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PCBs—In Perspective

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PCBs are very stable compounds which do not break down readily in the environment, but instead concentrate as they move up the food chain. Their effects on the environmental species and humans vary due to a number of factors.

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PCBs (Polychlorinated Biphenyls) have received much attention recently because of the public's concerns over their potentially damaging effects on the environment and human health. These concerns have prompted a search for answers to questions about PCBs and how their effects can be controlled. This article will broadly outline the PCB problem with emphasis on PCBs in the United States.

What are PCBs?

The term polychlorinated biphenyls, or PCBs, refers to a class of organic chemicals introduced into United States industry in 1929-1930. A 1979 report by The National Academy of Sciences [1] listed Monsanto Industrial Chemicals Company as historically the only important U.S. producer of PCBs. Monsanto's plants were located at Anniston, Alabama and Sauget, Illinois, where production of PCBs ended in 1970 and 1977, respectively.

PCBs have also been produced, imported or exported by a number of other countries. Some producers are Italy, France, Japan, the United Kingdom, Austria, Czechoslovakia, the Federal Republic of Germany, Spain, and the U.S.S.R.

According to the U.S. Environmental Protection Agency (EPA), countries which have imported PCBs include Finland, New Zealand, Canada, France, Italy, Norway, Sweden, and the United Kingdom. Countries which have exported PCBs include France, Italy, and the United Kingdom (EPA 1976).

It is important to be aware of the chemical structure and nature of PCBs because it is a critical prerequisite to understanding their toxicity and control.

PCBs are man-made compounds manufactured by chlorination of a biphenyl molecule. The biphenyl is composed of two six-sided carbon rings in which one carbon on each ring has joined together. This leaves ten sites for chlorine atoms to join the biphenyl molecule. The number of chlorine substitutions on the molecule corresponds to the ten possible chlorinated biphenyls which may be formed. These are monochlorobiphenyl, dichlorobiphenyl, trichlorobiphenyl, etc. Within each of the ten possible chlorinated biphenyls, the chlorine atoms may join the rings in various configurations creating many isomers.

Typically, the PCBs are sold as mixtures of the various possible chlorinated biphenyls. Commercial PCB mixtures typically contain various contaminants, including polychlorinated dibenzofurans (PCDFs) and polychlorinated napthalenes. These contaminants have been implicated as being partly responsible for some of the toxicity observed from PCB mixtures.

The chlorine content of the mixture is used as one method of describing it. For example, some common PCB mixtures are sold as AROCLOR[R] 1248, 1254, and 1260. These contain 48 percent, 54 percent, and 60 percent chlorine, respectively.

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Use and Distribution of PCBs

A 1976 report by Versar, Incorporated, for EPA [1] summarizes the various uses and distribution of PCBs.

PCBs have been used extensively in many industrial applications, but primarily in "closed" or "semi-closed" systems such as electrical transformers and capacitors, heat transfer systems and hydraulic systems. Much of the PCB marketed to U.S. industry is still in service, primarily in electric equipment. A significant portion has entered the environment and persistently remains, while the remainder has either degraded in the environment or been destroyed by man. Figure 1 describes estimates of PCB production, use and gross environmental distribution between 1930-1975.

FIGURE 1 PCBs In The U.S. 1930-1975*

PERCENT	MILLIONS LBS.	STATUS
3.9	55	Degraded or incinerated
20.7	290	Landfills and dumps
10.7	150	Free in the environment
53.4	750	Currently in use in Capacitors and transformers
0.6	8	Other than electrical uses, e.g., heat transfer, carbonless copy paper, hydraulics, lubricants, plasticizer uses, and other miscellaneous industrial uses
10.7	150	U.S. exports
100.0	1,403	Total U.S. commercial production/sales

*Condensed from EPA (1976)

Evolution of Concern over PCBs 1929-1975

Over the years since their first introduction in the U.S. in 1929-1930, the effects of PCBs have become better known.

