

Health and Safety Guide No. 68

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POLYCHLORINATED
BIPHENYLS (PCBs) AND
POLYCHLORINATED
TERPHENYLS (PCTs)
HEALTH AND
SAFETY GUIDE 1262/29



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Health and Safety Guide No. 68

**POLYCHLORINATED
BIPHENYLS (PCBs) AND
POLYCHLORINATED
TERPHENYLS (PCTs)
HEALTH AND
SAFETY GUIDE**

This is a companion volume to
Environmental Health Criteria 140: Polychlorinated Biphenyls and
Terphenyls (Second Edition)

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(a collaborative programme of the United Nations Environment
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INTRODUCTION

The Environmental Health Criteria (EHC) documents produced by the International Programme on Chemical Safety include an assessment of the effects on the environment and on human health of exposure to a chemical or combination of chemicals, or physical or biological agents. They also provide guidelines for setting exposure limits.

The purpose of a Health and Safety Guide is to facilitate the application of these guidelines in national chemical safety programmes. The first three sections of a Health and Safety Guide highlight the relevant technical information in the corresponding EHC. Section 4 includes advice on preventive and protective measures and emergency action; health workers should be thoroughly familiar with the medical information to ensure that they can act efficiently in an emergency. Within the Guide is a Summary of Chemical Safety Information which should be readily available, and should be clearly explained, to all who could come into contact with the chemical. The section on regulatory information has been extracted from the legal file of the International Register of Potentially Toxic Chemicals (IRPTC) and from other United Nations sources.

The target readership includes occupational health services, those in ministries, governmental agencies, industry, and trade unions who are involved in the safe use of chemicals and the avoidance of environmental health hazards, and those wanting more information on this topic. An attempt has been made to use only terms that will be familiar to the intended user. However, sections 1 and 2 inevitably contain some technical terms. A bibliography has been included for readers who require further background information.

Revision of the information in this Guide will take place in due course, and the eventual aim is to use standardized terminology. Comments on any difficulties encountered in using the Guide would be very helpful and should be addressed to:

The Director
International Programme on Chemical Safety
World Health Organization
1211 Geneva 27
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THE INFORMATION IN THIS GUIDE
SHOULD BE CONSIDERED AS A
STARTING POINT TO A COMPREHENSIVE
HEALTH AND SAFETY PROGRAMME

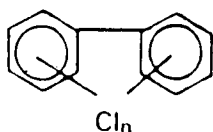
1. PRODUCT IDENTITY AND USES

1.1 Identity

1.1.1 Polychlorinated biphenyls - PCBs

Chemical formula—chemical structure

The chlorination of biphenyl can lead to the replacement of 1-10 hydrogen atoms by chlorine.



The chemical formula can be presented as $C_{12}H_{10-n}Cl_n$, where n is the number of chlorine atoms in the molecule.

Chemical composition

The PCBs are chlorinated hydrocarbons that are manufactured commercially by the progressive chlorination of biphenyl in the presence of a suitable catalyst (e.g., iron chloride). Depending on the reaction conditions, the degree of chlorination can vary between 21 and 68% (w/w). The yield is always a mixture of different compounds and congeners. Thus, a total of 209 different chemical components may exist, but only about 130 of these are likely to occur in commercial products or mixtures of these compounds.

Individual PCBs have been synthesized for use as reference samples in the identification of gas-liquid chromatographic peaks, for toxicological investigations, and in order to study their metabolic fate in living organisms.

Purity and impurities

Commercial PCBs are sold on the basis of their physical properties, not their chemical composition. Different batches may vary somewhat in their composition. The impurities known to be present in commercial PCBs include chlorinated naphthalenes and small quantities of the highly toxic polychlorinated dibenzofurans (PCDFs). There are no authenticated reports of the presence of polychlorinated dibenzo-*p*-dioxins (PCDDs) in commercial PCBs.

PRODUCT IDENTITY AND USES

Common name: Polychlorinated biphenyls—PCBs.

CAS registry number: 1336-36-3

RTECS registry number: TQ1350000

Relative molecular mass: Depends on degree of chlorination and composition of the mixture.

Major trade names

Apiolio (t,c)	Disconon (c)	PCBs
Areclor (t)	Dk (t,c)	Phenoclor (t,c)
Aroclor	Duconol (c)	Polychlorinated biphenyl
Arubren	Dykanol (t,c)	Polychlorobiphenyl
Asbestol (t,c)	EEC-18	Pydraul
Askarel	Elemex (t,c)	Pyralene (t,c)
Bakola 131 (t,c)	Eucarel	Pyranol (t,c)
Biclор (c)	Fenchlor (t,c)	Pyroclor (t)
Chlorextol (t)	Hivar (c)	Saf-T-Kuhl (t,c)
Chlorinated Biphenyl	Hydol (t,c)	Santotherm FR ^a
Chlorinated Diphenyl	Inclor	Santovac 1 and 2
Chlorinol	Interteen (t,c)	Siclonyl (c)
Chlorobiphenyl	Kanechlor (t,c)	Solvol (t,c)
Clophen (t,c)	Kennechlor	Sovol
Chlorphen (t)	Montar	Therminol FR ^a
Delor	Nepolin	
Diaclor (t,c)	No-Flamol (t,c)	
Dialor (c)	PCB	

^a Previous products (FR-series) used as heat transfer fluids contained PCBs, but since 1972 current products are different series and do not contain PCBs.

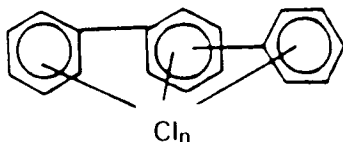
(t) used in transformers.

(c) used in capacitors.

PRODUCT IDENTITY AND USES

1.1.2 Polychlorinated terphenyls—PCTs

Chemical formula—chemical structure



The chemical formula can be written as $\text{C}_{18}\text{H}_{14-n}\text{Cl}_n$, in which n is the number of chlorine atoms, which can range from 1–14.

Chemical composition

The theoretically possible number of different PCTs is several orders of magnitude greater than the number of PCBs, but in practice, as with PCBs, PCTs are sold on the basis of their physical properties, which depend on the degree of chlorination, and not their chemical composition.

Common name:	Polychlorinated terphenyls - PCTs.
CAS registry number:	61788-33-8
RTECS registry number:	WZ6500000
Relative molecular mass:	Depends on degree of chlorination and composition of the mixture.

Main trade names

PCTs are known by a variety of trade names, some of which are similar to those given for PCBs in Section 1.1.1. In the Aroclor series, terphenyls are indicated by 54 in the first two places of the four digit code. In Japan, the PCTs are coded Kanechlor KC-C.

PRODUCT IDENTITY AND USES

1.2 Physical and chemical properties

Individual, pure congeners of PCB and PCT are colourless, often crystalline compounds, but commercial PCBs are mixtures of these congeners with a clear, light yellow or dark colour, and range from oily liquids to waxy or hard solids. They do not crystallize at low temperatures, but turn into solid resins. Because of the chlorine atoms in the molecule, the compounds have a fairly high density. In practice, PCBs are fire resistant, and have a fairly high flash-point (170–380 °C). They form vapours that are heavier than air, but they do not form an explosive mixture with air. The electrical conductivity of PCBs and PCTs is very low, and their resistance to thermal breakdown is extremely high. It is on the basis of these properties that they are used as cooling liquids in electrical equipment. The physical properties of some Aroclors are shown in Table 1.

PCBs are chemically stable under normal conditions. They are very resistant to a range of oxidants and other chemicals, and they remain chemically unchanged even in the presence of oxygen, or some active metals, at high temperatures (up to 170 °C), and for protracted periods.

PCBs are practically insoluble in water; however, they dissolve easily in hydrocarbons, fats, and other organic compounds, and they are readily adsorbed by fatty tissues.

The partition coefficient ($\log K_{ow}$) values for all 209 PCB congeners range from 4.46 to 8.18.

1.3 Analytical methods

Only a small number of laboratories in the world have access to, and experience of working with, the complicated techniques necessary for a reproducible determination of PCBs and PCTs.

One probable source of error is incomplete extraction and clean-up of the PCBs. The method used to quantify the gas-liquid chromatographic peaks also gives rise to variation between laboratories.

