POLYCHLORINATED BIPHENYLS IN MAN'S FOOD–A REVIEW[1,2]

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Abstract

Among environmental contaminants, polychlorinated biphenyls (PCBs) are similar to DDT in persistence, biological magnification through food chains, chemical inertness, and hydrophobic character. While toxicity to lower vertibrates and invertibrates is less than that of DDT, mammals are much more susceptible to the toxic effects. PCBs have been implicated in egg shell thinning in some predacious birds, failure to reproduce and deaths in mink, and economic losses in both the dairy and poultry industries. A wide variety of pathologic changes have been observed–teratogenesis, edema, damage to liver and kidneys, and retarded growth and development of sex characteristics. Growth retardation was temporary in chicks fed < 40 ppm PCBs in a ration and permanently impaired above this concentration. A by-product, tetrachloroparadibenzofuran found in trace quantities in PCBs of European manufacture, is more toxic than PCBs but has similar biological effects. Considerable national research emphasis is being directed toward full resolution of PCB-associated problems.

To extremists, the present amount and increasing rate of pollution in our environment will be terminal for all humans. It is like playing musical chairs on the Titanic. In so many words, if the pesticides don't get you, then the carbon monoxide will! At the other extreme are the apathetic, and the ill advised.

The vast majority of people occupy the middle category. These people care about our environment, wish to preserve it for future generations, and are willing to go to some economic expense to accomplish it. This group is generally aware that a total cleanup is impossible, impractical, unnecessary, and that we can live compatibly with certain amounts of contaminants. This is strengthened by the fact that, in general, the birth weight of babies is not decreasing, there is no apparent increase in congenital defects, rate of growth of children over a number of years is unchanged, and our life span continues to lengthen. To this group the decline of certain wild populations of mammals and birds, serves as a warning sign indicating that we could be in the same predicament if the misuse of the pollutant in question continued. An example of such an environmental contaminant is the subject of this paper.

Another chemical, useful to several industries and known to be inert, insoluble in water, thermally quite stable, and resistant to both acid and alkalis has presented itself as a primary environmental pollutant.

Polychlorinated biphenyls or PCBs are a complex heterogeneous group of chemicals and have been manufactured for 40 years. In 1970, Monsanto sold 36,500 tons of these materials and 18,800 tons in 1971. This is shown by domestic sales in Fig. 1 and by type of PCB in Fig. 2. Voluntary restriction of sales by Monsanto was used in an effort to curb contamination of foods and pollution of the environment *(27)*. This represents the difference in sales between 1970 and 1971 and includes curtailment of sales for plasticizers, surface coatings and sealers, adhesives, printing inks, pesticide extenders, microencapsulation of dyes, and wax modifiers *(16, 21, 27)*. Also, PCBs used as a heat transfer medium, which could lead to contamination of a food supply, was stopped. Uses that continue to be supplied with PCBs are hydraulic and dielectric fluids *(27)*.

