation (Carrico 1985; drake 1981). In 1985, 64% of the mercury used in the United States was for electrical applications. This use had declined to 29% in1992 (IARC 1993).

Medical applications:

Metallic mercury is used in dental restorations because of its ability to alloy with other metals. The World health Organization (WHO 1991) has estimates that, in industrialized countries, about 3% of total mercury consumption is for dental amalgams. Based on 1992 dental manufacturer specifications, amalgams (at mixing) contain approximately 50% metallic mercury, 35% silver, 9% tin 6%copper, and trace amount of Zinc. Estimates of annual mercury usage by United States dentists range from approximately 100,000 kg in the 1970s to 70,000 kg in 1995. More than 100 million fillings are replaced each year in the United States (Lorcheider et al. 1995). Until 30 years ago, mercury compounds were used extensively in pharmaceuticals. Mercury salts were components of antiseptics, diuretics, skin lightning creams and laxatives. Organic mercury compounds were employed in antisyphilitic drugs and some laxatives. Phenyl mercury acetate was used in contraceptive gels and foams and as a disinfectant (IARC 1993). Since then more effective and less harmful alternatives have replaced most pharmaceutical uses of mercury. Medical equipment, such as thermometers, use metallic mercury to measure temperature and manometers, use metallic mercury to measure temperature and pressure (Carrico 1985).

Chemical/mining application:

Mercury is a catalyst in reaction to form polymers, such as vinyl chloride and urethane foams. The preparation of chlorine and caustic soda (NaOH) from brines also uses mercury as a catalyst. In this process, mercury is used as a moving cathode to separate sodium and chlorine (Rieber and Harris 1994). This mercury can be recycled with 95% efficiency (Drake 1981). Consumption occurs, as mercury is lost in wastewater treatment, is recaptured, reprocessed, and sent to landfills (Winship 1985). Gold mining operations use mercury to extract gold from ores through amalgamation (Carrico 1985).

Other applications:

Phenyl mercuric acetate has been used in aqueous systems such as links, adhesives, and caulking compounds, a catalyst for the manufacture of certain polyurethanes, and as a fungicide in seed dressings and interior and exterior paints (IARC 2993; Reese 1990).

Discontinued applications:

The use of phenyl mercuric acetate as a fungicide in interior latex paints was banned in 1990 (Reese 1990) and in interior paints was banned in 1991 (Hefflin et al. 1993). Both of these bans were used until the mid- 1970s as a treatment to disinfect grain seeds. Most of these agricultural applications of mercury compounds in bactericides and fungicides have been banned due to toxicity of mercury. Mercuric nitrate was used in the production of felt hats to hydrolyze rabbit fur. The use of mercury as a wood preservative has ceased due to the use of polyurethane (Drake 1981).

PRECAUTIONS FOR HEALTH CARE WORKERS

Substitutes for mercury-containing medical devices should be used whenever possible, e.g. thermometers and sphygmomanometers. When mercury devices must be used, special precautions should be taken. These devices should never be used on a cloth surface, such as upholstered chair or in a room with a carpeted floor. If a spill occurred in such an area, the upholstery or carpeting would need to be discarded as it could not be effectively decontaminated. Children should never be left unattended near these devices. If mercury thermometers are used, a mercury spill kit should be kept readily accessible. The kit should contain a sulfur powder to suppress volatilization and a collection device.

SPILL RESPONSE

If a spill occurs, evacuate the immediate area and ventilate as well as possible. An environmental consultant will need to be contacted for clean-up and disposal. Do not attempt to clean-up a mercury spill using rags or an ordinary vacuum. This will only serve to disperse the mercury and encourage volatilization.

DISPOSAL

The best method of mercury disposal is reclamation. Button batteries can be recycled at many jewelry stores and other retail outlets that sell batteries. Larger quantities of mercury will need to be disposed of by a licensed hazardous waste hauler.