Data on concentrations of PCBs must be interpreted with the greatest care. Comparisons can only be made between data from the same laboratory, obtained using the same validated technique over a long period. Comparisons between data from different laboratories are possible in only the very few cases, in which very strict interlaboratory checks have been made on

Table 1. Physical properties of some Aroclors

Substance Aroclor	Water solubility (mg/litre, 25 °C)	Vapour pressure (torr, 25 °C)	Density g/cm ³ (25 °C)	Appearance	Henry's Law constant (atm-m ³ /mol at 25 °C)	Refractive index	Boiling point (distillation range) (750 torr, °C)
1016	0.42	4.0×10^{-4}	1.33	Clear, mobile oil	2.9×10^{-4}	1.6215-1.6135 (at 25 °C)	325-356
1221	0.59	6.7×10^{-3}	1.15	Clear, mobile oil	3.5×10^{-3}	1.617-1.618 (at 20 °C)	275-320
1232	0.45	4.1×10^{-3}	1.24	Clear, mobile oil	unknown	unknown	290-325
1242	0.24	4.1×10^{-3}	1.35	Clear, mobile oil	5.2×10^{-4}	1.627-1.629 (at 20 °C)	325-366
1248	0.054	4.9×10^{-4}	1.41	Clear, mobile oil	2.8×10^{-3}	unknown	340-375
1254	0.021	7.7×10^{-5}	1.50	Light yellow, viscous oil	2.0×10^{-3}	1.6375-1.6415 (at 25 °C)	365-390
1260	0.0027	4.0×10^{-5}	1.58	Light yellow, sticky resin	4.6×10^{-3}	unknown	385-420

PRODUCT IDENTITY AND USES

the basis of the same sampling and analytical techniques. Indications about trends can only be obtained when these basic considerations are taken into account.

Gas-liquid chromatography (GLC) with packed or capillary columns, is generally used for the analysis, and comparison of peak patterns, and various PCB standard formulations are used for quantification. Different approaches are used for the summing-up of individual peaks.

Analytical methods are discussed in more detail in the WHO/EURO (1987) document.

Individual congeners are identified using GLC, with either hydrogen flame ionization detection (HFID) or electron capture detection (ECD), and mass spectrometry.

1.4 Uses

The industrial usefulness of PCBs and PCTs depends on their chemical inertness, resistance to heat, non-flammability, low vapour pressure (particularly with the higher chlorinated compounds), and high dielectric constant.

The main uses are (or were):

(a) as dielectrics in transformers and large capacitors (considered to be closed systems);

(b) in heat transfer and hydraulic systems (nominally closed systems);

(c) in the formulation of lubricating and cutting oils;

(d) as plasticizers in paints, carbonless copying paper, adhesives, sealants, and plastics.

Both *c* and *d* are open-ended applications.

2. SUMMARY AND EVALUATION

2.1 Environmental transport, distribution, and transformation

In the atmosphere, PCBs exist primarily in the vapour phase; the tendency to adsorb to particulates increases with the degree of chlorination. The virtually universal distribution of PCBs suggests that they are transported in air.

At present, the major source of PCB exposure for the general population appears to be as a consequence of the redistribution of PCBs previously introduced into the environment. This redistribution involves volatilization from soil and water into the atmosphere, with subsequent transport in air and removal from the atmosphere through wet or dry deposition (of PCBs bound to particulates), and then re-volatilization. The concentrations of PCBs in precipitation range from 0.001 to 0.25 $\mu\text{g}/\text{litre}$. Since the volatilization and degradation rates of PCBs vary among the different congeners, this redistribution leads to an alteration in the composition of PCB mixtures in the environment.

In water, PCBs are adsorbed to sediments and other organic matter; experimental and monitoring data have shown that PCB concentrations are higher in sediment and suspended matter than in the associated water columns. Strong adsorption to sediment, especially in the case of the higher chlorinated PCBs, decreases the rate of volatilization. On the basis of their water solubilities and *n*-octanol-water partition coefficients, the lower chlorinated PCB congeners will sorb less strongly than the higher chlorinated isomers. Although adsorption can immobilize PCBs for relatively long periods in the aquatic environment, desorption into the water column has been shown to occur by both the abiotic and biotic routes. The substantial quantities of PCBs in aquatic sediments therefore act as both an environmental sink and a reservoir of PCBs for subsequent recycling in the environment. Most of the PCBs in the environment are in the aquatic sediment.

The low solubility of PCBs, and their strong adsorption to soil particles, limits leaching in soil; the lower chlorinated PCBs will tend to leach more than the highly chlorinated PCBs.

Degradation of PCBs in the environment depends on the degree of chlorination of the biphenyl. In general, the persistence of PCB congeners

SUMMARY AND EVALUATION

increases as the degree of chlorination increases. In the atmosphere, the reaction of PCBs in the vapour phase with hydroxyl radicals (which are photochemically formed by sunlight) may be the most important transformation process. The estimated half-life of this reaction in the atmosphere ranges from about 10 days to 1.5 years for a monochlorobiphenyl and a heptachlorobiphenyl, respectively.

In the aquatic environment, PCBs are not significantly degraded by hydrolysis and oxidation. Photolysis appears to be the only abiotic degradation process in water; however, insufficient experimental data are available to determine its rate or its importance in the environment.

Microorganisms degrade mono-, di-, and trichlorinated biphenyls relatively rapidly, and tetrachlorobiphenyls slowly, while higher chlorinated biphenyls are resistant to biodegradation. The chlorine substitution position on the biphenyl ring appears to be important in determining the biodegradation rate. PCBs containing chlorine atoms in the *para* position are preferentially biodegraded. Higher chlorinated congeners are biotransformed anaerobically, by reductive dechlorination, to lower chlorinated PCBs, which may then be biodegradable by aerobic processes.

Several factors determine the degree of bioaccumulation in adipose tissues: duration and level of exposure, chemical structure of the compound, and position and pattern of substitution. In general, the higher chlorinated congeners are accumulated more readily.

The bioconcentration factors of various PCBs determined experimentally in aquatic species (fish, shrimp, oyster) range from 200 up to 70 000 or higher. In the open ocean, there is bioaccumulation of PCBs in the higher trophic levels, with an increased proportion of higher chlorinated biphenyls in the higher ranking predators.

Transfer of PCBs from soil to vegetation takes place mainly through adsorption onto the external surfaces of terrestrial plants; little translocation takes place.

2.2 Environmental levels and human exposure

Because they persist for a long time, and because of other physicochemical properties, PCBs are present in the environment all over the world.

PCBs are found in air, all over the world, at concentrations of 0.002 up to 15 ng/m³. In industrial areas, higher levels of up to micrograms/m³ are

SUMMARY AND EVALUATION

found. In rain-water and snow, PCBs are found in the range of not detectable (< ng/litre) to 250 ng/litre.

Under workplace conditions, the levels in the air may be much higher. In the manufacturing of transformers or capacitors, for instance, levels of up to 1000 $\mu\text{g}/\text{m}^3$ have been observed. In emergency situations, concentrations of up to 16 mg/m^3 have been measured. In the case of fires and/or explosions, the soot may contain high levels of PCBs; concentrations of 8000 mg PCBs/kg soot have been found. In fires and explosions, PCDFs will also be present in the soot. In accidents with transformers in which chlorinated benzenes are present in addition to PCBs, polychlorinated dioxins (PCDDs) will also be found.

In these emergency situations, skin contamination with soot is possible, and ingestion or inhalation of soot particles may occur and result in serious exposures of personnel. However, the exposure of the general population through the air will be very low.

Surface water may be contaminated by PCBs by atmospheric fall-out, or by direct emissions from point sources, or waste disposal. Under certain conditions, levels of up to 100–500 ng/litre of water have been measured. In the water of oceans, levels of 0.05–0.6 ng/litre have been found.

In non-contaminated areas, drinking-water usually contains less than 1 ng PCBs/litre, but levels up to 5 ng/litre have been reported. Soil and sediments normally contain concentrations of PCBs in the range of <0.01–2.0 mg/kg. In polluted areas, the levels in soils have been much higher, up to 500 mg/kg.

Over the years, many thousands of samples of different foodstuffs have been analysed, in several countries, for contaminants, including PCBs. Most samples have been taken from individual food items, especially fish and other foods of animal origin, such as meat and milk. Food becomes contaminated with PCBs by three main routes:

- a*) uptake from the environment by fish, birds, livestock (via food-chains), and crops;
- b*) migration from packaging materials into food (mainly less than 1 mg/kg, but in some cases up to 10 mg/kg);
- c*) direct contamination of foodstuffs or animal feed as the result of an industrial accident.

SUMMARY AND EVALUATION

For the most important food items that contain PCBs, the following concentrations have been found: animal fat, 20–240 $\mu\text{g}/\text{kg}$; cow's milk, 5–200 $\mu\text{g}/\text{kg}$; butter, 30–80 $\mu\text{g}/\text{kg}$; fish, 10–500 $\mu\text{g}/\text{kg}$, on fat basis. Certain fish species (eel) and fish products (fish liver and fish oils) contained much higher levels, up to 10 mg PCBs/kg. Levels of $< 10 \mu\text{g}/\text{kg}$ were found in vegetables, cereals, fruits, and a number of other products. Fish, shellfish, meat, milk, and other dairy products are the main foods that give rise to concern as regards levels of PCBs. The median levels reported in fish, in various countries, are in the order of 100 $\mu\text{g}/\text{kg}$ (on fat basis); however, it appears that the levels of PCBs in fish are slowly decreasing.