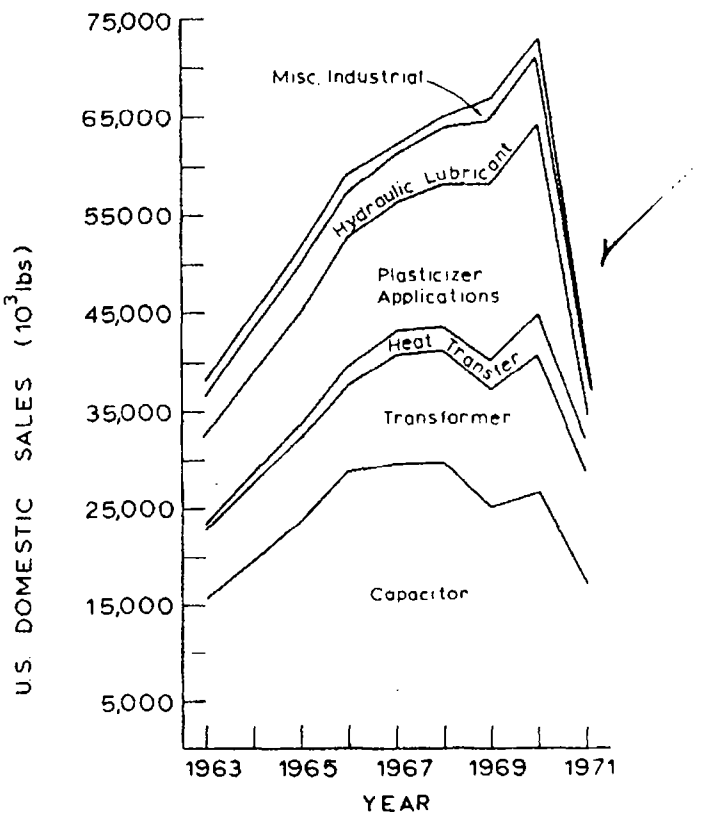

Figure 1. United States domestic sales of PCBs by use. *(27)*

[1]Contribution from the College of Agricultural and Life Sciences, University of Wisconsin-Madison, Madison, Wisconsin 53706.

[2]Presented at the 59th Annual Meeting of the International Association of Milk, Food, and Environmental Sanitarians, Milwaukee, Wisconsin, August 21-24, 1972.

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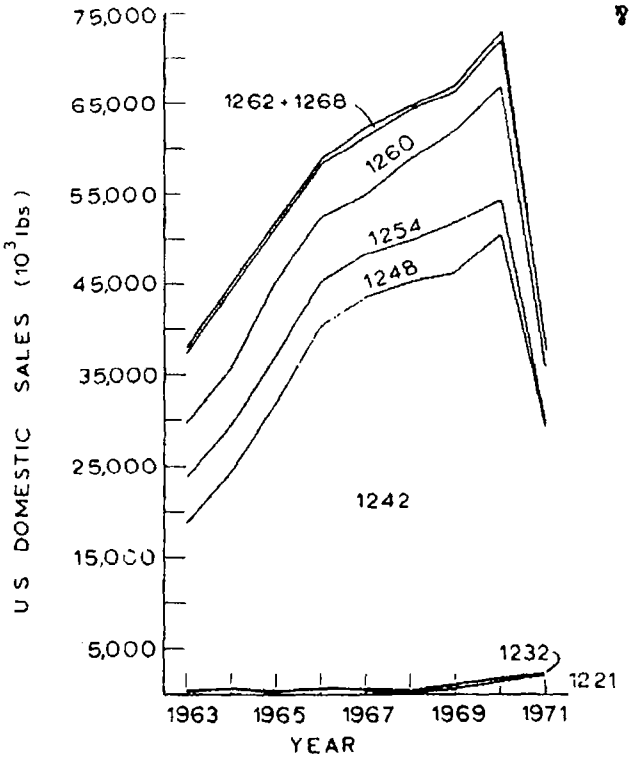


Figure 2. United States domestic sales of PCBs by type. *(27)*

Some Chemistry of PCB's

Structurally PCBs are a heterogeneous group of chemicals with various numbers of chlorine atoms substituted on the diphenyl radical *(11, 29)*. The diagram (Fig. 3) indicates the number of possible isomers and that a total of 210 different isomers is possible by chlorination of any or all of the 10 available positions. It is not known which or how many of these are involved in contamination of food.

The concentration of PCBs can be approximated using the gas chromatograph and an electron capture detector, techniques employed to separate and identify organochlorine pesticides *(12, 14)*, and a separation technique using silicic acid *(7)*. Known amounts of individual PCBs must be passed through silicic acid to quantitate against unknowns *(21)*. Typical chromatograms show the complex nature of Aroclor, the Monsanto product, 1221, and 1232 (Fig. 4). These are biphenyls containing 21% and 32% chlorine, respectively, as indicated by the last two digits of the identifying number. Moreover, in each of these figures similar peaks are evident and the same compounds appear in nearly all of these Aroclors. In Fig. 5, typical chromatograms for Aroclor 1242 and 1248 are shown. Notice that as the percentage of chlorine increases so does the number of constituents appearing later in the chromatogram or those having more chlorine and longer retention times. In Fig. 6,