ATSDR MINIMAL RISK LEVELS (MRLs)

April 2001

Name	Route	Duration	MRL	Factors	Endpoint	Final	Date	Case#
MERCURIC CHLORIDE	**Oral**	**Acute** **Int**	**0.007 mg/kg/day** **. 0.002 mg/kg/day**	**100** **100**	**Renal** **Renal**	**Final**	**03/99**	**007487-94-7**
MERCURY	**Inh.**	**Chr.**	**0.0002 mg/m3**	**30**	**Neural**	**Final**	**03/99**	**007439-97-6**

Chapter No: 5

Emission Control Requirements

Reductions of mercury emissions may be achieved by installing end-of-pipe controls (e.g. air pollution control devices) to capture mercury from an emission stream prior to its release. In addition, efforts can be made to reduce the amount of mercury actually entering the emission stream by source reduction efforts. Thirdly, capturing the mercury and recycling it may also effectively reduce its input to the general environment. State and Federal efforts to minimize mercury emissions have included a combination of all of these approaches.

Mercury emissions can be regulated on a national level by EPA by National Emission Standards for Hazardous Air Pollutants for stationary sources which should regulate mercury emission by processing mercury ore to recover mercury, use mercury chlor-alkali cells to produce chlorine gas and alkali metal hydroxide, and incinerate or dry wastewater treatment plant sludge. Wastewater sludge incinerators and dryers are the source categories, which should be regulated by these standards.

These limits should ensure that the public is not at risk of adverse health impacts from breathing the air and, should serve to limit total mercury emissions. Acceptable stack emissions using this approach should be established.

Mercury Source Reduction and Recycling

In addition to emission control requirements and limits, the legislative authorities should established policies to reduce the disposal of mercury as well as other toxic chemicals through recycling and source reduction. Consumer, medical and other commercial products together account for the largest overall share of mercury emissions in the country. The optimal "Environmental Control Technology" should be used for removing mercury found in these products in the first place. Reducing such mercury use can directly reduces the potential for emissions by product breakage as well as from product incineration or other disposal.

The legislative authorities should pass legislation aiming the removal of toxic heavy metals, including mercury, from the municipal waste stream, a significant overall source of mercury emitted from municipal waste combustors. These laws should focus on batteries and fluorescent lights, which can be identified as the two largest contributors of mercury to municipal solid waste. National action should also be taken on the sale of mercury-oxide button batteries. The reduction of the mercury can be achieved by taking some serious actions.

- Require battery manufacturers to reduce the mercury content in alkaline batteries;
- Ban the sale of mercuric oxide batteries;
- Ban the disposal of nickel-cadmium batteries; and,
- Require manufacturers to set up battery recycling programs.

In order to reduce environmental and public health risks it is important to educate the public about toxins and encourage the collection of specific materials containing mercury and other toxic metals such as cadmium.

The reduction of the mercury from the local community can be achieved by umplementing a proper plan under which button and nickel-cadmium batteries can be returned after use to their point of sale. In addition, the establisment of collection centers for spent fluorescent lamps can reduce the mercury pollution in the environment. The mercury and cadmium from collected batteries and fluorescent lamps can then be recycled rather than disposed of in municipal solid waste.

It is anticipated that recycling efforts will prevent a significant amount of mercury as well as other heavy metals from entering or landfills. Guidelines should be established for the collection, storage and transport of mercury containing batteries.

Batteries should also be collected from institutions such as hospitals, where mercuric-oxide batteries, which contain up to 40% mercury, are commonly used.

Fluorescent and other high intensity electric lighting fixtures also contain significant amounts of mercury. Makers of fluorescent lights can become a help to reduce the amount of mercury present in each bulb. There is increase in the sales and use of these bulbs, which has occurred because they use electricity more efficiently than incandescent bulbs. Such efficiency indirectly reduces several forms of air pollution, since less fuel is consumed to produce the needed electricity. Unfortunately, while energy savings are achieved, more mercury is ultimately used.

The recycling of fluorescent bulbs can become growing environmental business area which can prevent mercury from entering the general environment. Recycling and shopping for environmental friendly products are important facets in reducing mercury pollution. Each citizen of the country can help in these efforts by striving to buy only mercury-free batteries and by recycling batteries, fluorescent lights and other products that contain mercury.

