

Consolidated Guidance on PCB in Open Applications

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1 Executive summary

It is estimated that approx. 25 % of the total world production of polychlorinated biphenyls (PCB) - or approx. 375'000 tonnes respectively - were used in open applications.

Many of these open applications are still in use today, and they are usually not detected and defined as hazardous waste at the time of disposal. PCB in open applications often find their way into the environment.

Due to the persistence of PCB and the lipophilic properties, PCB are bioaccumulated and biomagnified. PCB can be found in the environment, and in the food chain. The chemical is transported over long distances to regions where it has never been used or produced before. PCB bio-accumulate in the fatty tissue of humans and other living organisms. Fatty animal-based foods like fish, meat and dairy products often contain PCB. Particularly high PCB levels can be detected in fatty fish types like herring and salmon caught in the wild.

It has been demonstrated that PCB cause a variety of adverse health effects. On the basis of sufficient evidence of carcinogenicity in humans and experimental animals, the IARC classified PCB in 2013 to be a Group 1 carcinogen. Furthermore, there are a number of serious non-cancer health effects in animals, including effects on the immune system, reproductive system, nervous system, endocrine system and other health effects. The different health effects of PCB may be interrelated. Alterations in one system may have significant implications on the other systems of the body.

Many buildings worldwide, especially those constructed or renovated between the 1950s and the early 1980s, contain PCB in a wide variety of applications which emit PCB into the environment. In buildings, PCB can contribute directly to human exposure.

PCB were used in open applications in many industrial, public and private buildings as well as in hydro power, nuclear power and water treatment plants, military installations, the car and shipbuilding as well as the mining industry, and more. Awareness of PCB in open applications is usually very low and partly compared to the awareness of PCB in transformers, capacitors and other closed systems.

PCB wastes from uses in open applications are often not recognized as hazardous waste at the time of disposal even in countries that are aware of the presence of PCB in open applications. As a result, there are possibilities that PCB escape into the environment at the end-of-life stage through inappropriate treatment of the materials during demolition and final disposal in unsuitable landfill sites.

2 Obligations under the Stockholm Convention

The Stockholm Convention on Persistent Organic Pollutants (POPs) entered into force in May 2004. The objective of the Convention is to protect human health and the environment from persistent organic pollutants through the elimination of the production, use, and trade of POPs.

Polychlorinated biphenyls (PCB) were included in the initial list of the twelve POPs under the Stockholm Convention. PCB are listed in Annex A of the Convention with a specific exemption for use of PCB in articles in accordance with the provisions of Part II of Annex A, which may be exercised by all Parties to the Convention.

The production of PCB is not allowed, and equipment containing PCB shall not be exported or imported except for the purpose of environmentally sound management. The Stockholm Convention requires international action to eliminate the use of PCB in equipment by 2025 and to manage PCB waste in an environmentally sound manner by 2028.

Annex A, Part II, Polychlorinated Biphenyls

Each Party shall:

- (f) In lieu of note (ii) in Part I of this Annex, endeavor to identify other articles containing more than 0.005 per cent polychlorinated biphenyls (e.g. cable-sheaths, cured caulk and painted objects) and manage them in accordance with paragraph 1 of Article 6

Article 6, Measures to reduce or eliminated releases from stockpiles of wastes

1. In order to ensure that stockpiles consisting of or containing chemicals listed either in Annex A or Annex B and wastes, including products and articles upon becoming wastes, consisting of, containing or contaminated with a chemical listed in Annex A, B or C, are managed in a manner protective of human health and the environment, each Party shall:
 - (a) Develop appropriate strategies for identifying:
 - (i) Stockpiles consisting of or containing chemicals listed either in Annex A or Annex B; and
 - (ii) Products and articles in use and wastes consisting of, containing or contaminated with a chemical listed in Annex A, B or C;
 - (b) Identify, to the extent practicable, stockpiles consisting of or containing chemicals listed either in Annex A or Annex B on the basis of the strategies referred to in subparagraph (a);
 - (c) Manage stockpiles, as appropriate, in a safe, efficient and environmentally sound manner. Stockpiles of chemicals listed either in Annex A or Annex B, after they are no longer allowed to be used according to any specific exemption specified in Annex A or any specific exemption or acceptable purpose specified in Annex B, except stockpiles which are allowed to be exported according to paragraph 2 of Article 3, shall be deemed to be waste and shall be managed in accordance with subparagraph (d);
 - (d) Take appropriate measures so that such wastes, including products and articles upon becoming wastes, are:
 - (i) Handled, collected, transported and stored in an environmentally sound manner;
 - (ii) Disposed of in such a way that the persistent organic pollutant content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of persistent organic pollutants or otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option or the persistent organic pollutant content is low, taking into account international rules, standards, and guidelines, including those that may be

developed pursuant to paragraph 2, and relevant global and regional regimes governing the management of hazardous wastes;

- (iii) Not permitted to be subjected to disposal operations that may lead to recovery, recycling, reclamation, direct reuse or alternative uses of persistent organic pollutants; and
- (iv) Not transported across international boundaries without taking into account relevant international rules, standards and guidelines;
- (e) Endeavour to develop appropriate strategies for identifying sites contaminated by chemicals listed in Annex A, B or C; if remediation of those sites is undertaken it shall be performed in an environmentally sound manner.

3 Definition, characteristics, production, trade names and history of PCB

PCB are chlorinated, often colorless compounds, manufactured synthetically. Depending on the number and position of the chlorine atoms in the molecule, the physical and chemical properties vary. This variation is also reflected for the toxicological properties of the different molecules.

PCB are fire resistant, have a low electrical conductivity, high resistance to thermal breakdown and a high resistance to oxidants and other chemicals.

PCB are a serious threat to human health and the environment. Among others, they are considered to be carcinogenic, immunotoxic and they affect reproduction and are therefore among the chemicals listed in the group of POPs regulated under the Stockholm Convention.