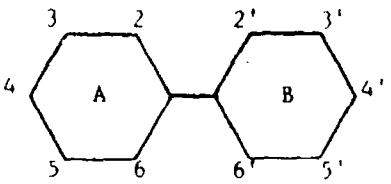
pical for Aroclor 1254, 1260.

g is added to the biphenyl structure at either the *ortho*, *meta*, or *para* position, a terphenyl results. Instead of 10 possible positions for chlorine there now are 14. A typical example containing 42% chlorine is Aroclor 5442 (Fig. 7). Some material appears early on the chromatogram similar to Aroclor 1242 and 1248, however the bulk appears late after 35 min have elapsed. It has been suggested that biological concentration could make this Aroclor appear as a PCB *(11)*. The terphenyls require special methods to isolate them, and these are usually not employed in residue chemistry laboratories.

Monsanto is the only manufacturer of PCBs in the U. S.; however, PCBs are produced in other countries, i.e., Japan (Kanechlor), Germany (Clophen), France (Phenoclor), Russia, Great Britain, and Italy. The total annual production is guesstimated at 110,000 tons *(27)*. Unfortunately an extremely hazardous and toxic material is a manufacturing by-product in some European PCB mixtures, a polychlorodibenzofuran (Fig. 8) *(42, 44)*. It may contain up to 8 chlorines with the tri and tetra substituted products being most common. This differs by one oxygen atom from tetrachlorodibenzo-p-dioxin identified previously as the causative agent in chick edema factor *(44)*.

Pollution

Pollution of our environment and of direct concern



Chlorines on A ring

Chlorines on B ring	0	1	2	3	4	5
0	1	3	6	6	3	1
1		6	18	18	9	3
2			21	36	18	6
3				21	18	6
4					6	3
5						1

Figure 3. The structural configuration for biphenyl and possible sites for chlorination *(11)*.

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TABLE 1. GROSS ESTIMATES OF RATES OF INPUT AND ACCUMULATION OF PCBs IN NORTH AMERICA IN 1970 (27)

Category of Input	Rate tons/year	PCB grade
Vaporization of plasticizers	$1\text{-}2 \times 10^3$	Mostly 1248-1260
Vaporization during open burning	4×10^2	Mostly 1242
Leaks and disposal of industrial fluids	$4\text{-}5 \times 10^3$	1242-1260
Destroyed by incineration and open burning	3×10^3	Mostly 1242
Disposal in dumps and landfills	1.8×10^4	1242-1260
Accumulation in service	7×10^3	1242-1254

Reservoir	Accumulation, tons
Soil excluding dumps	1.5×10^4
Oceans adjacent to North America	1.5×10^4
Fresh water (dissolved or in suspension)	1×10^3
Fresh water sediment	2×10^4
Biota	$<1 \times 10^3$

to us, food, has resulted in many ways. Available data (Table 1) are for 1970 (27). It is difficult to quantitate these losses; however, calculations show that the total rate of loss of PCBs is approximately 25,000 tons/year. This accounts for first, loss from manufacturing sites through combustion of waste materials and vaporization. This aerial contamination is then precipitated within a few days since, as with DDT, the PCBs are bound most usually to particulate material. The smaller particles will require rain to precipitate them which may occur in some remote area. Evaporation losses from products in which the PCBs were used to facilitate manufacture or application, such as, plastics, epoxy resins, rubber goods, varnishes, waxes, lacquers, dyes and adhesives are included in this estimate. Estimated emissions are 1,500 to 2,000 tons annually with the vast majority concentrated in urban areas. Exposure in an incinerator for 2 sec at 2000 F is not a significant source and represents the most commonly used and accepted method of destruction as opposed to open burning.