Reports as early as 1936 described choracne among persons occupationally exposed to PCBs. Later observations noted possible liver effects associated with some human exposures.[3] In 1968, an outbreak of "Yusho" disease occurred in Japan following accidental human consumption of rice oil contaminated with Kanechlor 400, a PCB manufactured in Japan (48 percent chlorine). The total number of "Yusho" patients exceeded 1,000. They exhibited a variety of effects which included increased eye discharge, acne-like eruptions, hyperpigmentation of skin and nails and various nervous system effects. Other studies of PCBs showed that they persist and accumulate in the environment and may cause damage there as well as to humans.

By the late 1960s it had become apparent that, while PCBs generally show relatively little acute toxicity, they do show chronic toxicity after accumulation in the tissues of many biological species, even when exposed to very low concentrations. Some researchers have reported significant widespread PCB contamination in U.S. foodstuffs, human tissue, and throughout the general environment.

Industry and government have responded to concerns over PCB contamination and its effects. By mid-1971, Monsanto voluntarily stopped sales of Arochlors (PCBs and polychlorinated triphenyls (PCTs)) for uses other than closed electrical systems. They also offered incineration service for waste liquid PCBs and ended production of the higher-chlorinated Arochlors. During 1972 and 1973 the Food and Drug Administration (FDA) developed rules to control PCBs in food. In 1975 a national conference on PCBs was held in Chicago.

Between the years 1929 and 1975, a span of 46 years, PCBs were controlled mainly through voluntary industry efforts which evolved in intensity and scope. An example of this control is ANSI Standard C107.1-1974 which outlines an *American National Standard Guideline for Handling and Disposal of Capacitor- and Transformer-Grade Askarels Containing Polychlorinated Biphenyls.*

The year 1975 is a convenient break point in the discussion of PCBs because, in 1976, Congress and the EPA changed the PCB picture radically through broad new federal regulations. These changes will be described later in this discussion.

Environmental Distribution and Occurrence

It was mentioned earlier that a substantial amount of PCB has found its way into the environment. Some methods of entry may be through air, water, and land discharge during manufacture and handling of PCB mixtures; PCB equipment manufacture; spills and leaks during final use of PCB-containing products; and through leaching from disposal areas.

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Agricultural soils rarely show detectable PCB levels, however, urban soils do. Soils within city limits show higher levels than suburban soils.

Nineteen cities were sampled between 1971 and 1974 in the National Soils Monitoring Program, EPA. Twelve cities showed detectable PCB levels in soils. Many sites were sampled in each city. Typical numbers of positive findings ranged from 0.5 percent—6.3 percent of total samples. Levels of PCBs detected generally ranged from 0.09—3.33 parts per million (ppm). One sample showed 11.94 ppm PCBs.[6] PCB contamination in urban air has been reported at levels in the range of 100 mg/m^3.[5] Some U.S. waters and sediment also show PCB contamination.[6,7]

PCBs are found at various levels in biota. One national study conducted between 1970 and 1974 by the U.S. Fish and Wildlife Service showed PCB residues in various freshwater fish, mallard and black duck, and starlings.[8] A 1972-1974 study of three Lake Michigan fish species taken in the eastern part of the lake showed mean whole fish concentrations ranging from 5.24-5.66 ppm in bloaters, 10.4-12.2 ppm in Coho salmon and 12.9-22.9 ppm in lake trout.[9] Other studies have shown PCBs in ocean-dwelling animals.[10]

PCBs have been found in foodstuffs in the United States. This may include low level contamination in some general food products, commercial fish species and other foods. Researchers are watching closely levels found from early years to more recent, and predicting trends for future years.[11,12]

PCBs have been found in the general U.S. population. Samples of human adipose tissue and milk, collected in 1973 and 1974 in a national survey, showed that 35.1 percent and 40.3 percent of the samples, respectively, showed 1 ppm or more PCBs on a wet-weight basis; 5.5 percent and 4.9 percent, respectively, showed greater than 2 ppm PCBs. Adipose tissue extracts were examined by gas chromatography/mass spectrometry (GC/MS) and found to contain penta-, hexa-, and heptachlorobiphenyl compounds most frequently. Less chlorinated isomers seemed to be metabolized and excreted more rapidly in a biological system.[13]

One sample survey in Canada showed human contamination to be about 1-2 mg/kg PCB in adipose tissue in Canadians sampled. PCB residues in human milk of Ontario residents were about 1 mg/kg fat.[14]

Health Effects and Human Exposure

There are two major areas of exposure to PCB mixtures which give a reasonably direct indication of human health effects. These are occupational exposures and one episode of accidental exposure of persons in Japan.