PCBs accumulate in human adipose tissue and breast milk. The concentrations of PCBs in different organs and tissues depend upon the lipid content of the organ or tissue, with the exception of the brain. The levels of PCB residues in adipose tissue of the general population in industrialized countries range from < 1 to 5 mg/kg, on fat basis.

The average concentration of total PCBs in human milk is in the range of 0.5 to 1.5 mg/kg fat, depending on the donor's place of residence, life-style, and the analytical methods used. Women living in heavily industrialized urban areas, or with a high fish consumption (especially fish from heavily contaminated waters), may have higher PCB concentrations in breast milk.

The composition of most PCB extracts from environmental samples does not resemble that of the commercial PCB mixtures. High-resolution gas chromatography (GC) analysis shows that the congener composition, and relative concentrations of the individual components, in adipose tissues and breast milk differ markedly from the composition of commercial PCBs. The GC-patterns of PCBs in human adipose tissues and breast milk indicate relatively high concentrations of mainly the higher chlorinated PCBs, such as, 2,4,5,3',4'-pentachlorobiphenyl; 2,4,5,2',4',5'-hexachlorobiphenyl; and 2,3,4,2',4',5'-hexachlorobiphenyl; 2,3,4,5,2',4',5'-hepta- and 2,3,4,5,2',3',4'-heptachlorobiphenyl. A few other PCB congeners are present at much lower concentrations, including the most toxic, coplanar PCBs: 3,4,3',4'-tetra-, 3,4,5,3',4'-penta- and 3,4,5,3',4',5'-hexachlorobiphenyl.

The daily intake of PCBs by infants from breast milk is of the order of 4.2 $\mu\text{g}/\text{kg}$ body weight (5.2 $\mu\text{g}/100$ kcal consumed) (WHO/EURO, 1987). The average total quantity of PCBs ingested in breast milk during the first 6 months of life is 4.5 mg compared with a calculated intake of 357 mg of PCBs over the subsequent life-time (0.2 $\mu\text{g}/\text{kg}$ per day in the diet of a 70-kg person over a 70-year life-time). Therefore, the nursing period contributes

SUMMARY AND EVALUATION

about 1.3% of the life-time intake, which is not large in light of the benefits of breast-feeding (WHO/EURO, 1987).

On the basis of the evaluated background data, the average dietary intake of PCBs for adults amounts to a maximum of 100 $\mu\text{g}/\text{week}$, or approximately 14 $\mu\text{g}/\text{person per day}$. For a 70-kg person, this is an intake equivalent to a maximum of 0.2 $\mu\text{g}/\text{kg body weight per day}$ (WHO/EURO, 1987).

2.3 Kinetics and metabolism

Animal studies have been reported involving mainly oral, inhalation, and dermal exposures to both PCB mixtures and individual congeners. In general, PCBs appear to be rapidly absorbed, particularly by the gastrointestinal tract after oral exposure. It is clear that absorption does occur in humans, but information on the rates of absorption of PCBs in humans is limited.

From the available studies, the data on the distribution of PCBs, suggest a biphasic kinetic process with rapid clearance from blood, and accumulation in the liver and the adipose tissue of various organs. There is also evidence of placental transport, fetal accumulation, and distribution to milk. In some studies with humans, the skin was a tissue with a high concentration of PCBs but the concentration in the brain was lower than would be expected on the basis of the lipid content.

Mobilization of PCBs from fat appears to depend largely on the rates of metabolism of the individual PCB congeners. Excretion depends on the metabolism of PCBs to more polar compounds, such as phenols, conjugates of thiol compounds, and other water-soluble derivatives. Metabolic pathways include hydroxylation, conjugation with thiols and other water-soluble derivatives, some of which can involve reactive intermediates, such as the arene oxides. The rates of metabolism have been shown to depend on the PCB structure and reflect both the degree and position of the chlorine substituents. The polar metabolites of the more highly chlorinated PCBs appear to be eliminated primarily in the faeces, but excretion in the urine can also be significant. An important elimination route, is via (breast) milk. Certain PCB congeners can also be eliminated via the hair.

The available kinetic studies indicate that there is a wide divergence in biological half-life among the individual congeners and this can reflect differences in structure-dependent metabolism, tissue affinities, and other factors, affecting mobilization from storage sites.

SUMMARY AND EVALUATION

Persistence in tissues is not always correlated with high toxicity and differences in toxicity between PCB congeners may be associated with specific metabolites and/or their intermediates.

2.4 Effects on organisms in the environment

PCBs are universal environmental contaminants and are present globally in most environmental compartments, both abiotic and biotic. Since many countries have controlled both use and release, new input into the environment is on a much smaller scale, compared with the past. However, the available evidence suggests that the cycling of PCBs is causing a gradual redistribution of some congeners towards the marine environment. There is a trend for the highest chlorinated congeners to accumulate preferentially. While a large proportion of the PCBs is adsorbed onto particulates in sediment, it is still bioavailable to organisms and will continue to be accumulated in the higher trophic levels.

2.4.1. *Laboratory studies*

Effects of PCB mixtures on microorganisms are highly variable, with some species being adversely affected by a concentration of 0.1 mg/litre and others being unaffected by 100 mg/litre; effects on different species do not vary consistently with the degree of chlorination of the mixtures.

Almost all of the studies of the effects of PCBs on aquatic organisms have involved Aroclor mixtures. Results are extremely variable with no consistent relationship between percentage chlorination or environmental conditions and toxicity, even with closely-related organisms. Over 96 h under static conditions, LC₅₀ values ranged between 12 µg/litre and > 10 mg/litre for various aquatic invertebrate species and different Aroclor mixtures. Flow-through conditions increased the toxicity of the PCBs. Generally, the most toxic mixtures were Aroclors in the mid-range of chlorination; low and high percentage chlorination mixtures were less toxic. This was also true for sublethal effects, such as reproduction of *Daphnia*. Crustaceans seem to be more susceptible to PCBs during moult. In model populations, the community structure of estuarine species changed on exposure to Aroclor 1254, with amphipods, bryozoans, crabs, and molluscs decreasing in representation and annelids, brachyopods, coelenterates, echinoderms and nemerines being unaffected. Too few of the groups have been included in acute tests to determine whether the result represents variation in susceptibility to PCBs or differences in interaction between species.

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There is similar variation in the toxicity of PCB mixtures for fish with 96-h LC₅₀s varying between 0.008 and > 100 mg/litre. Long-term tests show that acute exposure, particularly under static conditions, considerably underestimates the toxicity of the PCB. Rainbow trout were particularly susceptible, with embryo-larval stages showing a 22-day LC₅₀ of 0.32 µg/litre for Aroclor 1254. The no-observed-effect level (NOEL) over 22-days for rainbow trout embryo-larval stages was 0.01 g/litre for Aroclors 1016, 1242, and 1254.

Freshwater fathead minnow showed NOELs of 5.4, 0.1, 1.8, and 1.3 µg/litre for Aroclors 1242, 1248, 1254, and 1260, respectively. The estuarine sheephead minnow showed NOELs of 3.4 and 0.06 µg/litre for Aroclors 1016 and 1254, respectively.

Experimental evidence has confirmed field observations demonstrating reproductive impairment in seals fed on fish containing PCBs, accumulated in the wild. The effect occurs late in reproduction, preventing implantation of the embryo in the uterine wall.

In short-term tests, the toxicity of Aroclor for birds increases with increasing percentage chlorination; 5-day dietary LC₅₀s ranged from 604 to > 6000 mg/kg diet. The main reproductive effects in birds are reduced hatchability of eggs and embryotoxicity. These effects of the PCB continue after dosing has ended, as the hens reduce their PCB load via the eggs. There is no evidence that Aroclors cause egg-shell thinning directly; effects on the food consumption and body weight of hens have an indirect effect on shell thickness. Sublethal effects on behaviour and hormone secretion have been reported.

For mink, the acute toxicity of Aroclors decreases with increasing percentage chlorination, acute oral LD₅₀s varying between > 750 and 4000 mg/kg body weight; the ferret is less sensitive. Aroclors reduce food consumption and, thus, the growth rate of young mink. Reproduction in mink is reduced or eliminated by Aroclors, either given directly, or as natural contaminants in fish. Aroclors with a higher percentage chlorination (notably 1254) have a greater effect. The reproductive rate returns to normal after feeding with Aroclor is stopped.