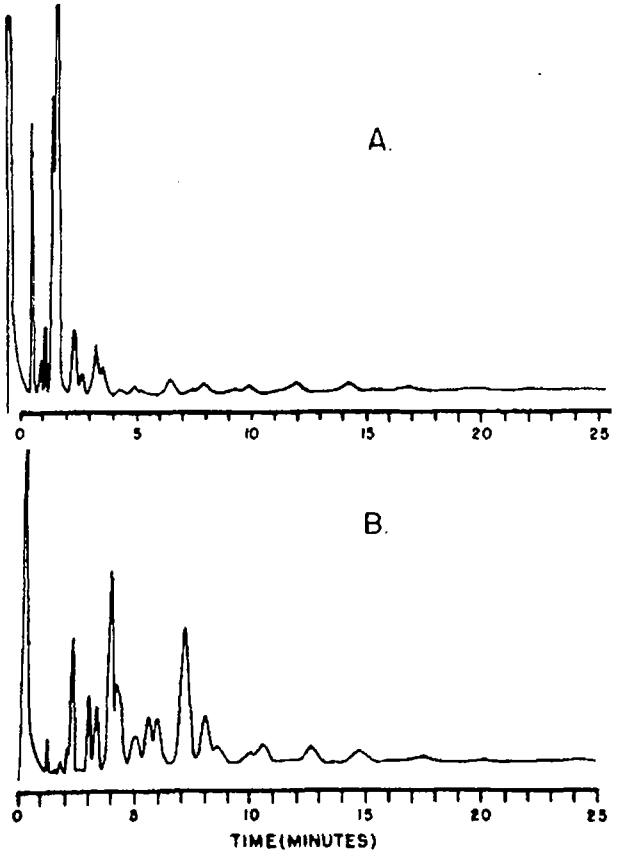

Figure 4. Gas chromatograms of Aroclor 1221 (A) and Aroclor 1232 (B) (11).

Second, loss from manufacturing sites directly into sewers and therefore rivers and lakes is another category and includes both direct dumping of waste fluids containing PCB and PCBs themselves. Because of their insoluble character, PCBs lost by this route usually are quickly bound in some organic entity, such as, river and lake sediment, algae, and protozoa. The amount of PCBs transported to the ocean and fresh water in 1970 was estimated at 4,000 to 5,000 tons. An estimated 18,000 tons were deposited in sanitary landfills, dumps, and incinerators. Another 7,000 tons accumulated in such units as heat exchangers and transformers. Third, losses through leaks in heat exchangers, transformers and capacitors represent another source. This loss has been combined with disposal of hydraulic fluid, heat transfer, and transformer oils to yield an estimated 4,000 to 5,000 tons. The last of the data represent estimations of amounts of PCBs existing at present in various segments of our environment. As a result of these annual losses, food has been contaminated whenever the situation has been correct.

CONTAMINATION OF FOOD

It is necessary to understand biological concentration where a chemical constituent like PCBs, which is lipid-soluble, is concentrated through a food chain

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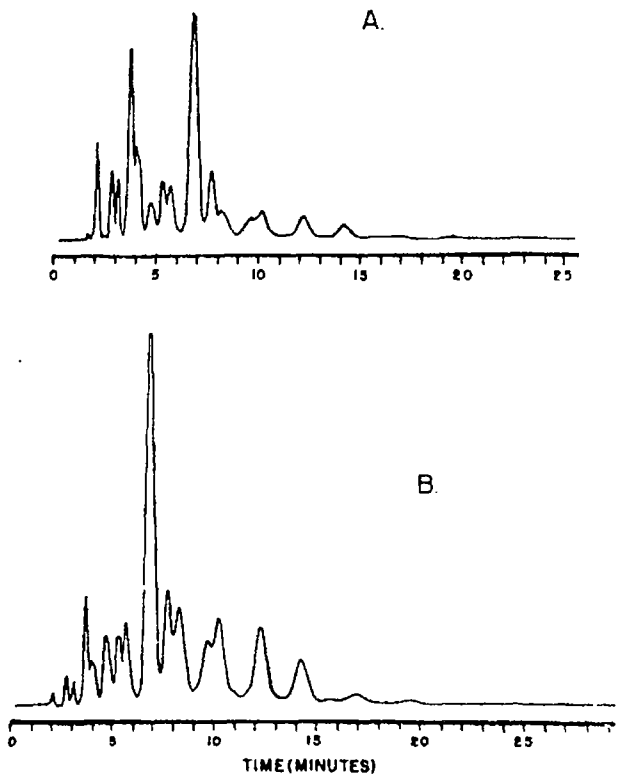

Figure 5. Gas chromatograms of Aroclor 1242 (A) and Aroclor 1248 (B) *(11)*.