While the Stockholm Convention prohibits production, PCB are still in use in many applications and stockpiled in many countries. Once released into the environment, PCB remobilize and enter the ecological food chain, eventually contributing to human exposure via food intake. According to WHO studies, more than 90 % of human exposure to PCB is through food, mainly meat, dairy products and fish.

PCB were manufactured worldwide by a small number of companies in mostly industrialized countries and often used as cooling and isolating agents in transformers and capacitors. As the characteristics of PCB are quite advantageous from a technical point of view, they were found in a wide range of applications. Globally, the PCB production peaked in the 1960s and 1970s. Between 1983 and 1993, the production of PCB was stopped in many countries. In some countries it had already been regulated since the early 1970s.

It is estimated that approx. **1.5 million tonnes** of technical grade **PCB** were produced since the late 1920s¹, and **open applications** of PCB accounted to approx. **25 %** of this total production.

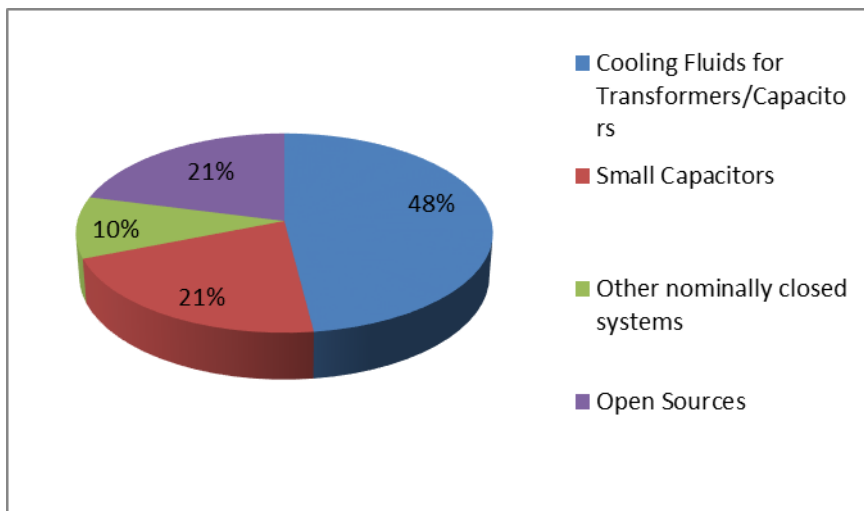


Figure 1: Approximate Share of PCB in Closed Applications and Open Applications

Approximately 48% of PCB were used for transformer and capacitor oils; approx. 21 % for small capacitors, approx. 10 % for other “nominally closed” applications; and approximately 21 % for open applications¹.

Consequently, **approx. 1/4 of the total world production of PCB or 375'000 tonnes respectively,** were used in open applications.

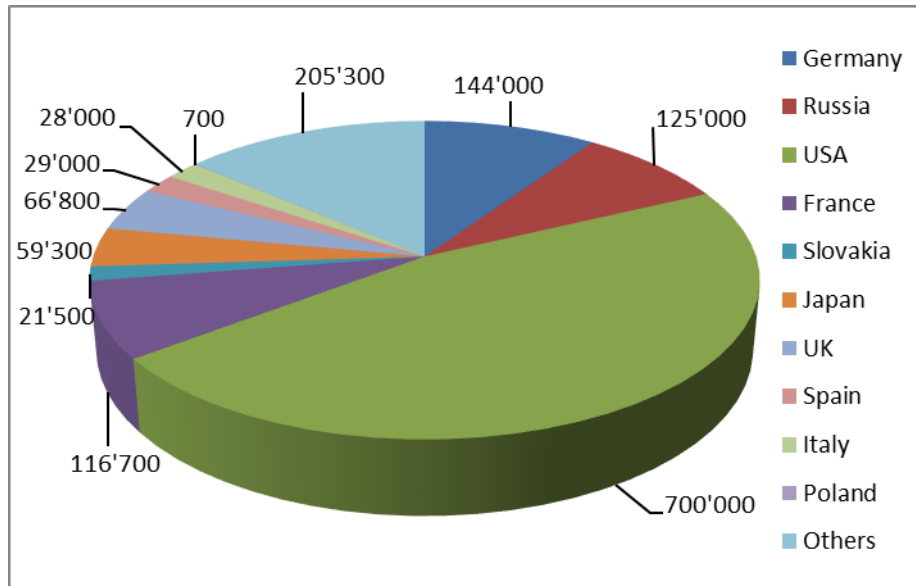


Figure 2: Estimated Total World Production of PCB (in Tonnes)

The largest quantities of PCB were produced in the USA, Germany, Russia and France. Approx. 200'000 tonnes of the total world production originated from other countries like Slovakia, Japan, the UK, Spain, Italy and Poland.

Commercial PCB mixtures were for example marketed as Apirolio in Italy, Ascarel in Brazil, Aroclor by Monsanto in the USA and the UK, Asbestol in the USA, Askarel in the USA and the UK, Bakola131 in the USA, Chlorextol in the USA, Clophen by Bayer in Germany, Delor in Czechoslovakia, Fenclor in Italy, Hydol in the USA, Inerteen by Westinghouse in the USA, Kanechlor by Kanegafuchi in Japan, Noflamol in, Phenoclor and Pyralène by Prodelec in France, Pyranol and Pyrenol by General Electric in the USA, Pyroclor in the UK, Saft-Kuhl in the USA, Santotherm by Mitsubishi in Japan, Sovol and Sovtol in the former USSR, and Therminol in the USA.

It is important to note that due to dilution and cross-contamination, the amount of liquids and equipment containing or contaminated with PCB is much larger than the amounts of PCB originally produced.

