Chemical Pollution: Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) are widely used industrial chemicals that were never intended for release into the environment, but they have nonetheless been found in rainwater, in human tissue, and in many species of birds and fish. How PCBs came to be widely distributed in the environment and what biological effects they have are still largely unknown. But like DDT, PCBs apparently degrade very slowly under natural conditions. They tend to accumulate in the food chain, and once ingested, they are stored in the body's fatty tissues. As is true with many other chlorinated hydrocarbons, even small doses of PCBs can be toxic, although it is not clear that the amounts found in fish or birds have had detrimental effects. The only epidemiological information about PCBs' effects on man comes from an accidental poisoning incident in Japan in which some 1000 persons were affected.

Polychlorinated biphenyls are relatively inert compounds that have low solubilities in water. The PCBs produced commercially are mixtures, incorporating some 50 or more of the 210 different PCB compounds that are theoretically possible from chlorinating biphenyl. The most common industrial mixtures average between 40 and 60 percent chlorine content, but their isomeric composition is only partially known, thus complicating the problems of sampling and analysis. Gas chromatographic techniques are now most commonly used to determine the presence and the amount of PCBs in a sample. The method is not specific for identifying particular PCB compounds because of the lack of samples of the different isomers as reference standards. There appears to be some variability in biological and chemical activities among the compounds; highly chlorinated PCBs seem to persist in the environment the longest and are less toxic than the more rapidly degraded low chlorine forms. There is also evidence that some commercial PCB mixtures, especially those manufactured in Europe or Japan, may contain trace amounts of dibenzofurans or other extremely toxic impurities, which may be the cause of some of the toxic effects ascribed to PCBs themselves.

The major uses of PCBs derive from their nonflammability, high dielectric constant, and plasticizing abilities. These uses include applications as dielectric fluids in capacitors and transformers, as hydraulic fluids, and as heat transfer fluids; also PCBs have been widely used as plasticizers and solvents in adhesives, sealants, paints, and printing inks. Some 95 percent of the large phase correction capacitors used in transmitting electric power, for example, contain PCBs—amounting in 1968 to almost 2.5 million gallons in the United States alone*; replacement of PCBs by other dielectric fluids, according to Martin Broadhurst of the National Bureau of Standards, would require that the capacitors be rebuilt and that they be 50 percent larger. Alternate materials for plasticizer applications of PCBs, on the other hand, are readily available.

Industrial use of PCBs has grown steadily since their introduction in 1930. U.S. sales in 1970 came to about 34,000 tons, with cumulative production over the years amounting to an estimated 4×10^5 tons. (By comparison, U.S. production of DDT in recent years has been about 70,000 tons.) Less, in fact almost nothing, is known about the quantities produced worldwide; in addition to the production in the United States, PCBs are made in Europe, Japan, and the U.S.S.R. The only U.S. producer of PCBs, the Monsanto Chemical Corporation, refused until recently to release production figures, but the company has taken the unusual step of refusing to sell any more PCBs for plasticizer applications and those heat transfer applications involving food preparation. Current annual U.S. sales, as a result, have fallen to about 20,000 tons per year, although exports have continued to increase.

How PCBs are released into the environment is not known, but several scientists believe that sewage outfalls and industrial disposal into waterways are major sources. Rivers and streams may be the primary means of transport for PCBs within the environment, although the atmosphere also appears to be a means of dispersal. Adel Sarofim of the Massachusetts Institute of Technology has estimated that from 1000 to 2000 tons per year escaped into the atmosphere in past years from plasticized materials containing PCBs, and that about 4000 tons per year entered waterways from dumping and leakage of lubricants, hydraulic fluids, and heat transfer fluids. Other sources may include leaching from dumps and landfills, where, Sarofim believes, about half of the PCBs produced eventually end up. Although measurements of PCBs in air and water are scant, the general pattern from these measurements and from more extensive measurements of PCB residues in biotas is consistent, according to Sarofim, with the hypothesis that discharge of PCBs into the environment occurs mainly near industrial areas. A similar pattern was found by Gilman Veith of the University of Wisconsin in his studies of Lake Michigan watersheds; he also detected PCBs in the sewage of all municipalities studied.

Once in the environment, PCBs appear to persist for a long time. Laboratory studies by O. Hutzinger of the National Research Council of Canada in Halifax and others have indicated that PCBs can be dechlorinated by ultraviolet light and lead to the formation of hydroxyl derivatives and other polar compounds that are more readily degraded by microorganisms, but the extent to which this occurs under natural conditions is not known. In many areas, however, PCB residues in fish are equivalent to or higher than DDT and other pesticide residues. David Stalling of the Bureau of Sport Fisheries and Wildlife, Columbia, Missouri, found PCB residues as much as 100 times larger than DDT residues in fish from heavily industrialized areas, with roughly equal residues of both substances in fish from many other regions.

The highest PCB residues in fish seem to occur in highly polluted coastal waters—like Tokyo Bay and Long Island Sound—and in some inland waterways—such as the Great Lakes—where coho salmon have been found with PCB concentrations in excess of 5 parts

* More detailed reference to many of the studies mentioned here can be found in the forthcoming initial issue of *Environmental Health Perspectives*, a journal to be published by the National Institute of Environmental Health Sciences, Research Triangle Park, North Carolina.

per million, the limit at which the U.S. Food and Drug Administration attempts to seize contaminated fish and poultry sold in interstate commerce. More typical concentrations, in most species of fish in the North Atlantic, range from 0.01 to 1.0 ppm. Fish taken from undisturbed arctic lakes have been found to contain comparable residues. Both surface-feeding fish and those that dwell at greater depths contain PCBs. Even higher concentrations are found in birds that feed on fish, reaching 300 to 1000 ppm in cormorants and ospreys. According to Robert Risebrough of the University of California's Bodega Marine Laboratory, residues are generally highest in bird specimens from the North Atlantic or from along the California coast, and generally lower in birds from the South Atlantic and Central Pacific Oceans. Residues appear to be lowest in wildlife from the Antarctic region.