(29). This is well documented and values show a magnification of 10- to 100-fold through each predator in a marine system, for example, ultimately reaching a magnitude of 10^5 to 10^7 times higher than in water *(27)*. The larger and older the fish in such an environment, the higher the level. The debacle of the supposed Coho salmon bonanza to the Great Lakes is an excellent example. No trout or salmon longer than 21 inches taken in Lake Michigan are salable presently because of PCB levels above 5 ppm on an edible parts basis *(26)*. This is the tolerance established by the Food and Drug Administration (FDA) for PCBs in fish *(6)*.

Milk has been contaminated because cows were fed silage stored in epoxy coated silos *(15, 38, 39)*. The area of concern is in Ohio, Indiana, and Kentucky. Silo walls were sealed with an epoxy paint that apparently had Aroclor 1254 as a solvent. Research showed migration of the PCBs into corn silage with the greatest concentration in that silage within 3 cm of the wall. It was suggested that the PCBs were dissolved in the silage liquor which with time descended in the silo thereby spreading the contamination. Moreover, automatic unloaders in the silo contributed to the problem by mixing the contaminated with the noncontaminated silage. Natural decontamination of cows is slow and similar to that observed with organochlorine pesticides *(15)*. Some evidence on the fate of PCBs in milk during processing showed that no change occurred in the distribution or content in finished dairy products except in skimmilk that was heated to 70 C for 10 min *(31)*. Also, these data show that, proportionately, PCBs in skimmilk and whey were higher than the concentration in milk from which these products were manufactured. This fact has been observed by others *(17, 24)* and involves the lipoprotein constituents of the milk fat globule membrane. FDA has a temporary guideline of 2.5 ppm PCBs in milk fat *(5, 6)*.

One of the most recent discoveries is that PCBs as a contaminant in paper packaging do migrate to the food product contained inside *(39)*. After investigating the problem, the American Paper Institute pointed to recycled fibers in paperboard as the source of contamination. These fibers proved to be contaminated from carbonless carbon paper *(22, 41)* and printer's inks *(41)*. Currently, because of swift action on the part of paper manufacturers, leaders in the paper industry stated that PCB concentrations presently in packaging materials are not hazardous. The Food and Drug Administration also is concerned about the amount of PCB material found in paper

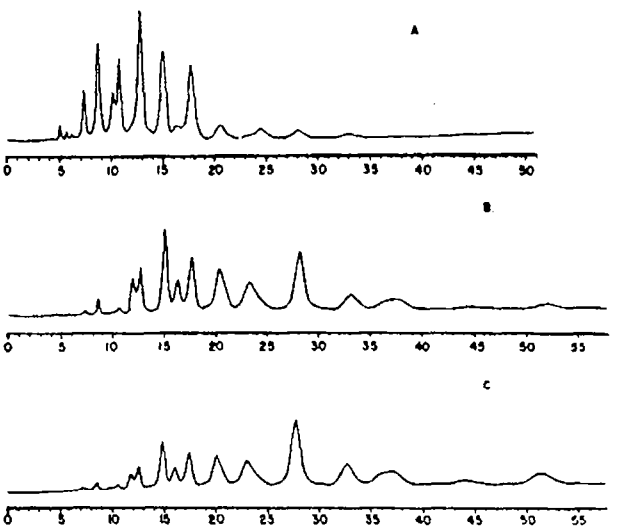

Figure 6. Gas chromatograms of Aroclor 1254 (A), Aroclor 1260 (B) and Aroclor 1262 (C) *(11)*.