Hospitals and other healthcare facilities use a variety of products that contain mercury, such as thermometers, blood pressure cuffs, fluorescent bulbs, batteries, laboratory chemicals and many cleaning products. The use of these mercury-containing items creates many pathways by which mercury may be released into the environment. The following are the three primary pathways:

- releases of mercury into the air by medical waste incinerators burning medical waste containing the chemical;
- the landfilling of mercury-containing medical waste; and,
- releases of the chemical into the wastewater stream.

Improper handling and disposal of mercury are common occurrences within hospitals. Once mercury is spilled, disposed of as solid waste or discharged to the receiving wastewater plant, the avenues into the environment are opened. Mercury is very mobile and persistent; it can easily make its way into the atmosphere, soil, groundwater and surface waters of local, regional and more distant areas. As a result, traditional methods of waste disposal are inadequate to deal with the problems associated with mercury use. Even mercury "captured" by costly air pollution control devices can make its way back to the atmosphere. Consequently, there is a need for a different approach when it comes to dealing with mercury and other deadly toxins.

Pollution prevention is any practice that reduces the use or generation of hazardous substances prior to recycling, storage, treatment or control. While recycling is a form of waste minimization that can reduce the volume of waste requiring disposal, it is *not* source reduction. Source reduction reduces and eliminates toxic substances such as mercury at the source. This approach is much better than addressing problems after they have been created through spills, improper transport handling and inadequate disposal and pollution control methods. It also allows hospitals to avoid the costs associated with expensive pollution control equipment, regulatory fines and potential legal battles.

The benefits of source reduction have become apparent to many of the industries targeted by this legislation, including the healthcare sector. The success stories highlighted in this report bear testament to the fact that pollution prevention is a logical, cost-effective and feasible approach to eliminating mercury pollution from healthcare sources.

In the Pollution Prevention the following five source reduction methods could be used:

1) Substitution of raw materials
2) Reformulation or design of products
3) Equipment or technology modifications
4) Process or procedure modifications
5) Improvements in housekeeping, maintenance, training, or inventory control (operational changes)

Hospitals can employ most of these methods to reduce the amounts of mercury used in their facilities. Examples include the following:

- creating and enforcing agreements with vendors to supply only mercury-free products as a means of controlling inventory and being environmentally responsible at the same time;

- using mercury-free thermometers as an equipment change that lowers the risk of mercury entering the environment;

- encouraging the use of mercury-free lab reagents as a process change that can bring the same diagnostic results yet be safer for the environment; and,

- using mercury-free cleaning products and checking lab coats and other work clothes for instruments or items containing mercury prior to washing as housekeeping improvements and operational changes that allow all staff to participate in keeping their facilities mercury-free.

Pollution prevention is a sound alternative to other forms of waste treatment and disposal, which are inadequate to deal with the problems associated with mercury use. Besides the obvious benefits highlighted, source reduction also goes a step further. It produces significant changes in behavior that often precede similarly significant changes in attitude. Once administrators and staff become involved in mercury pollution prevention, the importance of keeping mercury and other toxins out of their facilities and, consequently, the environment will become reinforced. In the future, instead of approaching the problem of pollution reactively, they will be inspired to take a proactive stance to new challenges.

Pollution prevention is an important issue that warrants serious consideration by hospitals and other healthcare facilities that contribute mercury to the environment. There are many ethical, scientific and economic reasons for converting to a mercury-free operation, and several hospitals have demonstrated this to be achievable and cost-effective.

Individuals interested in instituting mercury pollution prevention measures at their hospitals can ensure success by focusing on some basic yet important steps. The following steps are common to most successful mercury reduction and elimination plans:

- Spelling out the importance of mercury pollution prevention and highlighting the various cost and safety benefits associated with its implementation;

- Making an institutional commitment and extending it to all administrators and staff, especially key decision-makers within the facility;
- Keeping in mind the importance of planning, including the development of short-and long-term goals;
- Ensuring that staff in *all* departments are aware of the program, its goals and their responsibilities;
- Taking advantage of information that already exists and calling on local, state and federal regulators for materials and information assistance;
- Making manufacturers and vendors of healthcare products aware of their role in providing mercury-free products;
- designing plans with evaluation and measurement of results in mind, including tracking and communication strategies to ensure acknowledgment of successes; and,
- being patient and aware that a successful mercury pollution prevention program is a long-term undertaking.

