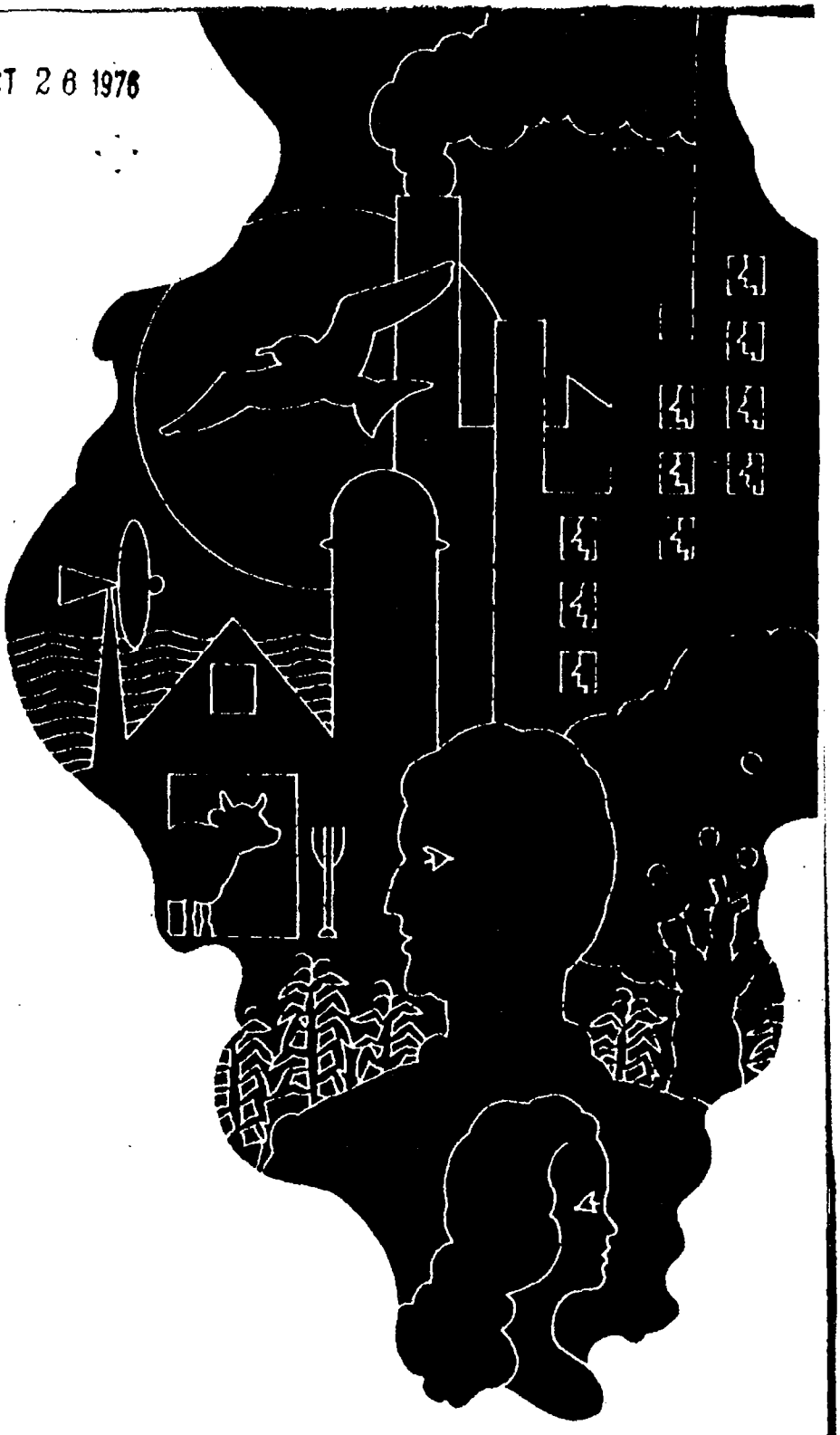
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POLYCHLORINATED BIPHENYLS
HEALTH EFFECTS AND RECOMMENDATIONS

IIEQ Document No. 76/05

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POLYCHLORINATED BIPHENYLS

HEALTH EFFECTS AND RECOMMENDATIONS

This document (EHRC Document No. 16) was prepared
for the Illinois Institute for Environmental Quality

by

The Environmental Health Resource Center

State of Illinois
Institute for Environmental Quality
Samuel G. Booras, Director

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FOREWARD

This publication deals with "Polychlorinated Biphenyls Health Effects and Recommendations". The Institute's Environmental Health Resources Center has prepared the material based on literature searches, investigation, and critical reviews. Recommendations for further research are made, both as a guide for research agencies, and as evidence of the state-of-the-art with respect to Polychlorinated Biphenyls.

The Environmental Health Resources Center is a facility of State government established by the Institute for Environmental Quality. Its services are available to anyone interested in environmental health problems.

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NON-TECHNICAL SUMMARY

Polychlorinated biphenyls (PCBs) are a group of chemicals which contain varying percentages of chlorine arranged on a double-ring chemical structure called biphenyl. Monsanto Company is the sole U.S. producer of PCBs and calls its products by the trade name AROCLOR. Polychlorinated biphenyls have been manufactured in the U.S. since 1929 in response to the electrical industry's need for an improved insulating fluid which is more fire resistant and also more resistant to biological and physical degradation. Their usage is now limited to what are called "closed systems" significantly reducing their immediate release into the environment.

Animal studies have revealed that PCBs can have deleterious effects on numerous organ systems including the liver, kidney, adrenal gland, spleen and skin; abnormal changes in the chromosomes of Ring Dove Embryos and in the reproductive capabilities of female monkeys have also been noted. In 1968, two thousand Japanese people suffered various skin and eye disorders after eating PCB-contaminated rice oil.

Environmental levels of PCBs remain quite high. They may be found in certain foods, especially fish in which PCB levels may be as much as a million times higher than the levels of the surrounding waters because PCBs become concentrated in fatty tissues.

Polychlorinated biphenyl liquids and electrical units containing PCBs should be destroyed or disposed of in a manner approved by the State and Federal Environmental Protection Agency to avoid needless environmental pollution. Suitable replacements for PCBs are being investigated.

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I. SUMMARY AND RECOMMENDATIONS

Polychlorinated biphenyls (PCBs) are one member of a class of synthetic chlorinated organic compounds composed of two, six carbon ring structures (Phenolic rings) with 10 possible chlorine attachments. These aromatic compounds encompass a complex heterogeneous group of 210 different chlorine-substituted isomers, although the number observed in commercial formulations is much smaller. Polychlorinated biphenyls are also highly toxic agents which have been shown to cause harmful effects in numerous animal species, including man. They are present in varying amounts in food, drinking water and air. Polychlorinated biphenyls have been used and manufactured in Europe, Japan, the Soviet Union and the United States. The sole U.S. producer is the Monsanto Company which has given the trade name Aroclor to its products.

Animal studies have revealed that PCBs can adversely affect numerous organ systems including the liver, kidney, adrenal gland, spleen, and skin. Other studies have shown that they may cause chromosomal aberrations in vivo in Ring Dove Embryos, but no aberrations as studied in Drosophila. Animal studies have also indicated that PCBs suppress the immune response system. Polychlorinated biphenyls when fed chronically to rats caused hepatic adenofibrosis and biliary epithelial hyperplasia similar to lesions caused by butter yellow (p-dimethylamino-azobenzene), a known carcinogen. Contamination of PCBs with compounds such as the chlorinated dibenzofurans (CDFs) and chlorinated naphthalenes have been suggested as the causative carcinogenic agents. This controversy is unresolved and needs further investigation. Other very recent experiments have indicated that as little as 2.5 parts per million (ppm) of a PCB (Aroclor 1242) in the diet of monkeys has caused loss of hair on the face and neck, as well as the development of acne and other skin lesions. Furthermore, the reproductive capabilities of PCB-fed female monkeys were affected as evidenced by the development of a greater number of both resorbed fetuses and significantly undersized infants. It has also been shown that weanling rats are more susceptible to Aroclor 1254 and 1260 than adult rats as determined by acute toxicity studies.

Despite the numerous research articles indicating the toxicity of PCBs for animal species and their possible implications for human beings, the best

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available knowledge of the effect of PCBs on man comes from the "Yusho" incident in which over 2,000 Japanese people became intoxicated by consuming PCB-contaminated rice oil. Many of the toxic effects which the afflicted Japanese people experienced were similar to results reported in animal studies. The lesions of the skin, facial swelling, and neurological disorders were similar to results reported in animal studies. Known toxic effects of PCBs in humans include chloracne, pigmentation of the skin and hands, distinctive hair follicles, excessive eye discharge, and swelling of the eyelids.