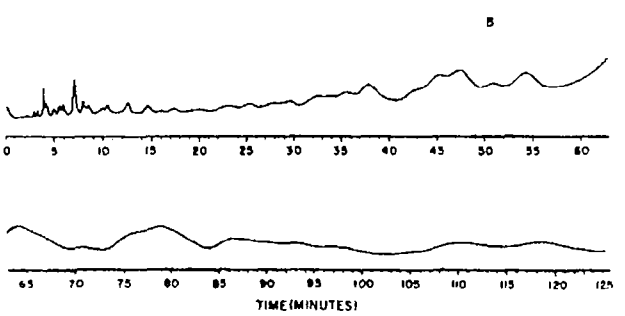

Figure 7. A gas chromatogram of Aroclor 5442 *(11)*.

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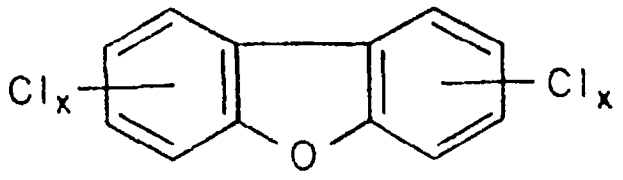

Figure 8. The structural configuration of polychlorodibenzofuran.

and paperboard. They have found PCBs in virgin paper, regular paperboard, and grey board. Presumably the PCB residues from virgin paper are attributable to environmental contamination and traces acquired during manufacturing *(6, 39)*.

Food Chemical News stated that the FDA was considering amending the law to read—no more than 0.1 ppm PCBs in pulp from reclaimed fiber *(3)*. This considered tolerance is at method sensitivity. In the interim, a "temporary guideline" of 5 ppm in food packaging materials has been established *(2, 6)*. In a survey FDA *(5)* found that although 67% of complete food packaging tested contained PCBs at levels as high as 338 ppm, only 19% of the foods in these packages contained PCBs at an average concentration of 0.1 ppm. The maximum level found in these food products was 5 ppm. About 75% of packaged infant cereals contained an average of 0.3 ppm PCBs with a high of 1 ppm. Of the recycled paper samples recently tested, 95% contained < 5 ppm PCBs but during 1970-1971 only 18% were < 5 ppm. FDA stated that progress is being made and this would in effect substantiate the statement from the leaders in the paper industry *(5)*. Of all paperboard, grey board presents the highest contamination in food packaging. Such food items as, crackers, cookies, ready-to-eat breakfast cereals, pretzels, chips, macaroni and noodle products, dry infant cereals, and dry prepared mixes have been contaminated from packaging materials *(20)*.

Hazelton Laboratories in a study supported by the American Paper Institute has examined PCB migration from food packaging *(4)*. Only materials of low gas permeability were checked. PVDC (polyvinylidinechloride or saran) coated paper was best and waxed glassine paper was second best in preventing migration of Aroclor 1242. Polyethylene films were ineffective over a long period. Foil laminates, copolymer films and paper laminates were not tested.

ANIMALS ARE AFFECTED BY PCBs

Of the animals raised by man and contaminated with PCBs, mink appear to be the most susceptible to the chemicals. When Lake Michigan Coho salmon containing high levels of PCBs was incorporated in a mink ration at the 30% level, reproduction either failed or the kits died within 24 hr of whelping. Death of adult mink resulted after 3 months on this diet *(8)*.

In another study *(1)*, Aroclor 1254 contaminated beef was added to a mink ration. All mink fed the diet containing 3.57 ppm PCBs on a whole ration basis died with no reproduction during a 105-day study. At the 0.64 ppm level only one of 12 mink produced kits and these died within 24 hr of whelp-