Most U.S. inhabitants apparently have some residues, if only traces, of PCBs in their bodies. Preliminary data from a nationwide monitoring program being coordinated by the Environmental Protection Agency show that 33 percent of more than 600 samples of human adipose tissue contained PCB residues of at least 1 ppm. One individual, an old man with no known industrial exposure to PCBs, was found by the Michigan Department of Health to have 100 ppm in his fatty tissues.

The source of PCB residues in human tissue is presumably food. Studies in Sweden have indicated that fish are the primary source of PCBs for most Swedes, with average intake of PCBs from all sources estimated to be about 1 microgram per kilogram of body weight per day. Individuals who ate large amounts of fish consumed about ten times as much PCBs. Babies received the highest doses per kilogram of body weight, largely from milk. Residues of PCBs in food were somewhat smaller than those of DDT and metabolites of chlorinated pesticides.

In the United States, the pattern appears to be the same, with PCBs common in freshwater fish such as coho salmon and lake trout. Small residues in cereals have been traced to the recycled paper used in packaging and thence to the ink in a brand of carbonless carbon paper, among other sources. The ink no longer contains PCBs, and efforts are being made to separate out old stocks of the carbon paper in the manufacture of recycled paper. Several batches of poultry and eggs with high PCB residues have been traced to contamination of the poultry feed by leaking heat exchangers, except in one instance where the source of the PCBs remains undetermined. Residues are present in dairy milk in some localities.

Officials of the Food and Drug Administration characterize PCBs as a "potential but not immediate health hazard," and claim, on the basis of their monitoring programs, that except for his eating of fish the American consumer receives no systematic exposure to PCBs. However, FDA authority extends only to interstate sales of food, and FDA guidelines tend to reflect only the average consumer. It seems likely, because of the localized nature of PCB sources and variations in individual diet, that heavy fish eaters and some other individuals experience more substantial exposures.

The only clinical experience with human illness that is directly traceable to PCB consumption occurred in 1968 in southern Japan. More than 1000 persons who had eaten rice oil contaminated with PCBs that leaked from a heat exchanger during manufacture developed darkened skins, eye discharge, severe acne, and other symptoms of what came to be called Yusho, oil disease. Patients were found to have consumed an average of 2 grams of PCB, with symptoms appearing at a minimum dose of about 0.5 g. The PCBs can readily cross the placental barrier, and several infants were born with Yusho symptoms, some to apparently unaffected mothers. Recovery appears to be difficult, according to Masanori Kuratsune of Kyushu University in Fukuoka, Japan, with symptoms still present in many cases 3 years later; no methods of treatment are known. It is not clear whether any of the subsequent deaths among the patients can be attributed to acute PCB poisoning, and it is still not known whether the commercial PCB mixture involved contained traces of dibenzofurans or other impurities.

Although PCBs have been in use for more than 30 years, detailed studies of their toxic properties have only recently been undertaken. The studies are complicated by variability in the toxicity of different commercial samples of PCBs. Experiments in the Netherlands by J. G. Vos of the University of Utrecht showed liver damage and edema in chickens and skin lesions in rabbits. The worst effects seemed to be caused by an impurity in the European PCB mixture, which Vos believes to be dibenzofuran.

The results of a 2-year study funded by Monsanto showed liver damage and some difference in weight gain in rats and dogs whose feed contained 100 ppm of PCBs, but no teratogenic or mutagenic effects. At a dose rate of 10 ppm, there were apparently no effects of any kind, except for some impairment to the hatching of chicken eggs. Reproduction was affected most by low-chlorine PCB mixtures, but long-term damage to the liver seemed to be due to high chlorine mixtures. By contrast, in one of the field occurrences of PCB contamination, the hatchability of eggs at Holly Farms in North Carolina was noticeably decreased, even though the concentration of PCBs in the feed was less than the no-effect levels reported in the Monsanto study.

Although most birds and mammals appear to be relatively resistant to PCBs, some species, such as mink, seem to be more susceptible. Fish are also more susceptible; Stallings found that bluegill and catfish died when exposed for several weeks to concentrations between 20 and 50 parts per billion, that trout died at about 8 ppb, and that lethal doses for shrimp were as low as 1 ppb.

The biological actions of PCBs inside the body are also relatively unknown. PCBs have been shown to alter liver tissue, inhibit the growth of cultured cells, and affect a variety of enzyme systems; but in most instances the mechanism of action is still uncertain. Paul Lichtenstein of the University of Wisconsin has shown that PCBs interact with DDT and other chlorinated pesticides; nontoxic amounts of PCBs in insects increased the toxicity of DDT and some organo phosphate pesticides by as much as 100 percent.

Much of the research on PCBs has pointed to the similarity of PCBs and DDT in their environmental effects. They are both widely distributed in the environment, they both affect the reproductive system of birds, and they enter the human diet primarily through residues in fish. But PCBs, unlike DDT, were seldom deliberately released into the environment. Their presence and persistence there reemphasize the likelihood that any widely used industrial chemical may become an environmental pollutant, and increase the responsibility for public disclosure of production quantities and use patterns when similar situations occur in the future.

—ALLEN L. HAMMOND