Bats are susceptible to Aroclor released from their fat during migration.

The majority of laboratory tests on aquatic and terrestrial organisms have been carried out using PCB mixtures and it has not been possible to identify the specific components of mixtures responsible for the effects. Similarly, because tests have been conducted under environmentally unrealistic

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conditions (e.g., beyond the solubility of congeners, and, in aquatic tests, without the presence of sediment) it is difficult to extrapolate from laboratory tests to the field.

2.4.2 *Field studies*

Results suggesting that PCBs affect fish populations in the field are inconclusive. Interpretation of field data on birds is difficult, since residues of many different organochlorines are also present. Most authors have shown a correlation between embryotoxicity and total organochlorine residues. The levels of PCB residues correlate best with the effects on embryos, but these results cannot be regarded as proof of a field effect of the PCBs.

There is evidence (confirmed in laboratory studies) that PCBs reduce the reproductive capacity of sea mammals. The effect is on implantation of the embryo, but PCBs can also lead to physical changes in the female reproductive tract.

It is not possible to extrapolate from the results of acute and short-term laboratory tests to effects on populations in the field. Uncertainties about which components of the PCB mixtures cause effects, the specific congeners present in the environment, and the bioavailability of PCB components to organisms, all combine to make it difficult to estimate the probable environmental exposure and effects. The effects on populations of sea mammals can be regarded as proved, but it is not yet known which component(s) of the PCB mixtures are responsible.

Given the trends towards increased contamination of the marine environment, attention should be concentrated on effects on marine organisms. There is clear laboratory and field evidence of reproductive effects of PCBs on populations of sea mammals in heavily polluted areas, and PCB residues and their effects are likely to increase in the future. It is less clear whether effects will be seen in other organisms, such as birds that feed on marine prey.

On the evidence of laboratory studies, population and community effects on lower organisms, i.e., phytoplankton and zooplankton, would be expected to occur. Both the degree and significance of such effects are difficult to assess. From currently available information, effects on fish populations would not be expected, though fish will act as a route of exposure of fish-eating mammals and birds.

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Previously reported effects on terrestrial species, fish-eating freshwater mammals and migratory bats for example, should be less evident as the residues of PCBs are redistributed. Residues in terrestrial biota currently show little decline overall, but information on changes in congeners is scarce or absent. Levels of the higher chlorinated congeners would only be expected to decrease slowly.

2.5 Effects on experimental animals and *in vitro* systems

2.5.1 *Single exposure*

The acute toxicity of Aroclors for rats after a single oral exposure is generally low. Young animals appear to be more sensitive (LD₅₀, 1.3–2.5 g/kg body weight) than adults (LD₅₀, 4–11 g/kg body weight). The lowest LD₅₀ reported for Aroclor 1254 in adult rats was 1.0 g/kg body weight. No sex differences were observed.

Dermal LD₅₀s in rabbits ranged from >1.26 to <2 g/kg body weight for Aroclor 1260 (in corn oil) and from 0.79 to <3.17 g/kg body weight for some other undiluted PCB mixtures. Intravenous application demonstrated an LD₅₀ of 0.4 g/kg body weight for Aroclor 1254 in rats; the LD₅₀, after intraperitoneal injection, in the mouse varied from 0.9 to 1.2 g/kg body weight.

2.5.2 *Short-term exposure*

The main targets in mammals with short-term oral exposure to PCB mixtures or congeners are the liver, the skin, the immune system, and the reproductive system. The rhesus monkey is the most sensitive species tested, females being more sensitive than males. Adult female rhesus monkeys exposed to a diet containing Aroclor 1248 at a level of 2.5 mg/kg diet, or 0.09 mg/kg body weight per day for 6 months showed an increased mortality rate, growth retardation, alopecia, acne, swelling of the Meibomian glands, and possibly immunosuppression. Microscopically, enlarged fatty liver with focal necrosis, and epithelial hyperplasia and keratinization of hair follicles were found. At higher exposure levels, microscopic changes have also been observed in other epithelial tissues, such as sebaceous and Meibomian glands, gastric mucosa, gall bladder, bile duct, nail beds, and ameloblast. Serum levels of total lipid triglycerides and cholesterol were decreased. Short-term exposure to commercial PCB mixtures induced an increase in the contents and concentrations of total lipids, triglycerides, cholesterol, and/or phospholipids in the liver. Among

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the PCB congeners, 3,4,3',4'-tetrachlorobiphenyl, 3,4,5,3',4',5'-, and 2,4,6,2',4',6'-hexachlorobiphenyl were the most potent. Aroclor 1254, at a dose level of 0.2 mg/kg body weight per day, also showed several other effects, such as lymphoreticular lesions, fingernail detachment, and gingival effects, but no acne and alopecia. A no-observed-effect level (NOEL) for the general toxicity of Aroclor 1242 of 0.04 mg/kg body weight per day was established in rhesus monkeys. Relatively mild effects were shown in suckling rhesus monkeys exposed to a much higher dose of Aroclor 1248 of 35 mg/kg body weight per day. Effects in the liver have been investigated most thoroughly in rats, and include hypertrophy, fatty degeneration, proliferation of the endoplasmic reticulum, porphyria, adeno-fibrosis, bile duct hyperplasia, cysts, and preneoplastic and neoplastic changes. In studies on rats and mice, individual PCB congeners caused effects in the liver, spleen, and thymus, the planar congeners being most toxic. In monkeys, planar congeners, at doses of 1-3 mg/kg diet, induced effects similar in character and severity to those seen with Aroclor 1242 at a dose of 100 mg/kg diet and with Aroclor 1248 at a dose of 25 mg/kg diet.

Following dermal exposure of rabbits and mice, PCB mixtures, and some congeners, caused effects on the skin and liver similar to those found after oral exposure. In rabbits, thymic atrophy, a reduction in the germinal centres of the lymph nodes, and leukopenia were also observed.

2.5.3 *Reproduction, embryotoxicity, and teratogenicity*

(a) Reproduction and embryotoxicity

Comprehensive reproduction and teratogenicity studies have not been conducted. In a two-generation reproduction study on rats, a NOEL of 0.32 mg/kg body weight was established for Aroclor 1254 and a NOEL of 7.5 mg/kg body weight for Aroclor 1260. However, the lowest tested dose (0.06 mg/kg body weight) resulted in increased relative liver weights in weanlings.

In rhesus monkeys exposed to Aroclor 1016, a NOEL of 0.03 mg/kg body weight was established on the basis of reproductive parameters. However, decreased birth weight was observed at this level and the lowest dose tested (0.01 mg/kg body weight) resulted in skin hyperpigmentation.

In rhesus monkeys, a NOEL of 0.09 mg/kg body weight was established for Aroclor 1248 (containing PCDFs) 1 year after exposure ceased.

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(b) Teratogenicity

Available studies on rats and monkeys did not indicate teratogenic effects when animals were dosed orally during organogenesis. A NOEL of 50 mg/kg body weight was demonstrated in rats for Aroclor 1254, with regard to pup weight, and a lowest-observed-effect level of 2.5 mg/kg body weight, based on fetotoxicity (lesions in thyroid follicular cells), could be assumed.

In teratogenicity tests of individual congeners on mice, rats, and Rhesus monkeys, no NOEL was demonstrated. In Rhesus monkeys, a dose of 0.07 mg/kg body weight indicated maternal toxicity (3,4,3',4'-tetrachlorobiphenyl).

2.5.4 Mutagenicity

PCB mixtures did not cause mutation or chromosomal damage in a variety of test systems. Chromosome breakage was induced in human lymphocytes *in vitro* by 3,4,3',4'-tetrachlorobiphenyl. High concentrations of PCB mixtures may cause primary DNA damage, as indicated by DNA single strand breaks in alkaline elution assays.

2.5.5 Carcinogenicity

The interpretation of the available animal data involving commercial PCB mixtures is often complicated by lack of information concerning the presence or contribution of chlorinated dibenzofuran impurities, as well as variations in congener composition.

A number of long-term carcinogenicity studies have been carried out in mice and rats. The PCB mixtures used were Kanechlors 300, 400, and 500, Aroclors 1254 and 1260, and Clophens A30 and A60. Except for the Clophens, which were reported to be free of polychlorinated dibenzofurans (PCDFs), no data were provided on the purity of the PCB mixtures used.

A significant increase in hepatocellular adenomas and/or carcinomas was observed in mice fed with a diet containing Kanechlor 500 and Aroclor 1254 at a dose level of approximately 15–25 mg/kg body weight. No neoplasms could be detected in mice treated with Kanechlors 300 and 400.