By approaching mercury pollution prevention with these steps in mind, all parties involved can rest assured that they are playing an important role in protecting the health of local residents, the community and the environment

Mercury Sources and Alternatives

Departments	**Typical Use**	**Alternative Action**
Laboratories	stains, fixatives, reagents, and calibration solutions in the form of mercury chlorides and thimerosal*	chemical changes such as zinc formalin; process changes such as using poly vinyl alcohol for B5/Fixatives
Maintenance	flourescent lights; thermostats and leveling devices; electrical relays; and batteries	digital technology; energy efficient lighting; mercury-free batteries; and recycling of lights and batteries
Housekeeping	bleach solution containing sodium hypochlorite and thimerosal additives; caustic drain cleaners*	thimerosal-free products; organic oils and compounds
Surgery	esophageal dilator	silicone-filled dilator; tungsten-filled dilator
Patient Care Units	blood pressure units; thermometers	aneroid blood pressure units; digital thermometers

Information from Terrene Institute Publication - 1995 and personal communication

Examples of Biomedical Equipment that may contain Mercury and Alternative Equipment

Items were included on the following lists because they have been reported to contain mercury as an intentional ingredient or component, or as an unintended contaminant.

Category	**Application**	**Alternatives**
ANALYTICAL INSTRUMENTS (Mercury chloride as reagent)	Sequential Multi-Channel Auto-analyzer (SMCA) AU 2000	Ion Selective Electrode
AUTO-ANALYZERS	Autodelfia Iris Cotter Technicon H2 Hitachi Chem-Array Chem-IMX-1 Chem-IMX-2 Chem-654 Chem-Autodelfia Chem-SEC 6 HEME MDA	
BATTERIES Mercuric oxide Silver oxide Mercury zinc Mercuric oxide Zinc air Contaminant in other types of batteries.	Blood analyzers Defibrillators Fetal monitors Hearing aids Holter monitors Pacemakers Pagers Picker calibers Spirometer alarms Telemetry transmitters Temperature alarms	Lithium Zinc Low-mercury alkaline Note: Mercury content of alkaline, zinc carbon, silver oxide, zinc air is being reduced or discontinued
BLOOD GAS ANALYZER (Reference Electrode)	Radiometer (brand)	Equipment without a mercury reference electrode
CENTRIFUGES	Older models-may use mercury in balance cups	Non-mercury weights
DENTAL AMALGAMS (Capsules and waste)	Tooth restoration	Porcelain and polymeric materials
ELECTRON MICROSCOPE	Mercury used as vibration Damper	
HITACHI CHEM ANALYZER	Hitergent Reagent has 65 ppb mercury	
LEAD ANALYZER ELECTRODE	ESA (brand) model 3010B	

INTERVENTIONAL GASTROINTESTINAL -- ENTERAL DEVICES Esophageal Dilators (Maloney/Hurst Bougies) Cantor Tubes Miller Abbott Tubes Feeding Tubes	Mercury used as a weight	Tungsten, water. Used as weight, Anderson Tube can replace Cantor tube
SPHYGMOMANOMETERS	Monitoring blood pressure	Electronic vacuum gauge, expansion, aneroid
THERMOSTATS	Ovens (laboratories) Nursing incubators	Thermostat with bi-metallic strip Electronic
THERMOMETERS	Blood bank Clerget sugar test Body temperature Incubator/water bath Min/max	Electronic (digital) Non-mercury liquid filled

Steps to Reduce Mercury Sources and Risks

As has been discussed throughout this report, mercury compounds exhibit several characteristics that make them of great concern to environmental and public health agencies across the country. These include:

1. significant potential toxicity, especially towards fetuses;
2. persistence in the environment once released; and,
3. the ability of organic mercury to bioconcentrate into living organisms, most notably fish.

These traits have led to significant adverse environmental impacts by mercury, especially on freshwater ecosystems.