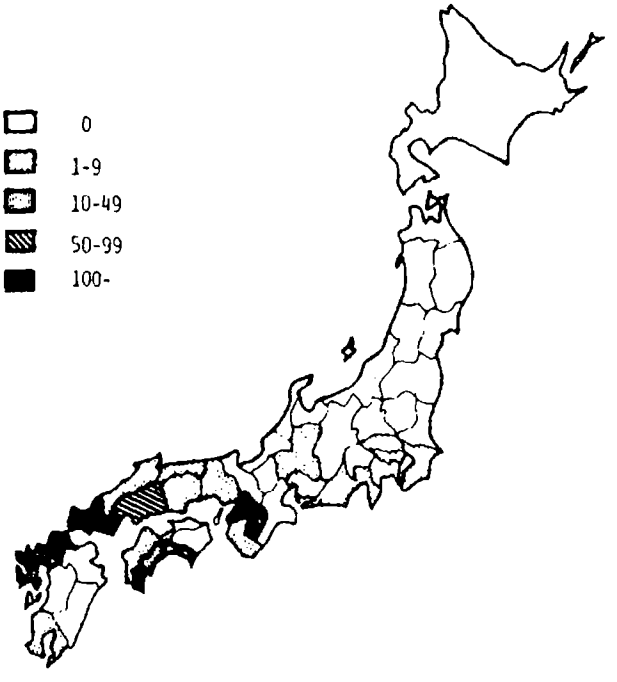

Figure 9. Number of patients with Yoshu by prefecture (23).



Figure 10. Hydropericardium in a chick fed a diet containing 50 ppm Aroclor 1248 *(33)*.

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ing. Similar results have been obtained with laboratory rats, however, dietary concentrations of PCBs used to produce reproductive failures were 100 ppm Aroclor 1254 *(13)*.

Poultry has been contaminated mostly through leaks in heat exchangers used to prepare feed or through contaminated fish meal *(39)*. Moreover, some poultry rations contain rejected bread, crackers, and cookies which were added to the feed with their packaging material. Such feed has resulted in contaminated poultry and eggs. As of March, 1972, 1,086,908 chickens were destroyed because of contamination *(5)*. FDA has established a temporary tolerance of 5 ppm PCBs in the fat of poultry and 0.5 ppm in eggs *(6)*.

The inspection staff of the U. S. Department of Agriculture (USDA) was alerted for evidence of leaks in heat processing equipment that uses toxic materials where food or feed might be contaminated *(5)*. Subsequently, FDA has in effect banned equipment using PCBs *(5)*.

PCBs In Humans

PCB contamination in humans *(32, 45)* has been found in quantities greater than 1 ppm in 31.1% of 637 adipose samples examined, while 19.6% had between trace and 1 ppm. The samples were collected in 18 states and the District of Columbia. Positive samples were obtained in all the states. Apparently humans like other mammals can degrade the PCB isomers that contain a few chlorine atoms; therefore chromatograms initially will show small peaks and later peaks indicative of high concentrations. In a study done in collaboration with the Michigan Department of Public Health, even house dust sweepings in homes of occupationally exposed population in Southwest Michigan contained up to 180 ppm PCBs.

Some Japanese people reportedly have been contaminated with PCBs in rice oil *(13, 23)*. The disease, called "Yusho" or oil disease, was first observed in October of 1968. The map of Japan (Fig. 9) shows the frequency of the disease by prefecture. The highest incidence occurred in Fukuoka-Ken. From a symptomatic standpoint, of the 136 initial cases 38.3% of the patients showed swelling of the upper eye lids and increased eye discharge and 33.1% exhibited acne types of skin eruptions. Others showed dark brown pigmentation of the nails and skin, accentuation of hair follicles, numbness and swelling, or edema of the limbs. To date 1,057 cases of Yusho have been reported. Most of the patients apparently used a particular brand of canned rice oil which contained between 2,000 and 3,000 ppm of Kanechlor 400, a PCB with 48% chlorine. The oil became contaminated through a leak in a vacuum deodorizer used for processing. This is the only case where significant contamination of humans has resulted from one source of food. A follow-up study has been conducted to show the current state of the patients and growth effects on children. Of 23 boys and 19 girls affected with Yusho during 1967-1969, the weight and height gains of boys decreased significantly while no effect was observed with the girls when compared to their classmates. About 50% of adult patients have shown improvement over original clinical symptoms, while about 10% showed worsening effects. Such effects as persistent headache, numbness in limbs, weight loss, and fatigue are clear indications that the effects of Yusho are extremely difficult to overcome.