In rats, an increase in hepatocellular adenomas and/or carcinomas was noted in the studies on Aroclors 1254 and 1260 and Clophen A30, with an exposure period of more than 1 year. The increase in occurrence of tumours

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in animals in these studies was not considered to be statistically significant; however, this was the case in two other studies. An increase in the incidence of hepatocellular (trabecular) carcinomas and adenocarcinomas was demonstrated with Aroclor 1260 and Clophen A60, at a dose level of approximately 5 mg/kg body weight.

The liver tumours concerned were considered to be non-aggressive (benign or weakly malignant, no metastasis) and not life-shortening. Adenofibrosis, a pre-neoplastic lesion, and/or neoplastic nodules in the liver were reported in some of the studies. In one test with Aroclor 1254, dose-related increases in intestinal metaplasia and adenocarcinomas of the glandular stomach were demonstrated in the rat. There is a substantial body of evidence indicating that PCBs increase the incidence of liver carcinogenesis in rodents pre-treated with hepatocarcinogens. There is weak evidence that PCB mixtures initiate carcinogenesis in rodents. From the genotoxicity studies reported, it can be concluded that PCB-mixtures are non-genotoxic. These results imply that the association of liver tumours with administration of PCBs in rodents is attributable to some epigenetic mechanisms involving enforcement of cell proliferation in the liver and other manifestations of liver toxicity, hence a threshold approach can be followed in the evaluation of PCB toxicity. The possibility that PCBs might increase carcinogenesis in tissues other than liver in animals pre-exposed to various tissue-specific carcinogens needs to be addressed. The anticarcinogenic activities of PCBs shown in some studies, where PCBs were given to animals during, and prior to, the administration of carcinogens, may be related to microsomal enzyme-inducing properties of PCBs that result in an increase of detoxication.

Overall, there is reason to exercise caution in extrapolating to humans the available animal data on the carcinogenic potential of PCBs.

2.5.6 *Special studies*

The lesions induced by exposure to PCB mixtures or individual congeners concern the liver, skin, immune system, reproductive system, oedema, and disturbances of the gastrointestinal tract and thyroid gland.

PCBs are able to induce various enzymes in the liver. This has been demonstrated in rats, mice, guinea-pigs, rabbits, dogs, and monkeys for Aroclor 1248, 1254, 1260, and Kanechlor 400 (induction of cytochrome P450 and P448). The inducing ability increases with the chlorine content of the molecule; it is also dependent on the congener composition, where congeners with chlorine in the *para* and *meta* positions induce the P450

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enzyme. For AHH (aryl hydrocarbon hydroxylase) induction, the position of the chlorine seems to be more important than the degree of chlorination. Congeners with both *para* and at least two *meta* positions substituted by chlorine are the most potent inducers of AHH. Distinct interspecies variations have been demonstrated. The lowest NOEL of 0.025 mg/kg body weight was found for Aroclor 1260 in Osborn-Mendel rats.

Effects have been demonstrated on the endocrine system, seen as alterations in hormonal receptor-binding and alterations in steroid hormone balance. Direct and indirect evidence for a weak estrogenic activity of various Aroclors has been observed. Decreased levels of gonadal hormones and increased relative testes weights were found in rats exposed to 75 mg Aroclor 1242/kg diet for 36 weeks. Decreased plasma corticosteroid levels without increased adrenal weight, were found in female mice exposed to Aroclor 1254 (25 mg/kg diet) for 3 weeks. Increased adrenal weight was found in another strain given a diet containing 200 mg/kg for 2 weeks.

PCB mixtures have been shown to have an immunosuppressive effect in various animal species. Monkeys and rabbits were the most sensitive species. The lowest NOEL in monkeys was 0.1 mg/kg body weight, and that in rabbits, 0.18 mg/kg body weight.

Depressed motor-activity was seen in mice exposed to a single oral dose of 500 mg Aroclor (1254/kg body weight). This was probably related to inhibition of uptake and release of neurotransmitters.

PCB mixtures have been found to decrease the levels of vitamins A and B₁ in the blood and liver of rats. Decreased levels of vitamins A, B₁, B₂, and B₆ were seen in rats and mice exposed to PCB mixtures.

2.5.7 *Factors modifying toxicity; mode of action*

Commercial PCBs produce a spectrum of toxic responses, partly resembling those of polychlorinated dibenzodioxins (PCDDs) and PCDFs. In addition, the analogous structure-activity relations of PCB congeners, with respect to most of their toxic responses and to their potency in inducing P448-dependent AHH (aryl hydrocarbon hydroxylase), indicate that PCB congeners that are approximate stereoisomers of 2,3,7,8-TCDD are the most active. These findings suggest a common mechanism of action based on the affinity of these compounds for the cytosolic Ah-receptor protein. Toxic equivalence factors relating to 2,3,7,8-TCDD have been proposed for these coplanar PCB congeners. The nature of the likely interactions between PCBs, PCDFs, and PCDDs has not been investigated adequately.

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As PCBs can stimulate microsomal enzyme activity, they can influence the action of other chemicals that undergo microsomal metabolism. Other so-called non-planar PCB congeners may cause other more subtle toxicities. In addition, PCB congeners, especially the lower chlorinated ones, may be metabolized through arene oxide intermediates and methylsulfonyl metabolites.

2.6 Effects in humans

The toxicological evaluation of PCBs presents many problems. PCBs usually occur as mixtures of many congeners, and many of the data on the toxicity of the PCBs are based on the testing of such mixtures. Some components of the mixtures are more easily degraded in the environment than others. Thus, exposure of the general population may be to mixtures different from those to which the workers are exposed.

The general population is exposed to PCBs mainly through contaminated food (aquatic organisms, meat, and dairy products). In most of the industrialized countries, the daily intake of PCBs is of the order of some micrograms per person. Such exposure has not been associated with disease. Infants are exposed to PCBs through their mothers' milk, and their daily intake of PCBs may be some micrograms/kg body weight.

There are great difficulties in assessing the human health effects separately for PCBs, PCDFs, or PCDDs, since, quite frequently, PCBs contain PCDFs, and occasionally PCDDs have been detected in the mixtures involved in certain accidents. Commercial PCBs have been shown to be contaminated with PCDFs and, therefore, in many cases it is unclear whether effects are attributable to the PCBs or to the much more toxic PCDFs. Thus, much of the data that can be retrieved from large intoxication episodes in humans, e.g., the Yusho, Yu-Cheng, and other intoxications, probably reflect effects of exposure to both PCDFs and PCBs.

The signs of intoxication in the Yusho and Yu-Cheng patients were hypersecretion of the Meibomian glands of the eyes, swelling of the eyelids, and pigmentation of the nails and mucous membranes, occasionally associated with fatigue, nausea, and vomiting. This was usually followed by hyperkeratosis and darkening of the skin, with follicular enlargement and acneform eruptions. In addition, oedema of the arms and legs, liver enlargement and liver disorders, central nervous system disturbances, respiratory problems, e.g., bronchitis-like disturbances, and changes in the immune status of the patients, were observed. In children of the Yusho

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and Yu-Cheng patients, diminished growth, dark pigmentation of the skin and mucous membranes, gingival hyperplasia, xerophthalmic oedematous eyes, dentition at birth, abnormal calcification of the skull, rocker bottom heel, and a high incidence of low birth weight were observed. Whether or not a correlation exists between the exposure and the occurrence of malignant neoplasms in these patients cannot be definitely concluded, because the number of deaths was too small. However, a statistically significant increase was observed in male patients, as regards mortality from all neoplasms, and liver and lung cancer.

Under occupational conditions, skin rash has occurred a few hours after acute exposure. Furthermore, itching, burning sensations, irritation of the conjunctivae, pigmentation of fingers and nails, and chloracne were found after exposure to high PCB concentrations. Chloracne is one of the most prevalent findings among PCB-exposed workers. Besides these dermal signs of intoxication, different authors have found liver disturbances, immunosuppressive changes, transient irritation of the mucous membranes of the respiratory tract, and neurological and unspecific psychological or psychosomatic effects, such as headache, dizziness, depression, sleep and memory disturbances, nervousness, fatigue, and impotence. The overall conclusion is that continuous occupational exposure to high PCB and PCDF concentrations may result in effects on the skin and liver.

Two large mortality studies have been carried out with cohorts of workers exposed to Aroclor 1254, 1242, and 1016. Increased mortality from cancer of the liver and gall bladder was observed in one study and from neoplasms and cancer of the gastrointestinal tract in the other. None of the available epidemiological studies provide conclusive evidence of an association between PCB exposure and increased cancer mortality owing to the small number of deaths in the exposed populations, the lack of dose relationships, and the problems with contaminants in the PCB mixtures.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

3.1.1 *Distribution*

Because of their physical and chemical properties, PCBs have become dispersed globally throughout the environment.