Even though there is considerable evidence that PCB exposure is harmful to human life, the environmental levels of PCBs still remain quite high. For example, two tributaries of Lake Michigan have levels of Aroclor 1254 consistently exceeding 100 parts per trillion (ppt) while the present EPA recommended water quality criteria is 1 ppt. Of greater concern is the fact that residents of Chicago draw their drinking water from Lake Michigan which has PCB levels in certain areas of the Lake between 4 and 10 ppt. Fish and other aquatic animals accumulate PCBs to levels of the order of 10^4 times higher than those in the ambient water. Predators at the top of the food chain such as birds, seals, and sharks may accumulate PCBs to levels 10^7 or more times the levels in the ambient water.

Much of the problem with respect to humans and PCB intake has to do with the fact that man usually resides at the top of the various food chains. Once PCBs get into food chains involving birds and mammals, biological magnification seems to occur with the concentration increasing by a factor of 10-100 at each step. Additionally, PCBs are poorly metabolized and tend to accumulate in lipid-rich animal tissues and organs.

PCBs have been manufactured in the United States since 1929 in response to the electrical industry's need for an improved dielectric insulating fluid with increasd fire resistant benefits when used in transformers and capacitors. It has been speculated that 400,000 tons of PCBs were produced between 1948 and 1973. The more highly chlorinated PCB isomers are highly resistant to microbial and physical chemical action in the environment.

Despite the all too apparent environmental problems associated with PCBs, they have remarkable properties which have prompted their use in numerous industrial products such as hydraulic fluids, plasticizers, adhesives

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(asphalt and concrete), printing products (carbonless carbon paper) and paper coating. They are still utilized as filling agents on impregnants in electrical transformers and capacitors. Since 1971, Monsanto Company voluntarily restricted its sales to only "closed" systems in transformers and capacitors; this has been a significant factor in restricting the accessibility of PCBs to the environment.

The action by Monsanto to restrict PCB sales to closed systems was a major step in preventing the immediate release of PCBs to the environment. However, Monsanto is still producing about 20,000 tons of PCBs each year. This material must be properly disposed of when it is no longer useful. There are 6 major incinerators in the United States to handle discarded PCB waste. If waste products are sent to these incinerators, needless environmental pollution can be avoided. Unfortunately, many companies discarding their old electrical units (containing PCBs) are still discharging many pounds of PCBs into the atmosphere and waterways each day.

As a result of the current state of our knowledge concerning the environmental and human health effects of polychlorinated biphenyls, the Environmental Health Resource Center supports the following national policy and research recommendations:

NATIONAL POLICY RECOMMENDATIONS

1. Polychlorinated biphenyls should no longer be permitted to be discharged into surface and ground waters.

2. Polychlorinated biphenyl liquids and electrical units containing PCBs should be destroyed or disposed of in a manner approved by the State and Federal Environmental Protection Agency (EPA).

3. Equipment containing PCBs should be labelled as such.

4. The industrial usage of PCBs in closed systems should be evaluated in light of findings of suitable replacements.

5. Proposed tolerances for PCBs should be made with regard to the properties of the different isomers.

6. The food packaging industry should either cease using recycled paper which contains PCBs, or make use of an impermeable barrier on the inner surface of the packages, thus restricting the transfer of PCBs into food.

7. The Food and Drug Administration (FDA) tolerance level for PCBs in fish should be lowered from 5 ppm to 2 ppm.

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RESEARCH RECOMMENDATIONS

1. Research on the replacement of PCBs with a substitute chemical in closed electrical systems and capacitors.

2. Further research for the purpose of setting standards with regard to toxicity and carcinogenicity of PCBs in humans.

3. Research to determine if the lack of a functional glucuronic enzyme pathway predisposes individuals to unusual accumulation of PCBs.

4. Determination of the relative toxicity of different isomers with respect to standard setting.

5. More research studies on the kinetics of PCBs with regard to absorption and distribution through different organs including the lungs with the development of appropriate animal simulation models which would lead to extrapolative predictions for man.

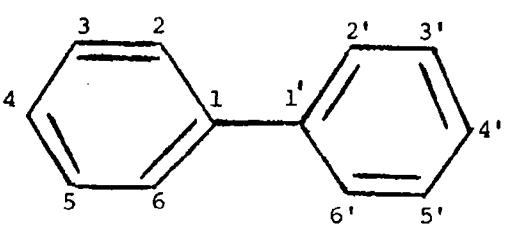
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II. CHEMICAL STRUCTURE

Polychlorinated biphenyls are one member of a class of chlorinated organic compounds composed of two, six carbon ring structures (phenolic rings) with 10 possible chlorine attachments. These aromatic compounds encompass a complex heterogeneous group of chemicals. Two hundred and ten different chlorine-substituted biphenyl isomers are possible, but the number observed in commercial formulations is much smaller (Figure 1). The different commercial products contain mixtures of isomers of biphenyls chlorinated to different degrees to meet specific operational specifications and may vary chemically from batch to batch.[1,2]

Polychlorinated biphenyls have been used and manufactured in Europe, Japan, the Soviet Union, and the United States.[3] The sole U.S. producer is the Monsanto Company which has given the trade name AROCLOR to its products.[4] Aroclors are distinguished by using a four digit numbering system. The first two digits, 12, specify polychlorinated biphenyl and the last two digits specify approximate weight percentage of chlorine in the mixture (e.g., Aroclor 1254).[1,4]

Trade name for known PCB containing products produced by foreign manufacturers include Clophen (Germany), Fenclor (Italy), Kanechlor and Santotherm (Japan), Phenoclor and Pyralene (France), and Sovol (U.S.S.R.).[1,2]



BIPHENYL

Figure 1: Biphenyl nucleus showing 10 possible chlorine attachments; positions 2-6 and 2'-6' may be substituted by chlorine. Two hundred and ten different chlorine - substituted biphenyl isomers are possible.

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Polychlorinated biphenyls were first identified in environmental samples in 1966. They were established as interference peaks on gas liquid chromatographic analysis of DDT and found to couple with DDT when analyzing the chlorinated pesticide residue.[5]

III. INDUSTRIAL USES

Most individual polychlorinated biphenyls are solids at room temperature, but the mixture may range in consistency from oils to viscous liquids or resins.[2,4,5] Table 1 denotes how each form can be used. Polychlorinated biphenyls have very broad industrial uses because of the following properties: non-flammability, high chemical stability, low vapor pressure, inert decomposition products, high dielectric strength and low dissipation factor.[6]

TABLE 1

WHERE PCBs WERE FOUND AND IN WHAT FORM PRIOR TO 1972

RESIN	LIQUID	SOLIDS
Protective coating	Dielectrics	Impregnate carbon resistors
Plasticizers and extenders	Hydraulic fluids	Sealers
Sealers in: waterproofing compounds and putty	Thermostats	Impregnating agents for electrical apparatus
Asphaltic materials	Cutting oils	
Printing inks	Extreme pressure lubricants	
Synthetic adhesives	Grinding fluids	
	Heat transfer media	

Since 1970, when the first substantial data concerning PCBs in the environment were recorded, Mousanto Company's production has been reduced; from 1960-1970 Monsanto's peak production was 42,527 short tons of PCBs. By the end of 1972, it was down to 20,236 short tons.[4,7] These restrictions which cut production in half resulted in a reduction in uses of PCBs in applications involving open systems where their loss to the environment had been less controllable. Major applications affected by the Company's program of terminating sales of PCBs to open application were in carbonless paper,

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fire resistant hydraulic fluids, heat transfer fluids and plasticizers. Monsanto made the decision to continue supplying PCBs only to the electrical power distribution industry where they were marketed as dielectric fluids in "closed" or sealed systems such as transformers and capacitors.[8]

At one time, fluorocarbons were used in capacitors, but it was found that they have low dielectric constants and also have decomposition products that are toxic. In 1969, 96% of United States transformers used mineral oil. This lasted until it was found that PCBs prevented fire and explosion hazards. The major value of PCB liquids with 4 or more substituted chlorines per molecule is the non-flammability of the PCB itself, as well as its decomposition products. They can be used as fluids at temperatures up to 700° F without the danger of explosions or fire. In many areas, electrical codes required the use of askarels (PCB capacitor liquids, commonly referred to as askarels, are mixtures of chlorinated biphenyls and chlorinated benzenes). The use of askarels is more expensive (1.3 X the cost of mineral oil); however, fire underwriters will not accept use of mineral oil. When fluorocarbons were tested in the U.S., their volatility and high cost quickly eliminated them from consideration for continued use.[6]

Polychlorinated biphenyls are also used as lubricants in hydraulic fluids. Because possible replacements have been found, the degree to which PCBs are now being used is unknown. Tricresyl phosphate, for example, is chemically stable as an additive in lubricants and although toxic, it is more biodegradable than the PCBs.[6]

With rare exceptions, after compiling the properties needed in order to make capacitors, transformers, hydraulics, gas turbines and vacuum pumps work efficiently and safely, PCBs are by far the best chemical fluid available.