Reported occupational exposure levels vary. Workplace air levels have typically ranged from very low levels up to 10.0 mg/m^3 PCBs in air depending on environmental conditions; type of operation (for example, electrical equipment manufacture or chemical manufacture); work procedures; and controls in effect. Very high levels, in fact up to 86 mg/m^3, have been reported in exceptional cases.

Effects of occupational exposure center on a few major areas and mainly depend on dosage, route of exposure, and individual biological variation among exposed persons.

Common effects are skin disorders. These include, but are not limited to, chloracne, hyperpigmentation, rashes, and irritation. These effects have been observed both in areas of the body contacted directly by PCB mixtures and in areas not directly contacted.

Other effects may include dry sore throat, upper respiratory irritation, asthmatic bronchitis, eye irritation, nausea, gastrointestinal disturbances, headache, dizziness, and liver effects.

The National Institute for Occupational Safety and Health (NIOSH) reports that there are no adequate studies to confirm or deny that PCBs are carcinogenic; that PCBs have little mutagenic potential, but may alter mutagenicity and carcinogenicity of other compounds by stimulating microsomal enzyme activities; and that teratogenic potential does exist. NIOSH further admonishes that there are no reports of infertility or abortions attributed to PCB consumption or exposure, or undesirable effects in children born to mothers exposed to PCBs in the diet, or undesirable effects developing from nursing such mothers.

Based on available data, PCBs should be handled as if they are potentially carcinogenic and potentially teratogenic.

Recalling the previously mentioned outbreak of "Yusho" (literally translated oil disease) which occurred in Japan between 1968 and 1975, approximately 1,300 cases were reported in which patients were found or presumed to have ingested rice oil which was accidentally contaminated with a PCB mixture, Kanechlor 400. Samples of oil contained 800-1,000 mg/kg PCB with some reaching 3,000 mg/kg. Concentrations of polychlorinated dibenzofurans (PCDFs) were in the range of 5 mg/kg. These levels of PCDFs are about 250 times more than are usually found in PCB mixtures. Intake of contaminated oil was estimated at 2.0 g (10 mg PCDF) among a highly exposed group. Minimum amounts ingested may have been 0.5 g.

The effects of "Yusho" are widely described in the literature. In the early stages these include ocular discharge, swelling of upper eyelids, dermatological symptoms mainly associated with follicular keratosis, and various nervous and general symptoms. Other features described are hypertriglyceridaemia with normal plasma cholesterol, adrenocortical and ovarian dysfunction, bronchitis (cough and phlegm), hepatomegaly, hypobilirubinaemia, low immunoglobulin levels and (possibly) disturbed calcium metabolism.[20]

While "Yusho" effects are generally attributed mainly to PCBs, Japanese researchers have suggested a need to investigate the role of PCDFs more fully.[21]

Effects on the Environment

The full impact of PCB contamination on ecological systems is not fully understood. However, there have been a number of attempts to summarize currently apparent effects and to estimate future possible impacts.

In general, PCBs may cause the following impacts on wildlife when high concentrations of PCBs are encountered: reproductive disorders, increased mortality, growth changes, and behavior changes. Other effects have been reported.[13,14]

PCBs resist degradation in the environment and persist for long periods of time. As they persist, they tend to accumulate in animals as they move up the food chain. This is most strongly demonstrated in aquatic ecosystems.[15,16,17,18,19] In any biological system, effects depend, among other things, on: dosage, route of exposure, and various species and individual biological factors.

Controlled Studies of Toxic Effects

Controlled studies typically involve dosing various animal species with lethal or sublethal levels of a test chemical under well-defined conditions.

Depending on the route of administration (oral, inhalation, dermal applications, etc.), the dose, the specific test species, individual biological factors and other factors, one can draw reasonably well-defined conclusions about the possible toxic effect of a chemical on man. The results of the studies noted below suggest a possibility of similar effects in man. However, one should bear in mind that animal data are not directly extrapolatable to man without careful evaluation of differences between the actual test species and man, the levels of exposure used in the experiment and many other factors.