With few exceptions, PCB were manufactured as a mixture of individual PCB congeners. These mixtures were created by adding progressively more chlorine to batches of biphenyl until a certain target percentage of chlorine by weight was achieved.

Commercial mixtures with higher percentages of chlorine contained higher proportions of the more heavily chlorinated congeners, but all congeners could be expected to be present at some level in all mixtures. While PCB were manufactured and sold under many trade names, the most common was the Aroclor series produced by Monsanto.

Aroclor is a PCB mixture which was produced approx. between 1930 and 1979. It is one of the most commonly known trade names for PCB mixtures. There are many types of Aroclors and each has a distinguishing suffix number that indicates the degree of chlorination.

The numbering standard for the different Aroclors is as follows:

- (a) The first two digits usually refer to the number of carbon atoms in the phenyl rings (for PCB this is 12);

- (b) The second two numbers indicate the percentage of chlorine by mass in the mixture. For example, the name Aroclor 1254 means that the mixture contains approximately 54 % chlorine by weight.

PCB were manufactured and sold under many different names. The names in Table 2 were used to refer to PCB or to products containing PCB. Some of these names may still be in use for substances or mixtures not containing PCB. Many of these names were used with distinguishing suffixes, indicating degree of chlorination, type of formulation, or other properties (e.g. Aroclor 1254; Clophen A60).

The plasticizer Sovol was produced in the former Soviet Union and used in a number of industries, especially paint and varnish production as well as in the manufacture of various lubricants.

The use of approx. 53'000 tonnes from the total production of Sovol was estimated as it is shown in the below table².

Table 1: Uses of Sovol

37'000 tonnes	Used in the production of varnish and paint
10'000 tonnes	Used in the production of lubricants
Approx. 5'500 tonnes	Used in defense-related industry plants and other industrial enterprises not otherwise included in the inventory

The following table shows some of the brand names used for the various applications of PCB.

Table 2: Trade Names of PCB

Abestol (t, c)	Diconal	Phenoclar DP6 (Germany)
Abuntol (USA)	Disconon (c)	Phenoclor (t, c) (France)
Aceclor (t) (France, Belgium)	Dk (t, c) (decachlorodiphenyl)	Phenoclor DP6 (France)
Acooclor (Belgium)	DI(a)conal	Phyralene (France)
Adkarel	DP 3, 4, 5, 6.5	Physalen
ALC	Ducanol	Plastivar (Great Britain)
Apirolia (t, c)	Duconal (Great Britain)	Polychlorinated biphenyl
Apirolio (t, c)	Duconol (c)	Polychlorinated diphenyl
Areclor (t)	Dykanol (t, c) (USA)	Polychlorinated diphenyls
Arochlor (t, c)	Dyknol (USA)	Polychlorobiphenyl
Aroclor (t, c) (USA)	E(d)ucaral (USA)	Polychlorodiphenyl
Aroclor 1016 (t, c)	Educarel	Prodelec
Aroclor 1221 (t, c)	EEC-18	Pryoclar (Great Britain)
Aroclor 1232 (t, c)	EEC-IS (USA)	Pydraul (USA)
Aroclor 1242 (t, c)	Elaol (Germany)	Pydraul 1 (USA)
Aroclor 1254 (t, c)	Electrophenyl (France)	Pydraul 11Y (USA)
Aroclor 1260 (t, c)	Electrophenyl T-60	Pyraclor
Aroclor 1262 (t, c)	Elemex (t, c) (USA)	Pyralene (t, c) (France)
Aroclor 1268 (t, c)	Elexem (USA)	Pyralene 1460, 1500, 1501 (F)
Arubren	Elinol	Pyralene 3010, 3011 (France)
Asbestol (t, c)	Eucarel (USA)	Pyralene T1, T2, T3 (France)
ASK	Euracel	Pyramol (USA)
Askarel (t, c) (USA)	Fenchlor (Italy)	Pyranol (t, c) (USA)
Auxol (USA)	Fenclor 42, 54, 70 (t, c) (Italy)	Pyroclor
Bakola	Fenocloro	Pyronol

Bakola 131 (t, c)	Gilotherm	Pyroclor (Great Britain)
Bakolo (6) (USA)	Hexol (Russian federation)	Pyroclor (t) (USA)
Blacol (Germany)	Hivar (c)	Pyromal (USA)
Biclor (c)	Hydelor	Pyronal (Great Britain)
Biphenyl	Hydol (t, c)	Pysanol
Chloretol	Hydrol	Saf(e)-T-Kuhl (t, c) (USA)
Chlorfin	Hyrol	Safe T America
Chlorextol (t)	Hyvol	Saft-Kuhl
Chlorinated biphenyl	Hywol (Italy/USA)	Saf-T-Kohl
Chlorinated Diphenyl	Inclar (Italy)	Saf-T-Kuhl
Chlorinol (USA)	Inclor (Italy)	Sanlogol
Chlorintol (USA)	Inerteen 300, 400, 600 (t, c)	Sant(h)osafe (Japan)
Chlorobiphenyl	Kanechlor (KC) (t, c) (Japan)	Sant(h)othera (Japan)
Chlorodiphenyl	Kanechor	Sant(h)othern FR (Japan)
Chloroecxtol (USA)	Kaneclor (t,c)	Santosol
Chlorofen (Poland)	Kaneclor 400	Santoterm
Chlorphen	Kaneclor 500	Santotherm (Nippon)
Chorextol	Keneclor	Santothern
Chorinol	Kennechlor	Santotherm FR
Clophen / Clophenharz (t, c) (Germany)	Leromoli	Santovac
Clophen Apirorlio	Leromoll	Santovac 1
Clophen-A30	Leronoll	Santovac 2
Clophen-A50	Magvar	Santovec (USA)
Clophen-A60	Man(e)c(h)lor (KC) 200,600	Santowax
Cloresil	Manechlor (Nippon)	Santvacki (USA)
Clorinal	MCS 1489	Sat-T-America
Clorinol	Montar (USA)	Saut(h)otherm (Japan)
Clorphen (t)	Monter	Siclonyl (c)
Crophene (Germany)	Nepoli	Solvol (t, c) (Russian Federation)
DBBT	Nepolin (USA)	Sorol (Russian Federation)
Delofet O-2	Niren	Soval
Delor (Slovakia)	No-Famol	Sovol (Russian Federation)
Delor/Del (Slovakia)	NoFlamol	Sovtol (Russian Federation)
Delorene	No-Flamol (t, c) (USA)	Tarnol (Poland)
Delor (Czech Republic)	No-flanol (t,c) (USA)	Terpenylchlore (France)
Delorit	Nonflammable liquid	Terphenylchlore
Delotherm DK/DH (Slovakia)	Non-flammable liquid	Therainol FR (HT) (USA)
DI 3,4,5,6,5	Olex-sf-d	Therminol
Diachlor (t,c)	Orophen (Former East Germany)	Therminol (USA)
Diaclor (t, c)	PCB	Therminol FR
Diaconal	Pheaoclor	Therpanylchlore (France)
Dialor (c)	Pheneclor	Turbinol