IV. WHERE PCBs ARE FOUND AND THEIR MODE OF TRANSPORT

Prior to 1970, 60% of sales were for closed systems (electrical and heat transfer uses); 25% for plasticizer applications; 10% for hydraulic fluids and lubricants; less than 5% for miscellaneous applications such as surface coating, adhesives, printing inks and pesticide extenders. Exports by Monsanto had averaged 13% of domestic sales for 1963-1970. Imports are

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thought to be small, comprised primarily of plasticizers in resins and adhesives, transformer oils and capacitor fluid in electrical equipment. Exports to Canada are equivalent to 7% of United States sales. As of 1971, approximately 90% of sales were for closed electrical systems, and by 1972, supposedly 100% of sales were for closed electrical systems. 1, 4, 9

In the summer of 1971, Monsanto Company stopped producing Aroclor 1260. They also reduced production of the higher numbered PCBs that are considered more persistent in the environment (i.e., 5, 6, 7 chlorines/biphenyl). The more highly chlorinated isomeric forms of Aroclors (1254 and up) comprised 30% of sales prior to 1971; this fell to 22% by 1972.[4] (See APPENDIX, P. 35).

V. ROUTES INTO THE ENVIRONMENT

Data on the amount of PCBs lost into the environment are limited. Possible routes that have been considered are the following:[4]

1. Leaks from sealed transformers and heat exchangers.
2. Leaks of PCB containing fluids from hydraulic systems which are only partially sealed.
3. Spills and losses in the manufacturing of PCBs or PCB containing fluids.
4. Vaporization or leaching from PCB containing formulations.
5. Disposal of waste PCBs or PCB containing fluids.

Any of these possible routes of PCB movements into the environment could eventually end up in the food chain. Examples are the Japanese rice oil contamination resulting from heat exchanger leaks[10] and the Escambia Bay area of Florida where leakage of hydraulic fluid from an air compressor contaminated chicken feed on the Holly Farms.[11]

The input into soil by use of Aroclors as pesticide extenders is believed to have been small. Based on purchase reports, it has been

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estimated that less than 10 tons/year are dumped into soil. Direct discharge into oceans by dumping of hydraulic fluids and lubricants from ships has been considered infinitesimal, but may have been locally significant.[4]

An important factor to consider is which Aroclor isomer is being discharged. This can be determined easily from sales and chemical records. Prior to 1972, most PCBs released into the atmosphere were Aroclor 1248 and 1260, vaporized from burning dumps. Discharge into waters are primarily isomeric forms of Aroclors that are used in hydraulic fluids and lubricants, including mixtures of Aroclor 1242 and 1260. The residual in dumps will have a large fraction of the Aroclor 1242.[4]

VI. RATE OF LOSS INTO THE ENVIRONMENT

The following figures represent orders of magnitude estimates of rates of loss. These estimates are yearly figures, most closely resembling losses incurred during 1970, which was the peak year of PCB production.

Transformers are fairly permanent installations, and therefore, only 10% of sales of transformer fluid is to replace oil that was removed. Ninety percent is for new units. The useful life of capacitors is usually under a decade. It has been estimated that the rate at which capacitors are discarded is equal to 1/2 the rate of production. A similar figure is assumed for the scrapping of heat exchangers. It is estimated that the rate of evaporation of plasticizers amounts to 10 to 20% of sales. The rate of disposal of plasticizers into dumps is assumed to equal the residual 80 to 90% of sales since numerous plastic objects have short useful lives. Hydraulic fluids and lubricants are rarely re-used; thus, it is assumed that a major fraction of these fluids used for this purpose, together with those going into miscellaneous applications, were scrapped at rates about equal to those of corresponding sales.[4]

On the basis of these gross approximations, it seems that only about 20% of the 1970 sales in North America, about 7×10^3 tons, represented a net increase in the amount of PCBs in service (in transformers, heat exchangers and capacitors). The remainder is considered to have been discharged into the environment; $1\text{-}2 \times 10^3$ tons by evaporation of plas-

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ticizers; 4-5 X 10^3 tons by leaks and disposal of hydraulic fluid and lubricants plus small quantities by disposal of heat transfer and transformer oils; and 22 X 10^3 by disposal in incinerators, dumps and sanitary landfill. Of the 22 X 10^3 quantity, it has been estimated that 10 to 20% were incinerated and 2% were vaporized, mainly by open burning of wire scraps, automobile components and material in dumps.[4]

VII. RATES OF TRANSPORT WITHIN THE ENVIRONMENT

Transport mechanisms take complex pathways within natural biogeochemical cycles. For example, vaporized PCBs may be absorbed on particulates, transported with the prevailing wind and deposited on land or water by particle sedimentation or rain-out. Polychlorinated biphenyls in streams may be absorbed by the waterborne particulates on benthos. Absorbed PCBs may diffuse into bottom sediments, redissolve in the water stream or be entrained into sediment eroded from bottom surface.[10,12] This whole process is further complicated by the assimilation, transport and degradation of PCBs by the biota.[13]

A major part of the PCBs discarded into dumps is in closed containers or plastic resins. This rate of loss will be low until the confining material is degraded and the PCBs subsequently released, usually diffusing slowly thru surrounding soil.[4] Polychlorinated biphenyls from discarded non-carbon paper may rapidly be diffused into the environment. However, because much of this paper is recycled, the actual rate of diffusion into the environment will often be retarded. PCB-impregnated paper is often used in the packaging of various common food products. This is now recognized as another avenue of food contamination.[14,15] Theoretically, the rates of transport may be calculated from knowledge of the physico-chemical properties of PCBs and pertinent data on atmospheric conditions, particulate transport, hydraulic dispersion, bottom sediment transport and biological degradation rates. Presently, data are too incomplete and the interactions are too complex to attempt formulation of anything more than the crudest of transport models.[4]

To avoid needless environmental pollution with PCBs and to stop the

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discarding of them in dumps, rivers and soil, the Monsanto Company built an incinerator at their plant in St. Louis, Missouri. It runs on 30 million BTU per hour and can handle 10 million pounds per year of PCBs and other discardable chemicals. It has been shown that this 10 million pound capacity only requires 5% of use time for repairs and cleaning.[7]

There are 6 other such incinerators in the United States. They are located in Pittsfield, Massachusetts; Model City, New york; Wilmington, Delaware; Gloucester City, New Jersey; Batton Rouge, Louisiana; and Houston, Texas.[7] These incinerators, if timed and heated properly, can burn PCBs and not let any toxic pollutants escape into the environment. Federal EPA proposed Effluent Standards for PCBs exist for both fresh and salt water.[16,17] Recommended procedures for disposal of PCB-containing wastes (industrial facilities) are outlined by the Federal EPA in the Federal Register. The recommended options for disposal of PCB-containing wastes in order of priority are incineration and controlled land disposal.[18]

VIII. PCB LEVELS IN ILLINOIS

A. Levels in Lake Michigan Fish Species

The Illinois EPA initiated a program in 1970 to obtain pesticide residue levels in several species of Lake Michigan fish. In 1971 and 1972, testing included PCBs.

A total of 209 fish were analyzed over the 2 year period, including samples of yellow perch, chubs, carp, coho salmon, alewife and brown trout. Difficulties in obtaining all species in 1972 limited collections to the yellow perch and chubs. Fish were collected from commercial fishermen and the Illinois Conservation Department in the Chicago and Waukegan regions of Lake Michigan. Table 2 shows that the edible portions of species of fish with the highest fat content (chubs and alewives) had the highest level of Aroclor 1254.[19]

Lake Michigan salmon containing PCB levels (regarded by the FDA as a food additive) in excess of the prescribed tolerance level of 5 ppm were seized by the FDA in May 1975.[20] The actual amount seized and PCB levels in the fish were not revealed in the reference, however, 1974 data from the Michigan Department of Natural Resources give values for PCB levels in lake trout and coho salmon ranging from 10 to nearly 25 ppm which is in excess of the present FDA maximum allowable concentration of 5 ppm for fish and shellfish.

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TABLE 2

POLYCHLORINATED BIPHENYLS FOUND IN EDIBLE PORTIONS OF SPECIES OF LAKE MICHIGAN FISH (1971, 1972)[19]
Values (ppm on a wet weight basis) for approximately 10 fish were used for each measurement.