Figure 11. External symptoms of edematous condition. Note gasping (33).

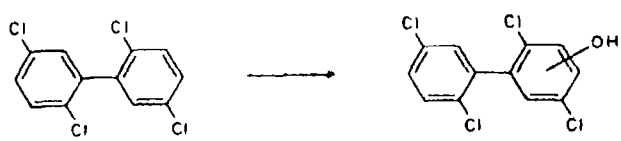

Figure 12. Metabolic product from 2, 2, 5, 5'-tetrachlorobiphenyl fed to rats and pigeons *(19)*.

Experiments With Animals

A study conducted at the University of Wisconsin and using rats has shown hypertrophy of the liver, lack of weight gain, and proliferations of the endoplasmic reticulum of the liver *(28)*. Concurrent with increased liver size was an increase in hepatic enzyme activity. The evidence of hepatic enzyme activity has been observed by others *(12, 29, 36, 40)* Moreover, PCBs have been shown to be antihormonal in

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hepatic microsomes *(9, 25, 30, 36)*. This can be correlated with poor reproduction in animals fed PCBs as well as retarded development of secondary sex characteristics in chicks *(34)*. The edema observed in the Yusho incident has also been noted in chicks. Evidence from research with one-day old chicks indicates general edema and provides a vivid example of hydropericardium (Fig. 10) *(33)*. The chick was fed a diet containing 50 ppm Aroclor 1248. The heart sac contained 7 ml of fluid. Also, results of edema can be seen externally in chicks with the gasping symptom shown in Fig. 11. Acnegenic reaction has been vividly shown by Vos and Beems using rabbits *(42, 43)*.

STABILITY OF PCBs

PCBs do not persist *ad infinitum*. Research has shown that 4-chlorobiphenyl fed to rabbits was excreted in the urine as 4-(p-chlorophenyl) phenol and 4-chlorobiphenyl glucosiduronide *(10)*. Subsequently, this metabolic hydroxylation of lower PCB homologs (Fig. 12) was identified in rats and pigeons as one route of excretion as a water soluble product *(19)*. Also, exposure of PCBs to ultraviolet energy at 310 nm causes polymerization, formation of hydroxylated and carboxylated products, and reductive dechlorination *(18, 37)*.

SUMMARY

The mechanism of toxicity of PCBs in humans and animals is still unclear. There are numerous areas where no substantive information exists. On the one hand we find extreme sensitivity with mink and on the other lack of sensitivity in some birds and mammals. PCBs appear to cause no mutagenic effects; are teratogenic when fed to chicks but not to rats *(13)*. Two instances of bladder cancer have been identified in rats *(13)*. Of all the factors studied, reproduction appears to be the most vulnerable function in birds, fish, and mammals *(40)*.

One of the most perplexing problems yet unresolved is the involvement of the various homologs and isomers, i.e., which are toxic, which are not; how is toxicity affected by the position of chlorine substituents, and is there a synergistic effect among them.

There are five distinct pathological patterns for humans—acnegenic, liver damage, porphyria, edema, and immunosuppression *(23, 42)*. However, none of the underlying reactions in the human body have been studied or reported in detail. It is obvious from a search of the literature that human contamination is ubiquitous much as with DDT and its analogs and the toxicity to humans is moderate to high especially when PCBs are inhaled as vapors. Again, no studies have outlined the fate of PCBs when ingested. We do know that, like organochlorine pesticides, PCBs are lipophilic and therefore stored in adipose tissue. When the total picture of the cases of Yusho in Japan is examined, perhaps a fuller understanding will be available of the toxicity, long-term effects, and rate and route of discharge of PCBs from the human body.

Finally it is apparent that Monsanto has limited its sales and controlled the uses of PCBs. Perhaps foreign manufacturers will follow this example. The concentration of PCBs in the environment is great and widespread. It will remain for some time *(35)*. How long it will be here appears impossible to estimate.

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