Diarol	Phenochlor	Ugilec 141, 121, 21
Dicolor	Phenochlor DP6	

4 Applications of PCB

Due to their chemical characteristics and physical stability, PCB commercial products were widely used in open and partially open applications. Examples for open applications include use in caulks (sealants), paints, anti-corrosion coatings, and flame retardants.

Open applications of PCB have also included plasticizers, carbonless copy paper, lubricating oils, inks, laminating and impregnating agents, paints, adhesives, waxes, additives in cement and plaster, casting agents, dedusting agents, sealing liquids, fire retardants, immersion oils and pesticide extenders³ of de Voogt and Brinkman, 1989 quoted by Breivik⁴.

Although no longer commercially produced, PCB may be still present in products and materials manufactured before the worldwide ban in the early 1980s. Products that, for example still may contain PCB are listed in Table 3. There were many more applications that however may not be in service anymore due to their expired life-time.

Table 3: Open Applications of PCB

Caulks / sealants
Paints / plasters
Anti-corrosion coatings
Cable-sheaths
Cable insulation
Lubricating fluids
Adhesives
Flame retardants
Floor finish
Carbonless copy paper
Fluorescent light ballasts and small capacitors

Below is a short summary of some further minor and not well documented open applications of PCB.

Table 4: Uncommon Uses of PCB

PCB in cast waxes
PCB as polymerisation catalyst
PCB as carrier for insecticides and bactericide
PCB pesticides extenders
and many more...

It is generally believed that PCB were used in open applications between the 1950s and the early 1980s. However, the time of usage of PCB in the different applications may vary from across countries.

Many of these open applications are still in use today, and they are usually not defined as hazardous waste at the time of disposal. PCB in open applications often find their way into the environment.

The percentage of PCB in the materials highly depends on the type of application, the product itself, and the manufacturer. PCB concentrations can vary considerably and may reach up to 80 %.

In Japan, most of the open use has been reported as being for carbonless copy paper (Masuda et al., 1972; Tatsukawa, 1976) quoted by Breivik³. Whilst much of this paper has been archived it has been

noted as a source of contamination in paper recycling. This was, however, early work before the scale of the use for sealants had been widely recognized and probably underestimate the open system use of PCB in Japan.

In the USA plasticizers were the principal open use (Nisbet and Sarofim, 1972). In 1972, Monsanto, the only North American manufacturer of PCB, voluntarily ceased marketing them in dispersive uses, e.g. in commercial products such as carbonless carbon paper, printing inks, sealants, paints, etc.⁵. The manufacture of PCB for all other uses stopped in 1977.

The elastic polysulphide sealants used on prefabricated residential buildings were identified in the 1990s in Germany, Sweden, Norway and Finland as a source of PCB contamination. Wong⁶ recently noted: *The “fresher” signature observed in urban areas is presumed to be due to emissions from past and present uses of the chemicals⁷. For example, fresh emissions include those from banned “legacy” substances such as PCB that are incorporated into the urban fabric within building sealants and other building materials.*

Since the mid-1990s the increasing importance of urban areas as current source regions of PCB to the atmosphere has been identified^{8,9,10,11}

Many houses and, especially, public buildings constructed with PCB containing materials during the period from 1950-1970s still exist¹². It is estimated that in the Federal Republic of Germany alone about 20'000 tonnes of PCB were used in the construction of kindergartens, schools, universities, office buildings and hospitals¹³ thus representing a potential lifelong exposure source. Estimates for the UK are 500 tonnes¹⁴. In Denmark it is estimated that 75 tonnes of PCB are still in buildings¹⁵.

Usage has also varied in different countries. In Germany, PCB containing sealants were used more often in indoor seams whilst in Finland PCB were mainly used in outdoor seams between concrete blocks¹⁶.

Estimates of the volume of PCB used in sealants in Finland vary from 130 tonnes to 270 tonnes¹⁶. The most frequently applied commercial mixture was Aroclor 1260 or Aroclor 1254¹⁷. In buildings constructed between 1966 and 1971, one-third of all joint sealants investigated contained more than 10 g/kg of PCB¹⁸ and a large block of flats can contain 40 - 50 kg of PCB¹⁶ and possibly more.

It appears that the use of PCB in sealants and similar uses has been restricted mainly to the more developed countries. Devanathan¹⁹ noted, for example, that although the suburbs the metropolitan cities tested for PCB in ambient air and breast milk were industrialized “PCB levels are still low, indicating minimal usage of PCB in open systems in India”.