SPECIES	SIZE RANGE IN INCHES	SAMPLE LOCATION	AROCLOR (MEAN VALUES) 1242	1254
Yellow Perch (1971)	7.0 - 12.0	Chicago	.1	0.3
(1972)	8.0 - 9.5	Waukegan	N.A.[a]	0.3
Chub (1971)	9.0 - 12.0	Waukegan	.3	2.6
(1972)	8.0 - 10.0	Waukegan	N.A.[a]	2.9
Carp (1971)	17.0 - 27.5	Chicago	1.0	1.5
Coho Salmon (1971)	18.0 - 23.5	Chicago	1.0	1.3
Alewife (1971)	6.0 - 7.0	Chicago	N.D.[b]	3.0

[a] N.A. - Not analyzed for
[b] N.D. - Not detected

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In 1974, the Wisconsin Department of Natural Resources found levels exceeding 5 ppm in Lake Michigan chinook and coho salmon, brown trout, tiger trout, lake trout, and carp. The levels were as high as 43.8 ppm in lake trout and 51.6 ppm in carp. The most contaminated fish in the U.S. to date have been found in the upper reaches of the Hudson River, near and below two General Electric plants. These plants manufactures electrical capacitors in which PCBs are used as insulating fluid, samples (1974) of yellow perch and shinner minnows showed residues of 17 and 78 ppm, respectively; one rock bass sample contained 350 ppm.[21]

B. Levels in the Sediment of Lake Michigan and Some Tributary Streams

The results indicated that levels of Aroclor 1254 and 1242 found in Lake Michigan sediments in 1971 ranged between 2.48 and 46.92 ppb and ND (not detectable) to 106.07 ppb, respectively (Table 3 and Fig. 2). In tributary sediments, the levels for Aroclor 1242 ranged from ND to 553.00 ppb with the maximum values found at an unnamed channel in Waukegan (Table 4 and Fig. 2). Aroclor 1254 ranged from 1.54 to 232.0 ppb with the maximum level found at Pettibone Creek in North Chicago (Table 4).[19]

C. Levels in the Water of Streams and Sewage Effluent Entering Lake Michigan During 1971 and 1972

The results indicated the Aroclor 1242 levels were markedly reduced in 1972 compared to 1971 in both the stream and sewage discharge water. Aroclor 1254 levels also decreased from 1971 to 1972 in sewage discharge, but stream discharge levels increased slightly (Table 5 and 6). Also, in most cases, sewage treatment plant effluents were shown to discharge higher concentrations of PCBs than the tributary streams in 1971, but in 1972, PCB levels were higher in the tributary streams (Figure 3).

Highest concentrations of PCBs in sediments were obtained in tributary streams and ravines, indicating possible contaminations by residential spraying and industrial discharge.

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Highest levels were obtained in industrial areas in North Chicago and Waukegan. In sediments, PCB levels were generally higher than pesticide (DDT, heptachlor epoxide, dieldrin, methoxychlor, phtalates and lindane) levels.[19]

It is also important to point out the extreme variablility in PCB levels (Table 5). In 1971, for example, water from the Waukegan River showed over 1,800 ppt PCB on one day, but less than a month before, samples revealed no detectable levels.[19]

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TABLE 3

PCBs FOUND IN LAKE MICHIGAN SEDIMENTS IN ILLINOIS (1971)
Values are expressed in parts per billion (ppb) based on a dry weight basis.[19]

SAMPLE LOCATION	AROCLOR 1242	AROCLOR 1254
1 to 3 Miles Offshore		
*NSSD Park Ave. STP (Highland Park)	11.11	12.42
NSSD Lake Forest STP (Lake Forest)	10.51	7.02
NSSD Lake Bluff STP (Lake Bluff)	44.36	14.45
NSSD North Chicago STP (North Chicago)	106.07	26.54
NSSD Waukegan STP (Waukegan)	17.32	11.97
Lake Bed Station 60	4.46	8.63
Lake Bed Station 55	3.58	3.15
Lake Bed Station 52	8.48	3.33
Lake Bed Station 49	13.65	12.42
Lake Bed Station 46	49.33	38.65
Lake Bed Station 43	83.35	46.92
Lake Bed Station 40	17.23	9.38
Lake Bed Station 37	30.82	33.50
Lake Bed Station 34	1.24	2.48
Lake Bed Station 31	ND	3.87
Lake Bed Station 28	18.55	17.25
Lake Bed Station 24	2.48	5.83
Lake Bed Station 21	8.60	6.64
Lake Bed Station 18	10.53	5.56
Lake Bed Station 15	7.43	5.26
Lake Bed Station 12	19.25	17.45
Lake Bed Station 8	24.76	16.30
Lake Bed Station 5	46.11	34.52
Lake Bed Station 2	4.98	8.36
	(23.66)	(14.66)

*NSSD - North Shore Sanitary District

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TABLE 4

PCBs FOUND IN SEDIMENTS OF SEVERAL STREAMS
AND RAVINES TRIBUTARY TO LAKE MICHIGAN (1971)
Values expressed in ppb on a dry weight basis [19]

SAMPLE LOCATION	AROCLOR 1242	AROCLOR 1254
10 to 50 Yards Upstream From Lake		
Bull Creek (Zion)	13.00	9.10
Dead River (Zion)	12.30	6.29
Unnamed channel (Waukegan)	553.00	83.04
Waukegan River (Waukegan)	374.00	131.00
Pettibone Creek (North Chicago)	173.40	232.00
Stone Gate Lane Ravine (Lake Forest)	2.48	8.74
Berry Hall School Ravine (Lake Forest)	6.34	12.34
Cary Avenue Ravine (Highland Park)	3.00	17.90
Ravine Drive Ravine (Highland Park)	ND	6.38
Park Ave Ravine (Highland Park)	4.32	1.54
Barat Ravine (Lake Forest)	4.37	2.91
Ravine Park Ravine (Lake Bluff)	1.31	2.54
Kellogg Creek (Zion)	1.77	2.56
	(95.77)	(32.27)

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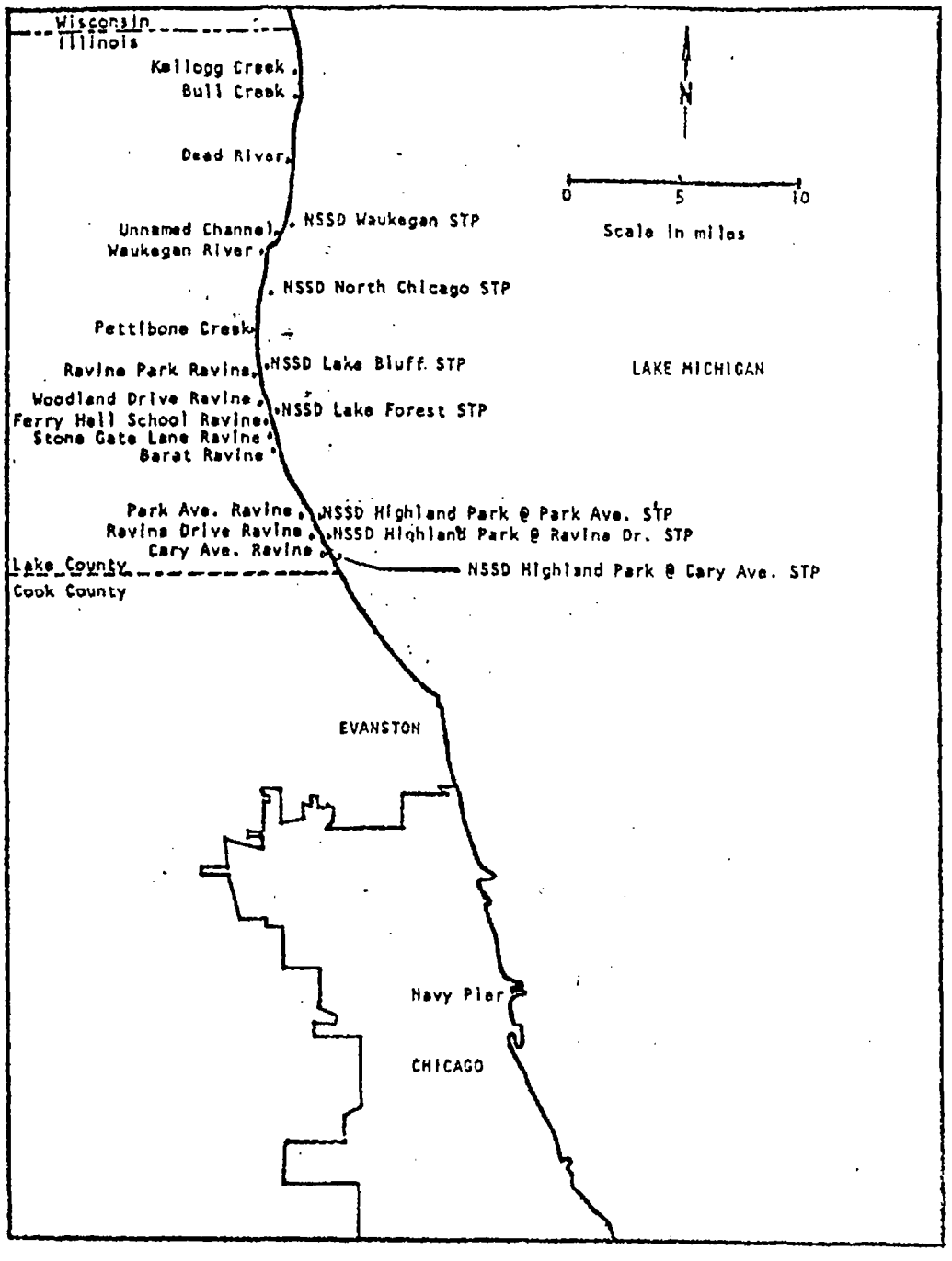


