Mercury in the Environment: Natural and Human Factors

The recent findings of high levels of mercury in marine fish such as tuna and swordfish have emphasized the complexity of the natural cycles of this heavy metal and of man's impact on those cycles. Mercury in many forms is known to occur in trace amounts throughout man's environment. Man's use of mercury has threatened bird populations in Sweden and contaminated lakes and rivers in some areas of this country to the point that fish from them are unsafe to eat. Existing deposits of mercury in inland waterways constitute a continuing source, through the action of microorganisms in the bottom mud, of the more toxic methylmercury. Mercury in the oceans, however, is apparently largely from natural sources. Scientists in several countries are working to understand the geochemistry and biochemistry of mercury, but much remains to be learned about its distribution, its conversion from one form to another, and its transport on a global basis.

Medical Implications of Mercury

Poisoning due to the consumption of mercury in food is a well-documented but poorly understood medical phenomenon, although recent experiments have added new information about the behavior of mercury in the body. Metallic mercury and inorganic mercury compounds usually attack the liver and kidney, but in ordinary exposures they do not remain in the body long enough to accumulate to serious levels. Methylmercury and other alkyl mercury compounds are more dangerous since they attack the central nervous system and remain in the body for longer periods of time. Studies with radioactive methylmercury have established that it is retained in the human body with a half-life of about 70 days, so that toxic amounts can be accumulated even with low dose rates.

Widespread incidents of methylmercury poisoning have been reported only in recent decades. In Japan, more than 168 illnesses and 52 deaths were reported in two separate incidents in the 1950's from consumption of mercury-contaminated fish. Since 1960, more than 450 persons in several countries have become seriously ill and many have died from eating seed grain that had been treated with mercury compounds. Recently three children in New Mexico sustained severe brain damage after having eaten pork from animals that had been fed treated seed grain.

Symptoms of methylmercury poisoning in man may include loss of vision, hearing, coordination, and intellectual ability. According to a recent report by a Department of Health, Education, and Welfare (HEW) study group on the hazards of mercury, the damage is usually permanent and there is no known treatment other than prevention. The HEW report notes that the nervous system's ability to compensate in part for partial brain damage may mean that early symptoms often go unrecognized. The long-term effects of exposure to less than clinically detectable amounts of mercury are not known. Cases of congenital damage have been reported in infants born to mothers who were exposed to large amounts of methylmercury during pregnancy, but who were themselves apparently not harmed. The danger to developing tissue is further emphasized by experiments in Sweden which indicated that methylmercury in the red blood cells of the fetus are 30 percent higher on the average than in those of the mother.

There is still some uncertainty as to what constitutes lethal concentrations of methylmercury in man, and comparison of data reported from Japan and Sweden indicates that there is variability in individual tolerance. The lowest concentration in the blood which is reported to cause identifiable symptoms is 0.2 part per million (ppm). Swedish authorities believe that this level is associated with a steady daily intake of 0.3 milligram of methylmercury for a 70-kilogram man. To keep dosages at least a factor of 10 below this figure, weekly consumption of fish containing 0.5 ppm of mercury, the maximum allowed by the Food and Drug Administration (FDA), would have to be limited to 420 grams for a full-grown man and correspondingly less for children or mothers-to-be. These guidelines may imply a severe restriction to persons in contaminated areas for whom, through preference or necessity, fish are normally a large part of the diet.

What governs mercury's behavior in the environment and how does it get into the food chain? Although mercury is a scarce element, it occurs widely in nature and readily forms a variety of organic and inorganic compounds; the most commonly occurring is cinnabar, the mercuric sulfide. Most rocks and soils contain mercury at concentrations averaging about 100 parts per billion (1 ppb = 1 part in 10^9) or less. Certain shales that are rich in organic material show higher concentrations—up to 10,000 ppb; and high concentrations are also reported in coal and in marine phosphates.

Mercury is also found in the atmosphere. Concentrations up to 16 ppb have been measured at ground level near ore deposits, although normal concentrations in air are much less. Surface waters in this country are reported by the U.S. Geological Survey in a recent study to contain generally less than 0.1 ppb, except in regions with anomalously high concentrations of mercury in the rocks and soils or near sources of man-made pollution. By comparison, the Public Health Service recommends that mercury in drinking water be limited to 5 ppb. Presumably because mercury bonds tightly to many organic and inorganic materials, concentrations diminish rapidly downstream from a source, and bottom sediments and suspended particulates usually contain more mercury than the water itself.

The mercury content of the oceans appears to vary considerably from place to place, although almost nothing is known about the distribution pattern. Reported measurements, some made 35 years ago, indicate a range from 0.03 to 2.0 ppb; but recent measurements with modern techniques seem to average close to 0.1 ppb. A few surveys have included samplings made over a range of depths, and, to the extent that generalizations can be made, it seems that the mercury content varies more with the amount of suspended material than with temperature, salinity, or depth. Apparently no one has yet determined whether seawater contains mostly methylmercury or inorganic compounds. Whatever the form, the fact that the oceans contain approximately 1.3×10^{18} metric tons of water implies that they also contain about 10^8 metric tons of mercury.