It was previously believed that products like PCB containing caulks/sealants and coatings had not been exported to developing countries because they were rather expensive. However, the analysis of random samples did confirm hot spot PCB sources from open applications both in developing countries and countries in transition. Examples of such open applications are anti-corrosion coatings on pipelines and machinery as well as paints on concrete floors in Guatemala, Peru, Paraguay, Kenya or Zambia²⁰.

Only a few of the countries affected, including Sweden, Switzerland and Norway appear to have taken some concrete steps by first recognizing the issue in their National Implementation Plans and to initiate action to address the problems that PCB were used in open applications.

The Swedish National Implementation Plan says, for example, that another important PCB use is as a plasticizer in sealants used for joints in buildings: between prefabricated concrete cladding panels, in dilatation joints for large brick façades, around retail store fronts and around windows. Insulating glazing has been sealed with a sealant plasticized with PCB. PCB have also been used in paints for ships and corrosive environments.

Norway has undertaken an inventory of PCB in building materials²¹. According to the inventory, around 85 tonnes, or approximately 18 % of existing PCB, is present in plaster in Norwegian buildings. Other sources of PCB calculated include, glue in double-glazing (200 tonnes), capacitors

(sic) (105 tonnes), joint sealants (50 tonnes) and paint (10 tonnes). The consequence is that plaster regularly exceeds the threshold for hazardous waste as do some entire homes, schools and office buildings built in the period 1960-1969.

4.1 PCB in the building industry

The addition of PCB to building materials (for example caulks, coatings or paints) greatly enhanced their physical and chemical resistance. PCB improved the flexibility, fire resistance or impregnating qualities of the products, and extended their operational lifetimes.

The large share of open applications of PCB was used in buildings and other constructions²², both in the structural and civil engineering sectors.

Today, PCB are detected in many industrial, public, residential and private buildings. Examples in the industrial sector include hydro power, nuclear power, coal and gas power plants as well as water treatment plants, military installations, the car and shipbuilding as well as the mining industry.

Many buildings and installations worldwide, especially those constructed or renovated between the 1950s and the early 1980s, contain PCB and/or substitutes like SCCPs etc. in a wide variety of applications.

As reported in the “Management of PCB from Open and Closed Applications – Case Study Switzerland”²³, it is estimated that approximately half of the buildings constructed in Switzerland and the US over this period have been contaminated by PCB and that some of these buildings contain hundreds of kilograms of PCB^{24,25}. Caulks and industrial paints have long operational lifetimes of perhaps 40 to 60 years. Since most of these buildings were built in the early 50s, they are now becoming increasingly relevant in demolition projects.

The use of contaminated construction materials (in particular caulks and paints) has resulted in the contamination of farms and their animals (e.g. chicken, cows and sheep). This becomes more important as steps are taken to move towards a closed cycle economy²⁶ with the increased importance of “urban mining” and re-use of wastes in future.

PCB containing debris/rubble and related recycling materials can result in PCB contamination and release in the further recycling, re-use and disposal of these materials.

The scrapping of metal (for example pylons, pipes, radiators, etc.) coated with PCB paints and the further treatment of the steel scrap in electric arc furnaces or smelting works is a contemporary source of PCB release. Furthermore, highly toxic polychlorinated dibenzofurans (PCDF) are present in PCB formulations. PCDFs are formed and released from thermal treatment of PCB such as fires/combustion^{27,28}, pyrolysis²⁹ or other thermal treatments³⁰. This needs to be considered in the demolition process particularly, for example, where flame cutting is used for breaking up PCB coated materials.

One possible source of PCB contamination of rivers and lakes are bridges with PCB containing anti-corrosion coatings and paints. In case of inexpert remediation works, large amounts of contaminated particles and dust are released into the environment, the water and the surrounding soils.

In 2016 approx. 3 km of the river Spöl in Switzerland were contaminated with PCB after an incident during PCB remediation and renovation work in a hydro power plant. In 2017, water samples from several rivers in the Swiss Cantone Graubünden were analysed for PCB. As expected, the highest PCB concentrations were measured in the water of the river Spöl³¹.

PCB wastes from uses in open applications are often not recognized as hazardous waste at the time of disposal, even in countries which are aware of the presence of PCB in open application. Therefore, there are possibilities that PCB also escape into the environment at the end-of-life by inappropriate treatment of the materials during demolition and the final disposal in unsuitable landfill sites.

4.2 PCB in other industries

From 1947 to the end of the 1970s, PCB were used as plasticizers in a variety of adhesives. A content of up to 25 % pure PCB was added to some paints, and for example used for military, maritime, and aviation purposes. PCB were also used in the automotive industry and can often be found in auto shredder residues (ASR).

Other applications were as plasticizers in paints and cements, pesticide extenders, reactive flame retardants and adhesives, wood floor finishes, such as Fabulon and other products of the US based Halowax, who was one of the largest US producer of polychlorinated naphthalenes and polychlorinated biphenyls for floor finishing, dedusting agents, waterproofing compounds, casting agents. It was also used as a plasticizer in paints and especially "coal tars" that were used widely to coat water tanks, bridges and other infrastructure pieces.

One of the major open applications of PCB was in carbonless copy ("NCR") paper, which may in rare occasions in some countries still result in paper contamination.

5 PCB cross-contamination and back-diffusion

PCB may diffuse from open applications into other materials. PCB containing caulks, for example, contaminate the surrounding materials (concrete, brick, wood, etc.) as well as the caulk backing materials. Analyses in Switzerland revealed that PCB contamination in the caulk concrete edges (3 -5 mm from caulk) is often $>1'000$ mg/kg. Depending on material type and porosity, paints containing PCB may also greatly diffuse into upper/lower coatings and substances.

Given the fact that PCB spread into other materials, just a simple removal or replacement of the source is not sufficient and cannot be considered sustainable. Trials in Switzerland clearly showed that PCB will diffuse back into new or replacing materials.