Figure 2: Locations of sediment sampling stations along Lake Michigan in Illinois.[19]

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TABLE 5

PCBs FOUND IN WATER SAMPLES FROM
ILLINOIS STREAMS TRIBUTARY TO LAKE MICHIGAN (1971-72)
Values are expressed in parts per trillion (ppt).[19]

SAMPLE LOCATION	DATE COLLECTED	AROCLOR 1242	AROCLOR 1254
Waukegan River	8/18/71	1810.0	388.0.
Waukegan River	7/29/71	ND	ND
Pettibone Creek	8/26/71	187.0	194.0
Pettibone Creek	7/29/71	140.0	192.0
		(534.2)	(193.2)
Waukegan River	5/24/72	62.0	114.0
Waukegan River	5/23/72	120.0	136.0
Waukegan River	5/25/72	57.0	61.0
Waukegan River	6/29/72	84.0	119.0
Pettibone Creek	5/24/72	ND	111.0
Pettibone Creek	5/25/72	ND	107.0
Pettibone Creek	6/29/72	653.0	841.0
		(125.1)	(213.0)

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TABLE 6

PCBs FOUND IN WATER SAMPLES FROM
SEVERAL ILLINOIS SEWAGE PLANTS TRIBUTARY TO LAKE MICHIGAN (1971-72)[19]
Values are expressed in ppt.

SAMPLE LOCATION	DATE COLLECTED	AROCLOR 1242	AROCLOR 1254
NSSD Waukegan STP	9/17/71	601.0	139.0
NSSD Waukegan STP	8/04/71	2105.0	472.0
NSSD Waukegan STP	7/22/71	4020.0	568.0
NSSD North Chicago STP	7/23/71	1070.0	250.0
NSSD North Chicago STP	8/04/71	268.0	153.0
NSSD North Chicago STP	8/25/71	534.0	217.0
		(1433.0)	(299.6)
NSSD Waukegan STP	5/16/72	ND	139.0
NSSD Waukegan STP	5/19/72	ND	105.0
NSSD Waukegan STP	5/23/72	ND	97.0
NSSD Waukegan STP	5/22/72	ND	118.0
NSSD Waukegan STP	6/17/72	17.0	111.0
NSSD North Chicago STP	5/22/72	ND	104.0
NSSD North Chicago STP	5/23/72	ND	100.0
NSSD North Chicago STP	5/16/72	ND	132.0
NSSD North Chicago STP	5/19/72	ND	161.0
NSSD North Chicago STP	6/17/72	21.0	178.0
		(3.8)	(124.0)

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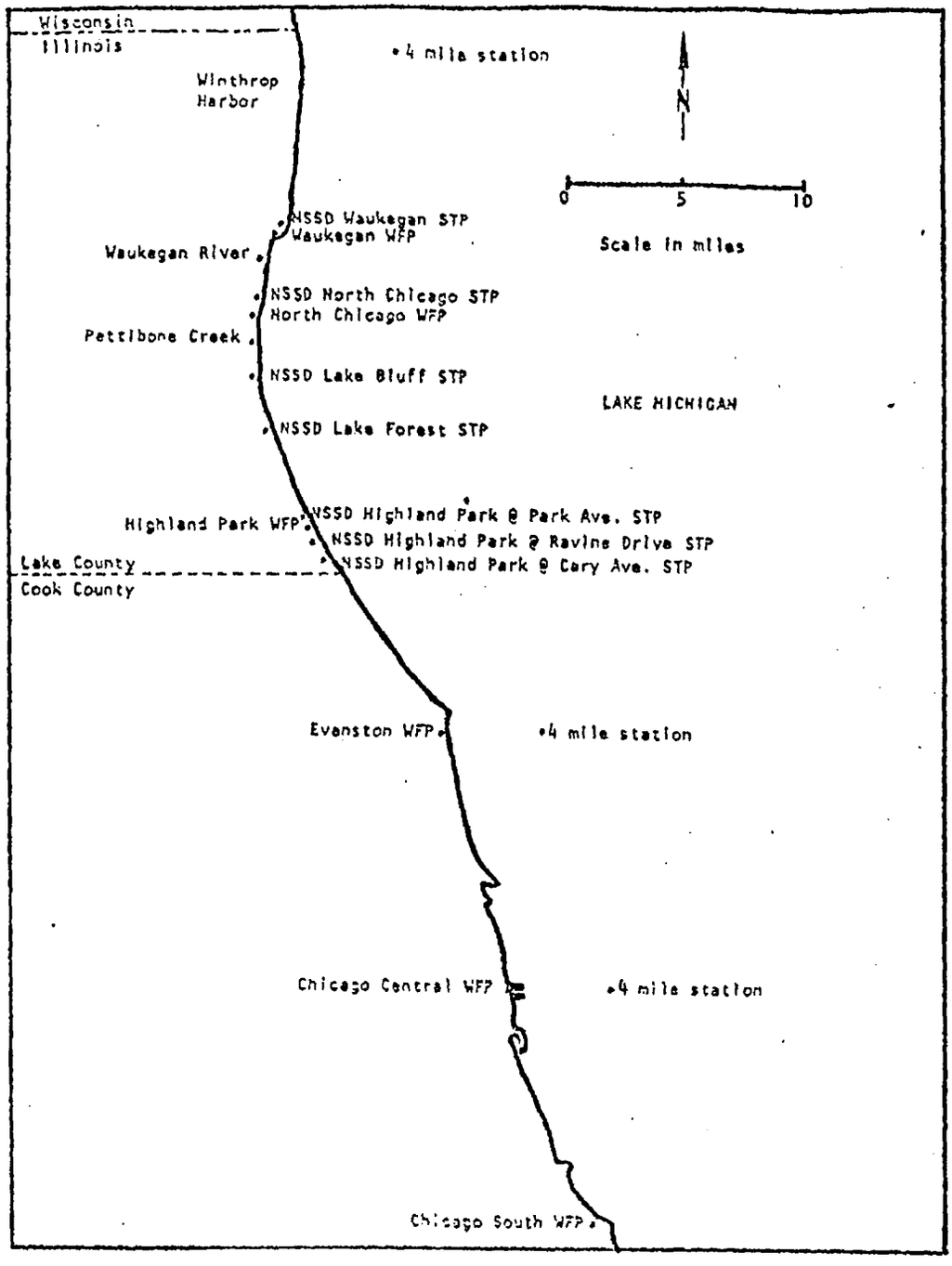


Figure 3: Location of water sampling stations, used in 1971 and 1972 for determination of PCB levels in Lake Michigan.[19]

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IX. HEALTH EFFECTS OF PCBs: ANIMAL STUDIES

A. Tissue Storage, Metabolism and Excretion

Experimental exposure of rats to dietary PCBs has revealed that the isomeric forms are retained to various degrees (as tissue residues) in most body fluids and tissue, with the highest value in adipose (fat) tissue. The adipose tissue often contained more than ten times the concentration of other tissues with the second highest PCB concentration (liver, usually) and more than 100 times the levels in other tissues including the blood, heart, kidney and brain.[22,23,24] Why isomeric forms are retained to various degrees is still not resolved. A possible explanation includes the differential absorption of the isomers through the digestive tract.[22]

The turnover rate of PCBs in tissue will vary with the degree of chlorination. The higher isomers are usually retained the longest in mammals and other vertebrates. It is still uncertain whether PCBs are stored in tissue until a specific point when a steady state is reached and the concentration does not increase further. The given level at which this equilibrium may be reached in adipose tissue could vary with the amount fed to the animals and the type of compound.[22,25]