PCBs are almost universally present in organisms in the environment and are readily bioaccumulated. Biomagnification in food-chains has also been demonstrated.

Higher chlorinated congeners accumulate preferentially.

3.1.2 *Effects on experimental animals*

Animal studies suggest that PCBs are immunosuppressive, as assessed by alterations in gross measures of immune function (spleen weight, thymus weight, or lymphocyte count). NOELs have been estimated in monkeys at 100 $\mu\text{g}/\text{kg}$ body weight for Aroclor 1248 and < 100 $\mu\text{g}/\text{kg}$ body weight for Aroclor 1254. Immunosuppression appears to be a congener-specific effect.

Reproductive toxicity is, in general, only seen at doses producing systemic toxicity in the mother. Neonates feeding on contaminated mother's milk (in monkeys and other animal species used as models) appear to be particularly sensitive to PCBs and show reduced growth, with other toxic symptoms. The NOEL for Aroclor 1016 in monkeys (on the basis of reproductive effects) is 30 $\mu\text{g}/\text{kg}$ body weight; no NOEL could be established for reproductive effects of Aroclor 1248.

CONCLUSIONS AND RECOMMENDATIONS

PCBs are not genotoxic and the evidence for any action as tumour initiators is inconclusive. PCBs do act as tumour promoters. The toxicity of PCB mixtures can be evaluated on a threshold basis.

3.1.3 *Effects on humans*

Exposure of the general population to PCBs is principally through food items. Babies are exposed through the mother's milk.

Two large intoxication episodes in humans have occurred in Japan (Yusho) and Taiwan (Yu-Cheng). The main symptoms of the Yusho and Yu-Cheng patients have frequently been attributed mainly to the contaminants of the PCB mixtures; specifically to PCDFs. The Task Group concluded that the symptoms may have been caused by the combined exposure to PCBs and PCDFs. Some of the symptoms, and principally the chronic respiratory effects, may have been caused specifically by the methylsulfone metabolites of certain PCB congeners.

3.1.4 *Effects on the environment*

While there have been reports of effects on populations of birds, the most important effect of PCBs on organisms in the environment is reproductive failure in sea mammals. This has been observed principally in semi-enclosed seas and has led to local decreases in populations. The prediction that residues of PCBs in the environment will gradually be redistributed towards the marine environment indicates an increasing hazard for sea mammals in the future.

CONCLUSIONS AND RECOMMENDATIONS

3.2 Recommendations

- International agreement on analytical procedures to improve the comparability of results of monitoring programmes is recommended. Development of methods for congener-specific analysis should be continued, though the value of analysis based on mixtures is recognized.
- In order to ensure reliability of analytical data, inter-laboratory quality control studies are strongly recommended. It is also recommended that an international network of technical support and supervision should be established to allow developing countries to participate in monitoring.
- Long-term studies using specific congeners and studies on the mechanism of action of constituents of PCBs mixtures, with special regard to tumour promotion, are recommended to improve the precision of risk assessment of PCBs.
- Epidemiological studies to improve the assessment of the risk to neonates are required, since newborn infants appear to be the most vulnerable sector of the general population, because of high exposure through milk.
- Sensitive and specific biomarkers for some of the more subtle aspects of PCB toxicity (such as reproductive, immunological, and neural toxicity) should be developed for use in future epidemiological studies
- PCBs should be disposed of by incineration in properly designed and run facilities that can guarantee the constant high temperatures (above 1000 °C), residence time, and turbulence needed to ensure complete breakdown.

CONCLUSIONS AND RECOMMENDATIONS

- Methods to remove PCBs already contained in landfills should be investigated.
- Worldwide monitoring of PCBs in the environment and in wildlife should be encouraged, to monitor the expected redistribution of residues already present.
- Marine mammals show evidence of reproductive failure as a result of PCB contamination. Studies on population size and reproductive success of cetaceans should be encouraged, together with further research to establish those congeners responsible for the effects.

4. HEALTH HAZARDS FOR MAN, PREVENTION AND PROTECTION, EMERGENCY ACTION

For a more detailed treatment of prevention and control of accidental and environmental exposures to PCBs and PCTs, the reader should refer to the WHO/EURO document listed in the Bibliography. A detailed description of the human and environmental hazards of PCBs is given in EHC 140 (WHO, in preparation).

4.1 Main human health hazards, prevention and protection, first aid

PCBs and PCTs are highly chlorinated organic substances. They are very persistent and may be hazardous for human beings if incorrectly or carelessly handled. It is, therefore, essential that the correct precautions are observed during handling, use, and disposal.

For details see the Summary of Chemical Safety Information in section 6.

4.1.1 *Advice to physicians*

4.1.1.1 *Symptoms of poisoning*

The acute oral and dermal toxicity is low, but under occupational conditions skin rash may occur a few hours after acute exposure. Furthermore, itching, burning sensations, irritation of the conjunctivae, pigmentation of fingers and nails, and (chlor)acne were found after exposure to high PCB concentrations for long periods. Massive doses can cause hepatitis, facial oedema, numbness, and weakness of the extremities. Chloracne is one of the most prevalent findings among workers exposed to PCBs, but may be due to the presence of PCDFs in the technical PCB mixtures. In addition to these dermal signs of intoxication, liver disturbances, immunosuppressive changes, transient irritation of the mucous membranes of the respiratory tract, neurological and unspecific effects, such as headache, dizziness, depression, sleep and memory disturbances, nervousness, fatigue, and impotence, have been reported.

4.1.1.2 *Medical advice*

Medical treatment is symptomatic and supportive.

HEALTH HAZARDS FOR MAN, PREVENTION AND PROTECTION, EMERGENCY ACTION

4.1.2 *Health surveillance advice*

A complete medical history and physical examination of workers regularly exposed to PCBs should be made annually. Special attention should be paid to the skin and to liver function.

4.2 Explosion and fire hazards

Fires and explosions involving PCBs have been reported mainly from their use in electrical equipment, such as transformers and capacitors, but PCBs may also be involved in fires during storage and transport. Fires may lead to the formation of highly toxic polychlorinated dibenzofurans (PCDFs). In dielectric fluid formulations, which also contain various tri- or tetrachlorobenzenes, polychlorinated dibenzo-*p*-dioxins (PCDDs) may be formed upon fire or explosion.

Fires should be extinguished with alcohol-resistant foam, carbon dioxide, or powder. With sufficient burning or external heat, PCBs will decompose, emitting very toxic fumes. Fire-fighters should be equipped with self-contained breathing apparatus, eye protection, and full protective clothing.

The use of water sprays should be confined to the cooling of unaffected stock, thus avoiding the accumulation of polluted run-off from the site.

4.3 Storage

Products should be stored in well ventilated, locked buildings, out of the reach of children and unauthorized personnel. Do not store near foodstuffs or animal feed.

4.3.1 *Leaking containers in store*

Take precautions, and use appropriate personal protection (see section 6). Empty any product remaining in damaged or leaking containers into a clean empty drum, which should then be tightly closed and suitably labelled. Sweep up spillage with sawdust, sand, or earth (moisten for powders), and dispose of safely.

HEALTH HAZARDS FOR MAN, PREVENTION AND PROTECTION, EMERGENCY ACTION

4.4 Transport

Comply with any local requirements regarding the movement of hazardous goods. Do not transport in the same compartment as foodstuffs. Check that the containers are sound and labels undamaged before despatch.

4.5 Spillage and disposal

4.5.1 Spillage

Before dealing with any spillage, precautions should be taken, as required, and appropriate personal protection should be used (see section 6).

Prevent material from spreading or contaminating other cargo, vegetation, or waterways, by making a barrier of the most suitable available material, e.g., earth or sand. Absorb the spilled liquid with sawdust, sand, or earth, sweep up and place the contaminated material in a closeable container for later transfer to a safe place for disposal. Care should be taken to avoid run-off into water courses.

4.5.2 Disposal

Dielectric fluids containing PCBs in transformers and capacitors should be recovered and sent for destruction.

Any surplus product, contaminated absorbants, and containers should be disposed of in an appropriate way. Waste material should be burned in a proper incinerator designed for organochlorine waste disposal, with effluent gas-scrubbing. For PCB wastes, incineration must be for more than 2 seconds at 1200 °C or higher. Cement kilns may meet the required temperature/time conditions and may be properly constructed for this purpose. If the PCB content of the waste is less than 500 mg/kg, any proper waste incinerator can be used as long as temperature exceeds 800 °C for 0.5 seconds. Combustion of PCBs can produce dibenzofurans; PCB dielectric fluids also containing tri- or tetrachlorobenzenes can also produce dioxins. If proper incineration is not possible, bury in an approved dump or landfill where there is no risk of contamination of surface or ground water. Decomposition of PCBs is extremely slow.^a

^a For a more complete treatment of the subject, refer to WHO/Euro, 1987.