For example: A PCB containing caulk at a concentration of 203'000 mg/kg had been removed. The surrounding structures were left unchanged. Due to back-diffusion, the new caulking material was contaminated with PCB within a month. Analysis showed a very high PCB content in the new caulk ($> 20'000$ mg/kg).

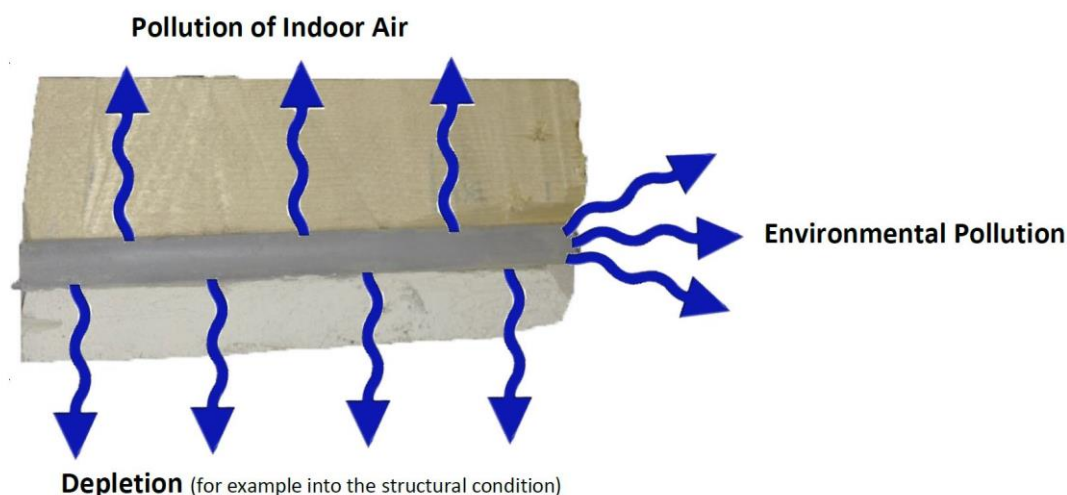


Figure 3: Diffusion of PCB from Open Applications

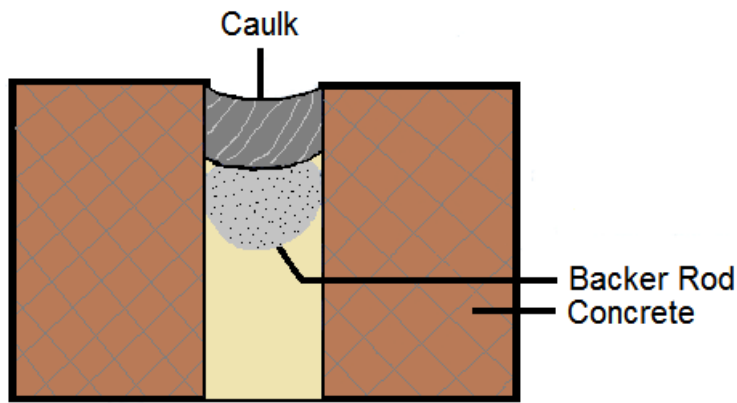


Figure 4: Cross-Section Caulking

In addition to the before-mentioned secondarily contaminated surrounding materials, also completely independent items and substances can be affected by PCB. For example, elevated concentrations of PCB were detected in furniture, dirt and dust.

PCB continuously emit into indoor air and can contaminate large surfaces and objects by the so-called “fogging effect”. The secondarily contaminated surfaces then again emit PCB and influence the contamination in the air.

6 Indoor and outdoor air contamination

PCB do not only diffuse into materials, but also emit into (indoor) air. Concentrations in indoor air greatly depend on the type of PCB application, the PCB percentage, composition of the PCB product and external conditions (temperatures). Buildings frequented by many people (schools, hospitals etc.) or with long duration of stay (flats) should be given extra consideration.

Indoor air concentration is influenced by both primary and secondary sources of PCB. A primary source of PCB is a product to which PCB was intentionally added to improve its characteristics. A secondary source of PCB is a product to which PCB was not intentionally added but that was later contaminated by PCB from other sources (e.g. fogging effect). Both primary and secondary sources continuously emit PCB and should therefore be considered when planning a clean-up.

Table 5: Definition of Thresholds for PCB Diffusion and Sources

Thresholds	Description
< 50 mg/kg PCB	Diffuse contamination
> 50 - 1'000 mg/kg PCB	Secondary source
> 1'000 mg/kg PCB	Primary source

Many sealants have been used internally together with PCB contaminated non-skid flooring and even floor polishes containing PCB.

According to the US EPA, another possible source of indoor air contamination are fluorescent light ballasts. PCB are continuously released into the air from intact, functioning PCB containing light ballasts. When the lights are off, emissions are low. When the lights are on, the ballast heats up, and emissions increase several-fold. PCB ballasts can fail, releasing PCB vapors into the air and liquid PCB onto surfaces: Air levels of PCB can become quite large, surfaces can be contaminated, and residues from previously failed ballasts can remain in light fixtures even if the ballast is replaced.

The most common way people are exposed to PCB from FLBs is through breathing PCB contaminated air or touching PCB contaminated materials after an FLB leaks or catches fire. Where they remain, leaking FLBs can continue to release PCB over several years and generate elevated levels of PCB in

the air. Since the likelihood of harm increases with added exposure, the best protection is to remove leaking FLBs. Intact FLB capacitors can also lead to the presence of PCB in school environments. Leaking or bursting capacitors are likely to substantially elevate PCB levels in indoor environments.