The urinary excretion of biphenyl and 4-chlorobiphenyl has been studied in rabbits. Biphenylglucosiduronic acid and 4-hydroxybiphenyl were isolated from the urine. The rabbits fed the 4-chlorobiphenyl excreted 4-(p-chlorobiphenyl)-phenol and 4-chlorobiphenyl glucosiduronide. Twice as much 4-chlorobiphenyl as biphenyl was excreted as the glucosiduronic acid derivative. It was suggested that other low chlorinated biphenyls are excreted in a similar manner.[26]

Of dogs injected with 2,4,4'-trichloro-2'-hydroxydiphenyl ether, nearly 100% of the material is recovered as the glucuronide or sulfate in urine and feces over a 5-day period. Humans similarly exposed excrete 65% in urine and 20% in feces after intravenous injection. It is excreted either as free compound or as a glucuronide.[25] Other evidence suggests that some chlorinated biphenyls are hydroxylated

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by species such as the rat and pigeon. No evidence of reductive dechlorination was observed in either the trout, rat, or pigeon.[27]

Fish and other aquatic animals accumulate PCBs to levels of the order of 10^4 times higher than those in the ambient water. Predators at the top of the food chain such as birds, seals, and sharks may accumulate PCBs to levels 10^7 or more times the levels in the ambient water.[1]

B. Toxic Effects of Various Isomeric Mixtures and Possible Contamination of PCB Samples by Other Compounds

There is no consistent relationship between toxicity and the degree of chlorination which is valid for different species and different routes of exposure. For example, in rats, acute oral toxicity decreases with increasing chlorine content, while in rabbits, acute dermal toxicity appears to be highest for aroclors of intermediate chlorine content. Also, as will be seen later, most of the data on mammals concerning reproductive effects, demonstrate that toxicity decreases with increasing degrees of chlorination.[1]

A study on White Leghorn hens using Aroclors 1221, 1232, 1242, 1248, 1254, 1268, 5442, and BP-6 (at the 20 ppm level; additionally,1242, 1248 and 1254 were fed at the 2 ppm level) showed that feeding 20 ppm Aroclors 1232, 1242, 1248 and 1254 reduced hatchability and caused teratogenic effects in the embryos (edema and unabsorbed yolk). It was determined that adverse effects of the PCBs were not directly related to the degree of chlorination of biphenyls, or the amount of the total residue since Aroclors 1221 and 1268 did not adversely affect the embryonic development.[28] Another study showed that weanling rats were more susceptible to Aroclor 1254 and 1260 than adult rats as determined by acute toxicity studies.[25]

An experiment comparing Aroclors 1254, 1242, and 1221 (respectively, 54, 42, and 21% chlorine) was conducted to determine the effect of varying chlorine content on rabbits (oral administration, 300 mg of the PCBs Aroclor 1221, 1242, 1254, once a week, for 14 weeks). The livers of the 1254 and 1242 treated rabbits were significantly enlarged compared to the control animals. The study suggests that the higher chlorine content of Aroclor 1254 causes the most toxicity of these mixtures. Aroclor 1242

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has a lesser, though significant effect on the liver. No significant lessions were found in the 1221-treated rabbits.[29] This would suggest that the PCB mixtures with the lowest chlorine content should be used commercially, but factors such as biodegradability and bio-accumulation should be taken into consideration, as well.

Chlorinated dibenzofurans (CDFS) and pentachloro napthalenes have been identified by combined gas chromatography/mass spectrometry in a polychlorinated biphenyl of Japanese manufacture (KC-400). The question of whether chlorinated dibenzofuran in KC-400 may have contributed to the reported "Yusho" incident (see section on Case History of PCB Poisoning--Japan) has been raised.[30] Controversy exists on two important factors in relation to the CDFs: 1) whether contamination occurrred during manufacture of the PCBs or during the use of the PCB mixture as a heat exchange fluid in the rice oil plant. High temperatures may have led to its formation through the hydroxilation and oxygen ring bridging of chlorinated biphenyl molecules, and 2) there is as yet no direct experimental evidence linking dibenzofuran derivatives with the long-term chronic effects similar to those which have been demonstrated with PCBs.[21,25,31]

Chlorinated dibenzofurans have been detected in several PCB preparations (Clophen A60, Phenoclor DP-6, Aroclors 1248, 1254, 1260) and have been shown to be acutely embryotoxic.[21] Other organochlorine compounds which may be present in food webs include the chlorinated dibenzodioxins in addition to the chlorinated dibenzofurans which are toxic to embryos in amounts less than 1 ug.[32,33]

1. Effects on the liver and spleen

The most significant effect of PCBs to the liver for birds and a variety of mammals (e.g., rats, rabbits, dogs) included weight increase, fatty degeneration and necrosis. Increased liver weights are probably caused by the proliferation of smooth endoplasmic reticulum. Along with such structural changes, there are increased activities of some drug metabolizing enzymes such as nitroreductase and aromatic hydroxylase.[25,33]

In a study testing the effect of PCBs on pentobarbital metabolism and alteration of sleeping time in rats, it was found that Aroclors 1254 and 1260 reduced sleeping time. Such results suggested an acceleration of pentobarbital metabolism caused by liver enzyme induction.[34]

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In rats exposed to Aroclor 1242, vitamin A storage in the liver was reduced by as much as 50%, although no toxic or deficiency symptoms were seen. If only marginal amounts of vitamin A were in the diets of some rats, it has been theorized that avitaminosis could result.[35] This suggests that PCBs may alter lipid metabolism and/or affect preferential absorption from the gastrointestinal tract.

Histopathological effects observed in pheasants fed 210 mg of PCBs daily included loss of appetite, degeneration of liver cord cells and depletion of lymphatic nodules in the spleen.[36]

2. Carcinogenesis and Tumorigenesis

Polychlorinated biphenyls when fed chronically to rats caused hepatic adenofibrosis* and biliary epithelial hyperplasia** similar to lesions caused by butter yellow (p-dimethylamino-azobenzene), a known carcinogen. Contamination of PCBs with compounds such as polychlorinated dibenzofurans and chlorinated naphthalenes have been suggested to be causative carcinogenic agents. This controversy is unresolved and needs further investigation.[1]

Studies indicated that when various Kanechlor mixtures were fed to rats liver weight increased and certain histopathological findings were observed these included the induction of nodular hyperplasias (increase in hepatic cells, forms nodes), but no heputocellular carcinomas were observed. The authors suggested that all kinds of Kanechlors have tumorigenic action in the rat liver.[37] Other studies had shown hepatocellular carcinomas were induced in the liver of mice by Kanechlor - 500 which contains a high proportion of chloride groups, but not by Kanechlor - 400 or-300.[37] This study also showed marked cholangiofibrosis (fibrous formations in lobules of the liver) in the rat liver. Further investigations are required of the difference in the tumorigenic actions of the PCBs since this was not observed in mice treated with PCBs.[37]

Evidence exists that some hepatocellular carcinomas may originate from nodular hyperplasias. The histopathological patterns of nodular hyperplasias

*adenofibrosis: glandular formation surrounded by proliferating fibrous tissue; benign, yet difficult to distinguish from cancerous tissue.

**biliary epithelial hyperplasia: an increase in the number of cells in the liver whereby the bulk of the liver is increased.

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seen in that study were similar to those induced by known chemical carcinogens such as 3'-methyl-4-(dimethylamino) -azobenzene, N-2-fluororenylacatamide, DL-ethronine, m-toluenediamine, and diethylnitrosamine.[37]

Findings suggested that hepatocellular carcinomas can be induced by administration of Kanechlor -500,-400, -300 for a longer period of time.[37] Increased liver weight, adenofibrosis and hepatomas were induced in mice fed 300 ppm Aroclor 1254 in diet for 11 months.[38] Hepatocellular carcinomas were observed in 26 of 184 rats fed 100 ppm Aroclor 1260 in their diet for 21 months in contrast to 1 of 173 control rats.[39]

3. Effects on adrenal gland

Rats receiving 200 ppm Aroclor 1221 in their drinking water for 6 weeks showed morphological alterations in the zona fasciculata of the adrenal gland, as well as increased levels of corticosterone. Such results have been interpreted as possible evidence of the need for a higher level of glucosteroids in defense against the stressor action of Aroclor 1221.[40]

4. Effects on the reproductive system (not including primates)

Rats were exposed to Aroclors 1242, 1254, and 1260 in the diet at levels of 1, 10, and 100 ppm. It was found that Aroclor 1242 did not affect the first generation, but mating indices were decreased in the second generation at 100 ppm. With Aroclor 1254, the number of young delivered and the number surviving to weaning were decreased in both the second and third litters. Aroclor 1260 was found to increase the number of stillbirths at 100 ppm. No effects were seen at concentrations of 1 and 10 ppm.[1]