A "Criteria Document" prepared by NIOSH in 1977 gives an exhaustive review of some important studies.[3]

The absorptions, distribution and excretion of PCBs have been described in various animal studies. PCBs are readily absorbed into the body from the digestive tract and respiratory system. Depending on the degree and pattern of chlorination, they are excreted in the feces, milk, and hair of animals. Trace amounts are excreted in the urine.

Metabolites of PCBs have been found in the urine, feces, and milk of mammals. Among mammals there appear to be quantitative differences in PCB metabolism and effects related to age and sex. In general, the lower chlorinated biphenyls are more rapidly metabolized than the highly chlorinated ones, which may persist in tissues for years after intake has been discontinued. Some metabolites found in urine, bile, feces and milk indicate that, at some point, PCBs may be metabolized to highly toxic arene oxides with may present a potential risk of carcinogenesis or mutagenesis.

Inhalation and dermal application studies of PCB mixtures in animal tests show a variety of effects. Inhalation studies show changes in liver, kidney, heart, spleen, thyroid, blood and growth rates. Dermal studies show changes in skin, liver, and kidney which suggests that PCBs may be absorbed through the skin. Some of the toxicity demonstrated by some PCB mixtures may be due to contamination by PCDFs.

Administration of PCBs to test animals by the oral route is the most common type of study. Oral dosage studies show that as the degree of chlorination increases the acute toxicity decreases. Effects observed include, but were not limited to, some immunosuppressive activity; changes in the liver, kidney, skin, blood, protein levels, DNA levels and RNA levels; growth changes; gastrointestinal disturbances; and loss of body weight.

Animal work done on reproductive and teratogenic effects of PCB mixtures shows that PCBs appear capable of crossing the placental barrier and having an effect on reproductive performance.

There is some evidence of the possible mutagenic and cytotoxic potential of PCB mixtures. One study using the Ames bacterial test showed that, as the degree of chlorination decreases, the mutagenic potential increases. The more highly chlorinated biphenyls showed very little mutagenic activity. The cytotoxicity of PCB mixtures increases with decreasing chlorination.

Tumors have been produced by PCB mixtures in a variety of animal test systems. Liver tumors were typical. Tumors of the pituitary gland have also been observed.

Regulatory Requirements

The Federal Government has taken an approach to regulation of chemicals in the U.S. that includes cradle-to-grave cognizance over their import or production, transport, handling, and disposal. PCBs fit into this regulatory philosopy.

There can be some problems in living with government rules. There are at least four U.S. government departments or agencies administering six laws which, in part, cover PCBs. Some regulations overlap confusingly, or are vague. Smaller businesses in the regulated community, which typically have small or nonexistent environmental/legal staffs, can be overwhelmed by the synergistic effects of these regulations.

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Some of these rules are listed below by agency or department. This list is extensive, but not meant to be all inclusive.

Environmental Protection Agency (EPA)

- Toxic Substances Control Act (TSCA):
  section 6e mandates broad control over manufacture, distribution, handling, and disposal of PCBs (refer to *Federal Register* May 31, 1979).
- Resource Conservation and Recovery Act (RCRA):
  mandates specific rules to regulate various aspects of disposal.
- Federal Water Pollution Control Act (FWPCA):
  mandates rules to regulate discharges of PCBs to waterways.

Department of Transportation (DOT)

- Hazardous Materials Transportation Act (HMTA):
  mandates rules to regulate transportation of PCBs.

Food and Drug Administration (FDA)

- Food, Drug and Cosmetic Act:
  mandates rules to regulate PCB residues in foods, etc.

Department of Labor (DOL)

- Occupational Safety and Health Act (OSHA):
  mandates rules to regulate occupational exposures to PCBs.

Summary

In response to the scientific evidence which indicates a potential problem from PCB overexposure, and because of the need to comply with existing laws and regulations, the following goal is appropriate for most applications: Persons who use PCBs should completely identify the disposition and quantity of all PCBs in their system; control its use by insuring it remains in a closed system or is quickly and adequately cleaned up in the event of a spill, or otherwise handled safely during necessary handling operations; and ultimately remove all PCBs from their system for safe disposal and substitute PCB equipment with non-PCB equipment as old gear wears out.

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