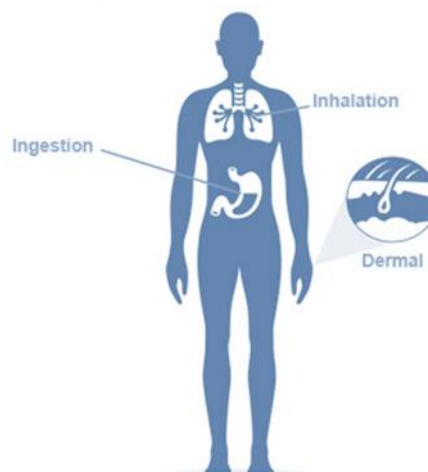
Evaporation and abrasion of PCB can result in considerable house dust and indoor air contamination^{12,32,33}, leading to the increased PCB body burden of residents and occupants, probably through inhalation or ingestion exposure^{32,34}. Most of PCB contaminated public buildings erected in the 1960s and 1970s are still in use and will further be used for years or even decades. If the PCB issue is not addressed now, it is likely to become worse and especially when the buildings are finally demolished.

Recent studies on the emissions of PCB show that open applications of PCB have a relevant impact on indoor and outdoor air. For example, in Switzerland in 2015 total PCB emissions to outdoor air was nearly 0.6 t/year, and it is estimated that the use of PCB in open applications will cause Swiss emissions to remain above 100 kg PCB per year, even after the year 2030³⁵. For Germany the current PCB emissions from open applications are estimated to 7 to 12 tonnes^{36, 37, 38}. These emissions lead to an impact on animal feed and related contamination of food producing animals. The presence of PCB in open applications in stables and farms and in establishments for animal feed production still results in exposure of food producing animals with related exposure of humans³⁹.

7 Health

The three main pathways of PCB are:

- (a) Food intake;
- (b) Inhalation;
- (c) Skin contact.



Picture: Cyanide in Sight

PCB and dioxins primarily enter the human body via food intake.

The pathways can depend on the type of PCB/congener patterns:

- (a) Food intake - mainly less volatile and higher chlorinated PCB;
- (b) Inhalation - mainly volatile and lower chlorinated PCB.

PCB are carcinogens and endocrine disruptors. On the basis of sufficient evidence of carcinogenicity in humans and experimental animals, the IARC classified PCB as carcinogenic to humans (Group 1). Additionally, dioxin-like PCB were also classified in Group 1.

PCB can cause serious health effects in humans and wildlife. Health effects include carcinogenicity, reproductive impairment, and immune system dysfunctions. In the environment, top predators are the most affected. Adverse effects associated with the exposure of PCB include damage to the immune system, liver, skin, reproductive system, gastrointestinal tract, and thyroid gland.

For a substantial part of the human population current exposure to PCB and to dl-PCB is close to the value of the tolerable daily intakes. Concentrations far above WHO safety levels have been found in human milk worldwide. It is therefore important to minimize any additional human exposure to PCB.

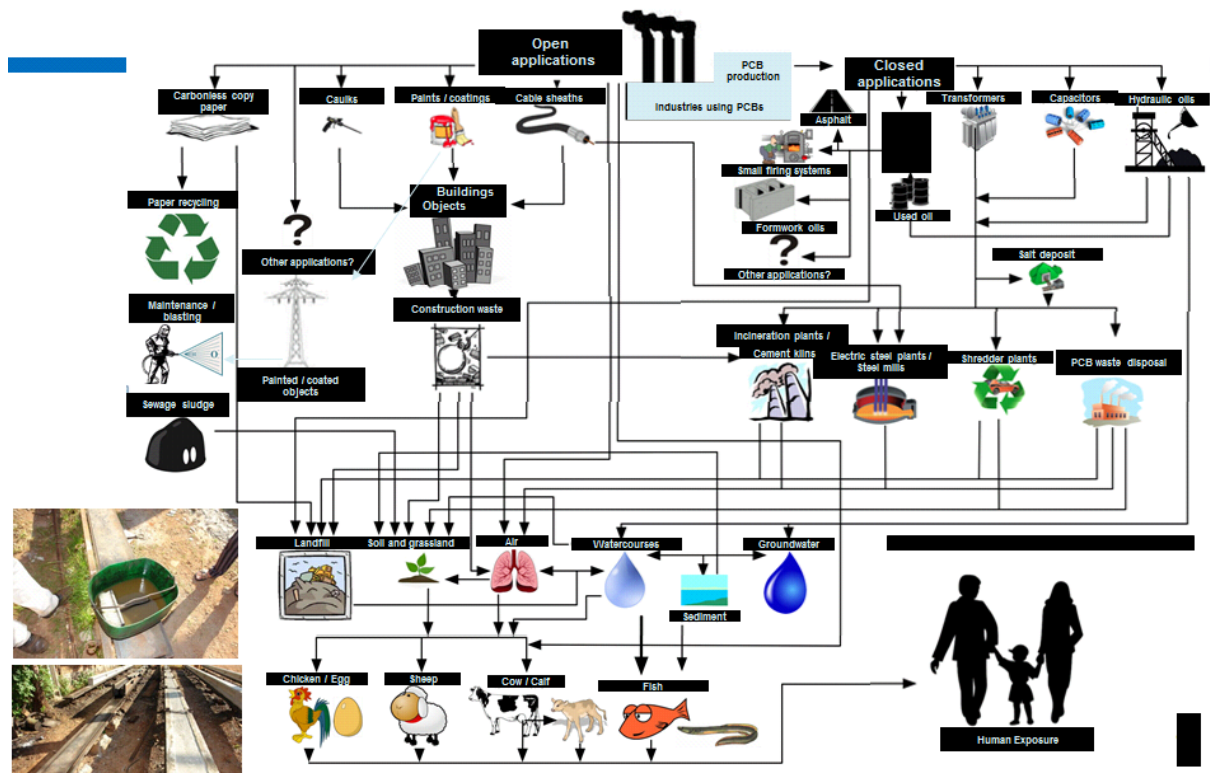
Results of a US population-based case-control study that examined non-Hodgkin lymphoma (NHL) risk and exposure to PCB in carpet dust as an exposure indicator suggest an increased risk of NHL associated with exposure to PCB, with evidence of greater effects for PCB 180⁴⁰. In recent years, exposure of PCB in open applications to humans has been demonstrated in developed countries. This includes for example indoor exposure and exposure to food-producing animals from PCB paints in silos, stables, and road markings.