Studies with chickens indicated decreased egg production at 100 ppm with Aroclors 1242 and 1254, but not with Aroclor 1260. Decreased egg shell thickness occured at 10 and 100 ppm of Aroclor 1242, but only at 100 ppm with Aroclor 1254; however, such effects were not seen with Aroclor 1260 even at 100 ppm. Pheasants have also been reported to have their reproductive capacities decreased by PCBs with reduced numbers of eggs laid and reduced developmental success of those that did hatch.[1]

Biochemical studies have indicated that PCBs are capable of inducing the microsomal hydroxylating activity in the liver so as to affect the

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hydroxylation of both progesterone and testosterone.[41] Such biochemical findings may provide the basis for understanding how PCBs interfere with reproductive processes. Such information may also shed light on the possible effects of PCBs on the depression of secondary sexual characteristics.[42]

5. Effects on chromosomes

The effects of Aroclor 1254 (10 ppm in the diet) on dove embryo chromosomes were examined. The experiments studied the largest 8 chromosome pairs occurring in metaphase cells of allantoic sac and limb bud origin with 365 metaphase cells examined per embryo. Parameters observed were aneuploidy, polyploidy and breakage rearrangement. The results, as summarized in Table 7, provide evidence that PCBs may act as clastogenic agents.[43] The studies showed that PCBs may cause chromosomal aberrations *in vivo* in Ring Dove Embryos, but no aberrations as studied in Drosophila.[44]

TABLE 7

THE CHROMOSOME ABERRATION RATE IN DOVE EMBRYOS TREATED WITH PCBs

	Rate	Range	Total # Sampled
Control	0.8%	0 - 2%	6
PCB Treated	1.8%	0 - 9.4%	17

6. Synergistic and Additive Effects

In a study where male rats were orally dosed with carbon tetrachloride (CCl_4) used in conjunction with Aroclor 1254, the Aroclor potentiated the toxicity of CCl_4. This study indicated that the liver is the main site of Aroclor 1254 metabolism and rats with CCl_4 damaged livers are not able to metabolize this compound as rapidly as rats with normal livers under the conditions of the experiment. The residues in the blood, testes, liver, kid-

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ney and heart of CCl_4 treated rats was higher.[23] PCBs given to laying pheasant hens adversely affected egg production, hatchability, and viability of the embryo about the time of hatching but did not affect fertility or eggshell thickness. However, when pheasants were fed 50 mg PCBs along with dieldrin[36] or DDE,[45] only additive and not synergistic interactions were found.

A study was done to determine the effects of PCBs on neoplastic changes induced by isomers of benzenehexachloride (BHC) in the livers of mice fed a diet containing BHC with or without PCBs for 24 weeks. Researchers observed that PCBs promoted the induction of hepatic neoplasms in mice by isomers of BHC.[46]

7. Immunosuppression

A reduction in lymphoid tissue and the presence of amyloid or amyloid-like material in the liver of PCB exposed chicks has been reported.[47] (Amyloid formation has been found to be stimulated by certain immunosuppressive drugs). Also, lymphopenia has been reported in rabbits,[48] while in guinea pigs, [33] PCBs decreased the number of antibody-forming cells after stimulation of the humoral lymphoid system with tetanous toxoid. Such immunosuppressive actions by PCBs may help to explain the increase in susceptibility of PCB exposed fish to fungal disease, [49] PCB exposed ducks to viral hepatitis [50] and the onset of liver cancer in PCB exposed rats. [20] (See section on Carcinogenicity)

8. Primate studies

Recent studies have indicated that very low levels of PCB exposure are toxic to primates. For example, in one experiment rhesus monkeys which ate food containing 25 ppm of Aroclor 1248 for 2 months developed facial swelling, loss of hair and acne lesions within a month. One monkey died from PCB intoxication 2 months after going off the experimental diet.[51a] Another experiment utilized 2 groups of rhesus monkeys which ate food containing 5 and 2.5 ppm of Aroclor 1248. Within 2 months both groups had lost hair from the face and neck and their skin was of

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"a sandpaper-like texture". Both groups developed acne, although the 2.5 ppm groups developed the lesions later. In 6 months, both groups reached a steady state concentration of PCBs in adipose tissue. Test monkeys were then mated with monkeys which had not been fed PCBs. Six of the 8 female monkeys which had eaten food containing 5 ppm of PCBs became pregnant, in contrast to all 12 females in the control group. In the test group, 4 of the 6 pregnant females aborted or resorbed the fetus, 1 gave birth to a stillborn and 1 to a very undersized infant.[51b] In the 2.5 ppm group, all 8 females in the test group conceived and of these, 3 resorbed and 5 gave birth to undersized infants.[51b]

X. HEALTH EFFECTS OF PCBs: HUMAN EXPOSURE VIA FOOD, AIR AND WATER

A. Occupational Exposure

Known toxic effects of PCBs in humans include an acnelike skin eruption called chloracne, pigmentation of the skin and nails, distinctive hair follicles, excessive eye discharge, and swelling of eyelids. Several cases of human tocicity to PCBs in an industrial setting have been reported.[52,53] Exposed workers developed small dermal cysts and comedos (blackheads). These were usually found on the face and ears, although such sores have been reported on numerous other parts of the body. Dermal sores generally persisted for several months after removal from the source and in some instances, lasted four years.[54] Systemic effects have also occurred in several cases. These effects include nausea, lassitude, anorexia, digestive disturbances, impotence and hematuria.[1,54]

A study done on PCB concentration in the plasma of refuse workers found that 32 out of 37 (81%) of the refuse workers had detectable levels as compared to only 11% (6 out of 54) of the controls. Median PCB concentrations for those with detectable amounts were similar in the two groups; refuse workers - 2.6 ppb, controls - 3.7 ppb. The higher frequency of measurable plasma PCB levels in refuse workers (i.e., 81% of refuse workers with detectable levels as opposed to only 11% of controls with detectable levels) is thought to reflect their increased PCB exposure from incinerated materials.[55]

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The American Conference of Governmental Industrial Hygienists has set a TLV of 1 mg/m^3 for occupational exposure to vapors of Aroclor 1242, with lower values for higher Aroclors. Based on an 8-hour exposure, this would result in the inhalation of approximately 5 mg/day. The current Occupational Health and Safety Administration, Department of Labor standards for chlorinated biphenyls are 1 mg/m^3 for 42% chlorine mixtures and .5 mg/m^3 for 54% chlorine mixtures, based on the TLVs. Presently, it is not known how much of the inhaled PCBs humans absorb through the lungs.[1,2]

B. Case History of PCB Poisoning - Japan

The most well known case of PCB contamination has occurred in Japan, with documented toxic affects in over 2,000 Japanese exposed to rice oil contamination. Kaneuri Rice Oil was polluted with Kanechlor 400, which is equivalent to Aroclor 1248. This contamination incident, which was finally traced to a rice oil shipment in February, 1968, was called "Yusho" and occurred in western Japan in the area of Fukuoka prefecture. The first affected people showed the development of dermal cysts predominantly on the face and ears, but also on most other parts of the body. In severely intoxicated individuals, nausea, lassitude, anorexia, impotence and hematuria were observed. It is apparent that the severity of symptoms are directly related to the amount of PCBs ingested.[56]

It is known that the concentration of Kanechlor 400 in the rice oil was 2,000-3,000 ppm and the average quantity of rice oil consumed by patients in a first epidemiological study (325 cases) was 800 ml. over a period of approximately 8-9 months.[57] Consequently, the average dose of PCB ingested by affected individuals was approximately 2 g. The smallest dose ingested by a patient was estimated to be 0.5g.[56]

The children of 13 women (9 of whom consumed between 0.3-2.6 liters of rice oil during pregnancy) were studied for possible teratogenic effects. Eleven children were born alive while 2 were stillborn.[56,57] The infants had a charcteristic grayish, dark brown skin pigmentation; 5 had dark nails and gingivae (the gums; the tissues which surround the neck of the teeth and cover the alveolar processes of the maxilla and mandible) and 9 had increased eye discharge. A detailed study of

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4 infants revealed abnormalities which included enlarged frontal sagittal suture. Faces were edematous, and there was an abnormal protrusion of eyeballs.[58,59] As a result of such symptoms, it has been generally concluded that placental transfer of PCBs had occurred affecting the fetus.