HEALTH HAZARDS FOR MAN, PREVENTION AND PROTECTION, EMERGENCY ACTION

Comply with any local legislation regarding disposal of toxic wastes.
Puncture and crush containers, to prevent re-use.

5. HAZARDS FOR THE ENVIRONMENT AND THEIR PREVENTION

5.1 Hazards

PCBs and PCTs are very resistant to degradation and hence very persistent in the environment. Because they are very soluble in lipids they bioaccumulate, especially in the fatty tissues of all living organisms, and biomagnify in the higher trophic levels of the food-chain.

Although their acute toxicity is relatively low, bioaccumulation and biomagnification may lead to lethal effects, especially at the highest trophic levels. Reduced growth and reproduction may affect populations.

5.2 Prevention

PCBs and PCTs should be replaced by alternative products wherever practicable.

Industrial discharges occurring during manufacture, formulation, or technical applications should not be allowed to pollute the environment and should be treated properly.

Any spillage or unused product should be prevented from spreading to vegetation or waterways, and should be treated and disposed of properly.

In all cases, immediate remedial action is essential.

6. SUMMARY OF CHEMICAL SAFETY INFORMATION

This summary should be easily available to all health workers concerned with, and users of, PCBs and PCTs. It should be displayed at, or near, entrances to areas where there is potential exposure to PCBs and PCTs, and on processing equipment and containers. The summary should be translated into the appropriate language(s). All persons potentially exposed to the chemical should also have the instructions in the summary clearly explained.

Space is available for insertion of the National Occupational Exposure Limit, the address and telephone number of the National Poison Control Centre, and local trade names.

SUMMARY OF CHEMICAL SAFETY INFORMATION

Polychlorinated biphenyls (PCBs)

Molecular formula: $C_{12}H_{10-n}Cl_n$
CAS registry number: 1336-36-3
RTECS registry number: TQ1350000

Polychlorinated terphenyls (PCTs)

Molecular formula: $C_{18}H_{14-n}Cl_n$
CAS registry number: 61788-33-8
RTECS registry number: WZ6500000

PHYSICAL PROPERTIES AND OTHER CHARACTERISTICS

Commercial PCBs and PCTs are complex mixtures of many different congeners with various degrees of chlorination. They are not produced to a composition specification; the criteria for use are based on physical properties. They are clear, light yellow, or dark liquids that may turn into solid resin at low temperatures.

Their distillation range is in general above 250 °C. Their relative molecular mass and density depend on the degree of chlorination. They are very fire-resistant, with flash-points above 170 °C. Their vapours are heavier than air, but do not form explosive mixtures. Their electrical conductivity is very low and their resistance to thermal breakdown extremely high. They are practically insoluble in water, easily miscible with most organic solvents, and accumulate in fatty tissues. They have high *n*-octanol/water partition coefficients.

They are mainly used as dielectrics in transformers and capacitors, in heat transfer and hydraulic systems, and, to a lesser extent, in lubricating and cutting oils, carbonless copying paper, adhesives, sealants, plastics, and as plasticizers in paints.

HAZARDS/SYMPTOMS

PREVENTION AND PROTECTION

FIRST AID

SKIN: May cause irritation and chloracne

Avoid contact with skin; wear suitable protective clothing and gloves

After contact with skin, wash immediately with plenty of water and soap; immediately remove all contaminated clothing and launder before reuse

EYES: May cause irritation

Avoid contact with eyes; wear eye protection

In case of contact with eyes, rinse immediately with plenty of water and seek medical advice

INHALATION: May cause irritation

Adequate ventilation; do not breathe vapours

INGESTION: Unlikely occupational hazard

Do not eat, drink, or smoke during work; wash hands before eating, drinking, or smoking

Accidental or intentional ingestion may cause poisoning

If swallowed, seek medical advice immediately and show container or label

ENVIRONMENT: Bioaccumulates and biomagnifies

Strictly avoid environmental pollution

SUMMARY OF CHEMICAL SAFETY INFORMATION (continued)

SPILLAGE	STORAGE	FIRE AND EXPLOSION
<p>Take appropriate personal precautions; prevent liquid from spreading or contaminating other cargo, vegetation, or surface waters and drainage systems, with a barrier of most suitable suitable material, e.g., earth or sand</p> <p>Absorb spilled liquid with saw-dust, sand, or earth; sweep up and place it in a closeable container for later safe disposal; care should be taken to avoid run-off into water courses</p>	<p>Products should be stored in well ventilated locked buildings; keep out of reach of children; keep away from food, drink, and animal feeding stuffs</p>	<p>Extinguish fires with alcohol-resistant foam, CO₂, or powder; with sufficient burning or external heat, PCBs and PCTs will decompose, emitting toxic fumes; firefighters should be equipped with self-contained breathing apparatus, eye protection, and full protective clothing; confine the use of water spray to cooling of unaffected stock, thus avoiding the accumulation of polluted run-off from the site</p>

WASTE DISPOSAL

PCBs and PCTs waste material should be burned in a proper incinerator designed for organochlorine waste disposal; if this is not possible, bury in an approved dump or landfill where there is no risk of contamination of surface or ground water; comply with any local legislation regarding disposal of toxic wastes

NATIONAL INFORMATION

National Occupational Exposure Limit:

UN No. 2315

National Poison Control Centre:

Local trade names:

7. CURRENT REGULATIONS, GUIDELINES, AND STANDARDS

The information given in this section has been extracted from the International Register of Potentially Toxic Chemicals (IRPTC) legal file and other United Nations sources. A full reference to the original national document from which the information was extracted can be obtained from IRPTC. When no effective date appears in the IRPTC legal file, the year of the reference from which the data are taken is indicated in the table by (r).

The reader should be aware that regulatory decisions about chemicals taken in a certain country can only be fully understood in the framework of the legislation of that country. Furthermore, the regulations and guidelines of all countries are subject to change and should always be verified with the appropriate regulatory authorities before application.

7.1 Previous evaluations by international bodies

PCBs have been evaluated by IARC in 1978 and 1987 (IARC, 1978, 1987 (Supplement)). It was concluded that there was sufficient experimental evidence to indicate a carcinogenic effect of some PCBs in rodents, and that epidemiological data provided suggestive evidence of a relationship between exposure to PCBs and the development of certain cancers in man. PCBs were classified in group 2A: the agent is probably carcinogenic for humans. For practical purposes, PCBs should be regarded as if they were carcinogenic for human beings.

7.2 Exposure limit values

Some exposure limit values for PCBs are given in the table on pages 43-45.

7.3 Specific restrictions

Several intergovernmental organizations have been active in providing directives or recommendations for regulatory measures to control PCBs.

On 13 February 1973, the Council of the Organisation for Economic Cooperation and Development (OECD) adopted a Decision on the Protection of the Environment by Control of Polychlorinated Biphenyls (C(73)1). The Council decided that PCBs would not be used for industrial or

CURRENT REGULATIONS, GUIDELINES, AND STANDARDS

Exposure limit values					
Medium	Specification	Country	Exposure limit description	Value	Effective date
AIR	Workplace	Czechoslovakia	Maximum permissible concentration	0.5 mg/m ³	1985
			- time-weighted average (TWA)	1.0 mg/m ³	
		- short-term exposure limit (STEL)			
		Japan	Maximum permissible concentration	0.1 mg/m ³ a	1985
			- time-weighted average (TWA)		
		Netherlands	Maximum allowable concentration (MAC)		
			- time-weighted average (TWA)	0.5 mg/m ³	-
		Sweden	Occupational exposure limit		
			- time-weighted average (TWA)	0.01 mg/m ³ a	1985
			- short-term exposure limit (STEL)	0.03 mg/m ³	
		USSR	Maximum permissible concentration		
			- time-weighted average (TWA) (vapour)	1.0 mg/m ³	1977

CURRENT REGULATIONS, GUIDELINES, AND STANDARDS (continued)

Exposure limit values (continued)					
Medium	Specification	Country	Exposure limit description	Value	Effective date
AIR	Workplace	United Kingdom	Recommended limit		
			- time-weighted average (TWA)	0.5 mg/m ³	-
			- short-term exposure limit (STEL) (10-min TWA)	1.0 mg/m ³	
FOOD	Animal	USA (ACGIH)	Threshold limit value (TLV)		
			- time-weighted average (TWA)	0.5 mg/m ³	-
			- short-term exposure limit (STEL)	1.0 mg/m ³	
			Maximum residue limit (MRL) (specified products)	0.008-0.6 mg/kg	1988
FOOD	Animal & plant	Sweden	Maximum residue limit (MRL) (Specified)	0.05-2 mg/kg	1983
			Maximum residue limit (MRL) (fish)	2 mg/kg	-
			Maximum residue limit (MRL) (Specified)	0.2-3 mg/kg	-
			Maximum residue limit (MRL) (Specified)	0.3-1 mg/kg	-

	Switzerland	Maximum residue limit (MRL) (Specified)	0.5-2 mg/kg	-
	USA	Temporary residue tolerance (Specified)	0.2-3 mg/kg	1981
FEED	Japan	Maximum residue limit (MRL) (Specified)	0.05-3 mg/kg	-
	Netherlands	Maximum residue limit (MRL) (Specified)	0.3 mg/kg	-
	USA	Maximum residue limit (MRL) (Specified)	0.2-2 mg/kg	-
WATER	EEC	Maximum permissible concentration (total PCBs + PCTs)	0.5 µg/litre	1982
	Japan	Environment water quality standard	not detectable	1981
	USSR	Permissible limit	0.0 mg/litre	1978
	Japan	Effluent standard	0.003 mg/litre	1981
GOODS	USA	Temporary residue tolerance	10 mg/kg	1983

^a Skin absorption.