Because of these characteristics, national regulatory agencies, should initiate a number of efforts to reduce sources of mercury; to control mercury releases into the general environment; and to minimize risks attributable to mercury already in the environment. In order to reduce potential mercury impacts the following specific actions in the areas of source reduction; emission controls and risk reduction should be taken:

- Efforts should be made on those areas where controllable sources of this metal exist, through both reduced use of mercury and collection and recycling of products containing mercury, including batteries and fluorescent lights. Efforts to prevent mercury pollution will reduce environmental contamination in the future and thus reduce risks to people and wildlife. Elimination or reduction of mercury and other toxins in products promotes their safe recycling and reuse and decreases the need for disposal of hazardous wastes.

- Adoption of a Battery Collection and Recycling policy. The collection and recycling of these products. Collection of mercury containing fluorescent lights should also be encouraged.
- Legislation should be made to ban the sale of many mercury-added batteries in country and to require that manufacturers to provide for the collection and recycling of mercury containing button cell batteries.
- The management of solid waste, targeting a variety of hazardous materials, including mercury containing products from households and small businesses, for collection prior to disposal to landfills or combustion facilities. The efforts should include the development of informational materials to assist municipalities, small businesses and citizens in recycling mercury containing batteries and lights.
- Although most important, source reduction efforts will not eliminate mercury emissions. Thus, efficient end-of-pipe pollution control will still be needed.
- Continued environmental monitoring to identify waterbodies where fish contain unsafe levels of mercury and announcements of fish consumption advisories as appropriate.
- Public outreach efforts, to inform the public about the potential risks of mercury .
- Research into mercury sources and risks. This should includes completion of a study on the distribution and determinants of mercury in freshwater fish to better understand and predict potential areas of risk.

In addition to these regulatory actions there is much that individual citizens can do to reduce mercury pollution. As noted above much mercury enters the environment from the disposal of everyday household products. Consumers can significantly reduce such mercury pollution by buying mercury free batteries and recycling batteries, such as many button cells, that continue to contain mercury. For older household batteries, all button cell batteries and all imported batteries it is best to assume that they have mercury unless stated otherwise and to recycle them. Fluorescent and other high intensity light fixtures also contain mercury and should be recycled when possible.

Many other household products may also contain substantial amounts of mercury. In particular, older thermostats, thermometers, paints and some pesticides are likely to have significant mercury in them. These should be disposed of through your community's household hazardous waste collection program rather than into the trash.

There also some simple steps we can all take as individuals to minimize potential risks from mercury. Should products containing mercury (such as a thermometer) break it is important to carefully cleanup any spilled mercury (the silvery, liquid metal) and get the material and broken product out of the house. This should be done by scooping up the mercury droplets, which look like round spheres of silver liquid, gently into a container or vial using, for example, a cupped piece of paper as a scoop. The mercury should not be vacuumed! Vacuuming will break up the mercury into small particles and spew it into the air - even high efficiency vacuums cannot prevent the mercury from getting into the air. If you accidentally vacuum up mercury, immediately dispose of the vacuum bag.

By taking some simple steps, we can all help to minimize mercury pollution and the risks to human health that such pollution causes. Together, state, national and individual efforts are needed to address this problem. Many steps should be taken which can ultimately reduce the health risks posed by mercury, it is important to note that these efforts are unlikely to lead to immediate reductions of mercury concentrations in specific environments (e.g., lakes). In particular, concentrations of mercury in freshwater fish may not be reduced quickly. The persistence of mercury once released into the biosphere means that continued recirculation of mercury already emitted will occur for many years. This recirculation, combined with continuing inputs from natural sources, means that even successful efforts to control human-derived mercury releases may not result in detectable, short-term reductions in the concentrations of this metal in areas already affected. Discernible reductions may require many years to become evident and thus will require patience and perseverance.

Widespread industrial production of mercury, along with lack of careful handling and disposal practices, has contributed to environmental contamination.

In addition to the early workers in the cinnabar mines, modern workers in industries using mercury are at risk from overexposure. The Occupational Safety and Health Administration (OSHA) has been reviewing the current occupational exposure standard of 0.1 mg/m3 (milligrams per cubic meter of air) to determine if they should reduce the 8 hour acceptable exposure limit to 0.05 mg/m3. Although no regulatory limit exists for airborne exposure to mercury outside of an occupational setting, the EPA suggests that 0.3 ug/m3 (micro-grams per cubic meter of air) of mercury is a no-effect level (or reference dose = Rfd) for chronic inhalation exposure.

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