The growth of school children afflicted with Yusho has also been studied. Both height and weight gain of boys with Yusho illness were significantly less than a control group, while the girls of Yusho did not differ significantly from the control group.[57]

C. Consumption Via Food and Drink

Based on market basket samples of PCB levels in food, an adult is estimated to ingest approximately 5-10 µg PCB/day. This figure was based, in part, on an assumed level of 0.1 ppm in 3% of the food. Such a calculation may lead to an inaccurate representation of the total PCB intake of various consumer groups. It is known that human fish consumption and PCB levels in fish vary considerably.[1] Although the FDA tolerance for PCB residues in fish is 5 ppm,[15] it is not uncommon to find PCB levels between 10-20 ppm in fish found in the Great Lakes, especially Lake Michigan.[60] Thus, individuals who habitually eat large quantities of fish, especially from such areas as the Great Lakes, will have much higher intakes than the general population. For example, an individual who eats 50 g of fish per day (1.8 oz./day) containing 2 ppm of PCBs will ingest 100 µg/day of PCBs. For a person following the recommended "weight watcher's diet", the levels of PCBs in the diet may be even significantly higher. The "weight watcher diet" suggests 5 fish meals/week, which is approximately 98 g (3.5 oz.) of fish consumed per day.[61] Assuming a contamination of 2 ppm, the "faithful weight watcher" would consume about 200 µg/day of PCB just from fish alone.

In addition to high levels of PCBs in fish, considerable concentrations may also be found in human milk. For example, samples of human milk from two cities in California contained average PCB levels of 60 ppb, while average levels in human milk in Sweden and Germany were 16 ppb and 100 ppb, respectively. Based on a daily milk intake of 150 ml/Kg, breast fed infants in California would ingest about 9 µg/Kg/day of PCB (at least 5 X more than a recommended reasonable dose). Sporadic instances of

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contamination of other foods such as milk and poultry may also lead to higher intakes for short periods.[1,62]

A report of measurement of ambient PCB atmospheric levels ranged from 1-50 ng/m^3. This would result in the inhalation of less than 1 µg/day by an adult.[1] The intake from drinking PCB-contaminated water, assuming 10 ppt as the concentration, would result in about 2-5 µg/day by an adult. Lake Michigan levels are usually less than 10 ppt.[20] A range of 1-3 µg/Kg/day (70-210 µg/day for an adult) has been suggested as a "reasonable" level for an Acceptable Daily Intake.[1] One µg/Kg/day has been reported as being 100 times less than the lowest "no-effect level" reported in animal studies.[33]

The Federal Drug Administration established PCB tolerance levels in a number of food products as follows:[21,63]

Food	Concentration (PPm)
Milk *	2.5
Dairy Products *	2.5
Poultry *	5.0
Fish and Shellfish **	5.0
Eggs	0.5
Infant & Junior Food	0.2
Complete and Finished Animal Feed	0.2
Animal Feed Components	2.0
Paper food-Packaging Material	10.0

* on fat basis

** on edible portion

However, toxicity data obtained subsequently showing reproductive abnormalities with concentrations of PCBs in primates ranging from 2.5 to 5.0 ppm and the recent demonstration of adenofibrosis and other toxic effects in rats indicate a need for revisions of the present FDA tolerance limitations of PCBs in foods. The FDA is expected to enforce its guidelines more forcefully in the future based on a recent legal decision that allows the FDA to define pesticide residues in foods as an indirect food additive.[21]

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Studies have also shown that migration of PCBs from packaging materials does occur.[21,64] In the absence of an effective barrier, Aroclor 1242 was shown to migrate from paperboard to food in measurable amounts when food was purchased in paperboard containing a significant amount of Aroclor 1242. It is considered an absorption phenomenon dependent primarily on the surface area of the food and secondarily on the fat content of the food. The study suggested that materials of low gas permeability could be effective barriers to PCB migration.[64]

XI. PCB LEVELS IN TISSUE OF HUMANS IN THE UNITED STATES

Adipose samples were collected from tissues withdrawn for therapeutic surgery or from post-mortem exams. Positive samples were obtained from 18 states, one of which was Illinois. The other 17 states include eastern, western and southern states, thus indicating that PCBs are widespread. It was reported that 165 of 637 (25.9%) samples of human adipose tissue contained 1-2 ppm. Thirty-three of the samples (5.2%) contained greater than 2 ppm; 125 (19.6%) contained between a trace and 1.0 ppm; the remaining 314 (49.3%) were negative at the level of ppm identification.[65]

XII. HIGH RISK SEGMENTS OF THE POPULATION

Embryos, fetuses and neonates (2 to 3 months old) often lack the liver microsomal enzyme systems that oxidize various natural and foreign chemicals, including those of a biphenolic nature. The activation of such enzyme systems often facilitate the detoxification and excretion of such substances. Usually by the age of 2 to 3 months, adult levels of the enzyme systems are achieved.[66,67] Unfortunately, this "developmental immaturity" in the unborn and the very young may predispose them to the toxic effects of certain substances since they may be unable to detoxify and excrete them as quickly as necessary. Clinical experience has shown that infants may respond differently to doses of drugs which are easily tolerated by older children and adults. Presumably, this is because older children and adults have fully functioning enzyme detoxification systems while the neonate lacks such development.[66,67]

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One such microsomal enzyme system includes the glucuronidation pathway which functions in the detoxification and excretion of a variety of chemicals including alcohols and phenols.[66] Inefficient glucuronidative mechanisms in infants have broad significance since the absence of such mechanisms prevents the prompt elimination of toxic substances from the body. Since some young children have been shown to consume more PCBs per unit of body weight than adults (since PCBs have appreciable concentrations in human milk),[62] the lack of appropriate detoxification enzyme systems compounds the PCB problem for the very young.

A tragic example of toxicity arising from the inability to form glucuronides has been reported. The drug chloramphenicol, which is known to be metabolized in humans by the action of the glucuronic pathway, caused the death of more than 30 premature babies who had been treated with the antibiotic for infectious diseases.[68] Theoretically, the premature babies were not able to conjugate the drug with glucuronic acid and thus the drug could only be slowly excreted and so tended to accumulate in the body to toxic proportions eventually leading to death.

An additional problem encountered by many neonates is that approximately five percent of the mothers of normal infants secrete milk which inhibits the activity of glucuronyl transferase (and thus the glucuronidation process) by more than 20% via the action of a steroid present in the breast milk. Inhibition of this glucuronyl transferase has been reported for up to 49 days after birth. Clinically, these children have been reported to develop unusually severe neonatal jaundice. This condition develops because glucuronide formation, which assists in the elimination of bilirubin (breakdown product of hemoglobin), is partially inhibited. Cow's milk does not contain sufficient amounts of this steroid to affect a noticeable inhibition of the glucuronide-conjugation process.[69] Consequently, about 5% of the breast-fed neonates would be expected to have their ability to excrete PCBs impaired. Administration of the antibiotic novobiocin has also been associated with unconjugated hyperbilirubinemia in infants.[70] Novobiocin is a noncompetitive inhibitor of glucuronyl transferase activity in vitro.[71] Thus, children receiving concomitant exposure of novobiocin and PCBs would be expected to have their ability to detoxify and excrete PCBs impaired.

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After the neonatal period, a broad range of conditions is associated with the improper or incomplete development of the glucuronide conjugation system. The usual physiological problem associated with these conditions is the inadequate detoxification of bilirubin. This spectrum extends from the frequently occurring "mild" condition known as Gilbert's syndrome, to the very rare, but severe and often fatal Crigler and Najjar syndrome.[72]

Since the clinical effects associated with these syndromes are considered to be caused by metabolic disturbances of the glucuronide conjugation scheme, it is expected that PCB elimination in these individuals would be impeded. Although Gilbert's syndrome has been mentioned as being "encountered relatively often" in a clinical sense, no estimates of the gene frequency of such a trait has been reported.

Concomitant exposure to PCBs and other compounds may enhance the toxic effects of PCBs. For example, rats and monkeys given β-diethylaminoethyl-2,2-diphenylpentanoate (SKF525A, a non-specific inhibitor for many of the microsomal enzyme activities, especially hepatic microsomal enzymes) during the initial 24 hours of exposure to PCB, succumbed rapidly as compared to the control group.[51a] Of possible significance is the fact that SKF525A inhibits the proper functioning of the glucuronidation pathway.[68]

Individuals with liver infections may also be at high risk with respect to PCBs. For example, depression of glucuronide synthesis has been observed in humans with infectious hepatitis.[68]

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XIII. APPENDIX

AROCLOR PRODUCTS MANUFACTURED IN THE UNITED STATES

CURRENT	DISCONTINUED	PERCENT CHLORINE
1221		21
	1232	32
1016		41*
1242		42
	1248	48
1254		54
	1260	60
	1262	62
	1268	68

*Aroclor products are identified by a four digit numbering code in which the first two digits, 12, indicate the parent molecule is biphenyl and the last two digits specify the weight percent of chlorine. The exception is Monsanto's newest product, Aroclor 1016 (41% chlorine), which retained the 1016 designation by which it was known during development.

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