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commercial purposes, except for five essentially closed purposes. These are: dielectric fluids in transformers; large power-correcting capacitors; heat-transfer fluids (but only in installations that do not process food, feed, pharmaceuticals, or veterinary products); hydraulic fluids (but only in mining equipment); and in small capacitors (though Member Countries have recommended working towards the elimination of this last use). PCBs should only be used in the exempted applications where non-flammability requirements outweigh the environmental protection considerations and where sufficient controls are exercised to minimize risk to the environment. The Council also made some recommendations concerning the elimination of other uses of PCBs and PCB replacements. It also provided for certain administrative and engineering control measures for PCBs still in use, and for the disposal of PCB wastes. The OECD Council decision provided for an exchange of information on PCBs between Member Countries within the framework of the OECD Environment Committee and information on PCBs was exchanged annually between 1974 and 1980. The information exchanged and the experience gained by Member Countries was summarized in a report (OECD, 1982). This report indicated that, while considerable progress had been made in reducing environmental contamination by PCBs, some important problems remained.

An extensive synopsis of national regulatory measures in a number of countries was prepared by the OECD in 1982. Countries have rather complex and very different systems to control PCBs in the general environment. Most regulations impose usage restrictions and prescriptions for transportation and labelling, require notification of production and/or importation, and provide rules for the disposal of PCB-containing wastes.

On 13 February 1987, the OECD Council adopted a further Decision-Recommendation (C(87)2(final)) on "Further measures for the protection of the environment by control of polychlorinated biphenyls". With this Decision-Recommendation, the OECD Member Countries committed themselves to ban virtually all new uses for PCBs, accelerate the phasing out of PCBs from existing uses, control PCBs in contaminated products, articles, or equipment, and ensure appropriate disposal methods for wastes containing PCBs.

In the countries of the European Economic Community, the use of PCBs and PCTs is prohibited by Directive 85/467/EEC (6th Amendment (PCBs

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and PCTs) Directive 76/769/EEC) but until 30 June 1986 the following uses were excepted: (a) closed-system electrical equipment; (b) large condensers; (c) small condensers (provided that the PCB has a maximum chlorine content of 43% and does not contain more than 3.5% of penta- and higher chlorinated biphenyls); (d) heat-transmitting fluids in closed-circuit heat-transfer installations; (e) hydraulic fluids used in underground mining equipment; (f) primary and intermediate products for further processing into other products which are not prohibited under the Directive. The use of equipment, plant, and fluids referred to in points *a* to *f* above that were in service on 30 June 1986 shall continue to be authorized until they are disposed of or reach the end of their service life. Derogations considered to have no deleterious effects on health or the environment could be granted after 30 June 1986. These provisions apply to PCBs and PCTs (except mono- and dichlorinated biphenyls) and preparations with a PCB or PCT content higher than 0.01% by weight.

Apart from the above restrictions in OECD and EEC countries, several other countries have similar, more or less severe restrictions on the use of PCBs (and PCTs). In Japan, the manufacture and import of all PCBs is prohibited without authorization from the Government. In the USA, the manufacture, processing, distribution in commerce and use of PCBs is prohibited without Government authorization.

7.4 Labelling, packaging, and transport

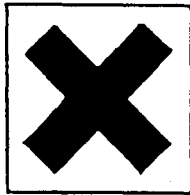
The United Nations Committee of Experts on the Transportation of Dangerous Goods classifies PCBs in:

Hazard Class 9:	Miscellaneous dangerous substance.
Packing Group II:	Substances presenting medium danger.

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The European Economic Community legislation requires the labelling of PCBs and PCTs as harmful substances using the symbol:

Xn



- ES: Nocivo
- DA: Sundhedsskadelig
- DE: Mindergiftig

- EL: Επιβλαβες
- EN: Harmful
- FR: Nocif
- IT: Nocivo
- NL: Schadelijk
- PT: Nocivo

The label must read:

Danger of cumulative effects. This material and its container must be disposed of in a safe way. It should be stated on the label whether the substance is a specific isomer or a mixture of isomers.

7.5 Waste disposal

The following is an excerpt from the EEC Council Directive 84/631/EEC:

“EEC Member States shall: (1) prohibit the uncontrolled discharge, dumping, and tipping of polychlorinated biphenyls (PCBs) and polychlorinated terphenyls (PCTs) as well as mixtures, objects, and equipment containing one or both of the substances; (2) make compulsory the disposal of such waste; (3) ensure that it is disposed of without endangering human health or harming the environment; (4) promote the regeneration of PCB and PCT; and (5) set up or designate installations which are authorized for disposing of such waste.

“Waste containing or contaminated by polychlorinated biphenyls is classified as ‘hazardous waste’. Member States shall take the necessary measures for the supervision and control, with a view to human health and the environment, of the transfrontier shipment of hazardous waste both within and if entering and/or leaving the community. Where the holder of such waste intends to have it shipped into, through or from one to another Member State he shall notify the competent authorities through a consignment note. He must provide satisfactory information

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in particular on: (1) the source and composition; (2) provisions made for routes and insurances; (3) measures to ensure safe transport; (4) contractual agreement with the consignee of the waste. The hazardous waste must: (a) be properly packed; (b) have appropriate labels indicating nature, composition, quantity and telephone numbers of persons from whom instructions can be obtained; (c) instructions to be followed in the event of danger or accident."

Under proposed EEC Council Directives, combustion gases in combustion chambers must be kept at, at least 850 °C for 2 seconds, and all plant must be fitted with auxiliary burners which come into use automatically when combustion chamber gases fall below 850 °C. These conditions must be met immediately by new plant and by 1994 by existing plant (United Kingdom House of Lords paper 17, 1989, HMSO, London).

In the USA, PCBs are classified as toxic pollutants and acute hazardous wastes, subject to handling, transport, treatment, storage, and disposal regulations, and permit and notification requirements. An owner or operator of a hazardous waste incinerator must achieve 99.9999% destruction and removal efficiency for these substances. Effluent limitations and pre-treatment standards are set for industries using PCBs. The interim emission standards for incinerators are 0.25 mg/m³ (peak value) and 0.15 mg/m³ (peak value from liquid PCB incinerators).

Under the Environmental Contaminants Act, the Canadian Ministry of Environment published "*Guidelines for the management of PCB wastes*". The *Guidelines* set out recommended procedures and criteria for the safe storage, handling, and disposal of PCB wastes.

In Italy, an emission standard for PCBs and PCTs of 0.1 mg/m³ for urban incinerators has been adopted by the Lombardy Region.

In Sweden, enterprises producing wastes that contain PCBs are required to report the type, content, quantity, and handling of the waste to the health authorities. Permission from the authorities is required for the transport, handling, and export of such waste (1975).

The Assembly of the Intergovernmental Maritime Consultative Organization (IMCO) passed Resolution A 394(x) on 14 November 1977, inviting governments to take steps to ensure that the operational sea discharge of tank washings from incinerator ships containing PCBs is prohibited, except where this is permitted under specific regulations or technical guidelines adopted by the contracting parties.

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In 1972, the Final Act of the Intergovernmental Conference on the Dumping of Wastes at Sea prohibited the dumping of PCBs at sea. The Third Consultative Meeting organized by IMCO in 1978 adopted the Amendments to the Convention Annexes which made incineration of waste at sea subject to controls under the Convention.

The Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter (Oslo, 1972), concerned with the NE Atlantic, came into force in 1974. It prohibits the dumping of organohalogen (i.e., PCB-inclusive) sources.

At its sixth meeting (1979), the Interim Baltic Marine Environment Protection Commission decided to draft a resolution concerning regulation of the use of PCBs and the prevention of discharges

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