No quantitative measurements are available concerning the movement of mercury through the environment, but it seems clear that it is readily exchanged among air, land, and water. Mercury enters the atmosphere in both particulate and vapor forms and is deposited on the earth's surface by rainfall and dry fallout. Measurements in Sweden, for example, have shown an average of 0.2 ppb of mercury in rainwater. Water runoff from the land washes mercury into the waterways. The transport of mercury in the environment is increased by its conversion to methylmercury, which is more readily taken up and retained by living organisms. This conversion is apparently responsible for the high levels of mercury found in aquatic food chains.

The mechanism of methylation is not well understood, but it has been shown to occur through microbial action in both natural and aquarium sediments. According to a report prepared by scientists at Oak Ridge National Laboratory in Tennessee that summarizes much of the available information on mercury in the environment, most forms of mercury can be converted to methylmercury, and a variety of microorganisms appear to be involved. Although methylation can occur in anaerobic circumstances, it seems to proceed more efficiently in aerobic systems; both enzymatic and nonenzymatic mechanisms have been proposed. Microorganisms in some animal intestines are able to methylate mercury—for example, chickens have been shown to convert a small proportion of mercury compounds in their feed to methylmercury—but it is not known whether a similar conversion takes place in fish and mammals.

Methylmercury accumulates in animals for the same reasons that it does in man—long retention times. Experiments in Sweden have shown that in several types of fish the mercury is retained with a half-life of about 200 days. Most of the mercury found in animal tissue is methylmercury. The concentration of this substance by living organisms apparently comes both by way of the food chain and by direct absorption. In some of the primary producers, such as marine diatoms, mercury is reported to be accumulated largely by passive adsorption on the organism's surface. In contrast, fish can apparently concentrate methylmercury both through their food and directly through their gills so that their flesh contains concentrations several thousand times higher than those in the surrounding water. In one experiment, trout exposed for an hour a day to 0.1 ppm concentrations of ethylmercury showed muscle concentrations of 4 ppm after 10 days.

Large marine animals have also been reported to contain unusually high concentrations of methylmercury. Both swordfish and tuna have been reported to contain as much as 1 ppm of methylmercury, and seals and whales apparently contain more. However, concentrations in samples taken from a given species may vary. The FDA reports that only a few tuna have concentrations in excess of 0.5 ppm, the legal limit. FDA scientists find that large fish weighing more than 23 kilograms average about 0.25 ppm of mercury, while tuna smaller than 12 kilograms average about 0.13 ppm.

Mercury from Man's Activities

Man has been working with mercury for centuries and has often been very careless with this convenient but dangerous material. Quicksilver, as mercury was known to miners, was extensively used in previous centuries to separate gold and silver from their ores. The largest uses of mercury at present are for the electrolytic production of chlorine and caustic soda and for the manufacture of electrical equipment and antifouling paint. Substantial amounts are also consumed in agriculture as pesticides and seed treatments. Consumption of the metal in the United States since 1900 has been about 10^5 metric tons, with world consumption probably several times as great. Reliable estimates of how much of this has been lost to the environment are hard to come by, but it may be as much as a third. World production of mercury is currently about 9000 metric tons per year. Discharges from industrial plants into rivers, incineration of used electrical equipment, exhausts from metal smelters, and crop applications put mercury into the air, soil, and waterways.

In addition to losses from direct uses, mercury is released in the combustion of coal and petroleum products. The mercury content of these fuels varies widely, depending on their source; and for coal the distribution is irregular even within a single sample. Really systematic studies have yet to be done, but a number of investigators report concentrations averaging about 1 ppm in coal. Since world production of fossil fuels totals about 5×10^9 metric tons per year these findings indicate that, as a rough estimate, perhaps 5×10^3 metric tons of mercury per year are released to the air from fossil fuels. This amount is about equal to estimates of the natural yearly runoff from streams and rivers.

Not all the mercury that man releases to the environment reaches the sea, but even if it did, the total released in this century seems to be small compared to the amounts already there. Fossil fuel use has been rising in this century, so that probably less than 10^5 metric tons of mercury has been released since 1900 from this source; the estimated losses from industrial and agricultural consumption are about the same. Hence the total input of mercury from man's activities seems to be between 2 and 3 orders of magnitude less than the 10^8 metric tons of mercury estimated to be present in the ocean, so that except for coastal and estuarine areas it does not seem likely that man could have increased concentrations in the sea by as much as 1 percent. Recent reports that mercury concentrations found in preserved specimens of tuna caught as much as 90 years ago are about the same as those in recently caught fish would seem to confirm this picture; whatever the source, however, the health hazard from too much contaminated fish is the same.

Many puzzles remain to be solved before the natural cycles of mercury in the environment and man's contribution to those cycles can be completely sorted out. If mercury in the oceans is largely of natural origin, as it seems to be, then does methylation also take place in the sea bottom sediments? Can the many inland waterways with existing deposits of mercury be rendered harmless? Remedial measures for agricultural uses of mercury are easier: in the 4 years since Sweden banned seed coatings and pesticidal uses of methylmercury, bird populations have begun to recover, and the amounts of mercury in many types of food have decreased. Man's use of mercury needs to be especially cautious, because, unlike some other pollutants, the difference between tolerable natural background levels in the environment and levels harmful to man and animals is very small, and this may also turn out to be true for other heavy metals.—ALLEN L. HAMMOND