While inhalation is the principal indoor pathway under a typical dust ingestion scenario, exposure via dust ingestion can exceed that from either inhalation or diet for some North American toddlers⁴¹. Priha¹⁶ demonstrated that in the most exposed cases of outdoor sealant use children can be exposed to daily doses near the level of the reference dose.

Direct transfer to food is possible in some applications. Sweeney⁴² reported that while testing a bulk milk sample for pesticides in 1974, the Michigan Department of Agriculture detected PCB which was subsequently traced to a sealant called Kumar (33% PCB) that had been introduced in Michigan in 1941. Since exposure via food is gradually declining, indoor air is likely to become a more visible source for human exposure with dioxin-like PCB and should be urgently addressed because evaporation from non-remediated PCB sources in the indoor and urban environment continues over very long periods.

In residents of PCB contaminated dwellings higher plasma PCB levels were found for most of the lower chlorinated and many of the higher chlorinated congeners⁴³. OH-PCB levels in urine of workers were increased several folds after PCB waste transportation work, and also a slight increase of OH-PCB was observed in the researchers doing the air sampling at PCB storage area⁴⁴. After recommended PCB exposure reduction measures had been enacted, the workers' OH-PCB levels did not increase during handling of PCB equipment.

By inhalation of contaminated indoor air, the tolerable daily intake (TDI) for PCB, set by the WHO in 2003⁴⁵, may be exceeded at air concentrations as low as 60 ng PCB/m³. With regard to dioxin-like PCB, special attention is warranted. Many important studies about this issue are available.



Picture: Dr. Roland Weber

Figure 5: Applications, distribution and impact of PCB

8 Identification of and environmentally sound management of PCB in open applications

PCB from open applications can be released into the environment by weathering and inappropriate removal of PCB containing materials. However, wastes generated from use in open applications are usually not defined as hazardous waste.

Current national PCB inventory activities mainly focus on closed systems, such as cooling fluids in electrical equipment, e.g. transformers, capacitors, and switches.

It is however important to be aware of the fact PCB applications can be found throughout industrial facilities and other buildings. It is therefore important to also identify these applications.

It should be noted that a detection of PCB in open applications is only possible if the (building) material is sampled and analysed in a laboratory.

The recording of data of buildings, facilities, objects and materials with PCB in open applications after their identification would minimize the risks of inexpert treatment, non-environmentally sound management and disposal and therefore minimize the impact on the environment and the human health.

Many buildings worldwide, especially those constructed or renovated between the 1950s and the early 1980s, contain PCB in a wide variety of applications which emit PCB into the environment. In buildings, PCB can contribute directly to human exposure.

8.1 PCB in caulks/sealants - facades and walls



Photo: Igor Kecskés Maconkai

Description:

Caulk is a flexible material used to seal gaps. PCB were added to caulk because PCB imparted flexibility. Objects constructed between the 1950s and the early 1980s often contain PCB in their caulks. Old caulks have often lost their flexibility and can therefore be more or less stiff. Detection of PCB is only possible by sampling and analyzing the material.

Applications:

Joints in buildings and other structures, caulks between prefabricated concrete panels, dilatation joints for large brick facades, etc.

Objects:

Houses, residential and public buildings (schools, kindergartens, theatres, universities, hospitals, shopping malls, sports and leisure centers, hotels, swimming pools, car parks, etc.), industries, power plants, water reservoirs, military bases etc.

<p>No immediate risk:</p> <ul style="list-style-type: none"> ▪ Objects built after 1985 ▪ Silicone and rubber sealants do not contain PCB (unless secondarily polluted) 	<p>Potential risk:</p> <ul style="list-style-type: none"> ▪ Interior: caulk in good condition, but high PCB content may cause indoor air pollution ▪ Exterior: caulk in good and poor condition may cause depletion into soils and waters 	<p>High risk:</p> <ul style="list-style-type: none"> ▪ Caulks in fire (formation of dioxins and furans) ▪ Deteriorating caulks accessible to public ▪ Inexpert removal and inappropriate disposal
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8.2 PCB in caulks/sealants - windows and doors



Description:

Caulk is a flexible material used to seal gaps. PCB were added to caulk because PCB imparted flexibility. Objects constructed between the 1950s and the early 1980s often contain PCB in their caulks. Old caulks have often lost their flexibility and can therefore be more or less stiff. Detection of PCB is only possible by sampling and analyzing the material.

Applications:

Sealants around windows, door frames and vents, etc.

Objects:

Houses, residential and public buildings (schools, kindergartens, theatres, universities, hospitals, shopping malls, sports and leisure centers, hotels, swimming pools, car parks, etc.), industries, power plants, water reservoirs, military bases etc.

No immediate risk:

- Objects built after 1985
- Silicone and rubber sealants do not contain PCB (unless secondarily polluted)

Potential risk:

- Interior: caulk in good condition, but high PCB content may cause indoor air pollution
- Exterior: caulk in good and poor condition may cause depletion into soils and waters

High risk:

- Caulks in fire (formation of dioxins and furans)
- Deteriorating caulks accessible to public
- Inexpert removal and inappropriate disposal

8.3 PCB in paints and plaster



Description:

From 1947 to the end of the 1970s, PCB were used as plasticizers, and added to different formulas of paint to enhance the physical and chemical resistance of the paint. Detection of PCB is only possible by sampling and analyzing the material.

Applications:

Paint and plaster on facades and walls, emulsion priming and top coats for use on concrete or plasterwork, for both indoor and outdoor applications.

Objects:

Houses, residential and public buildings (schools, kindergartens, theatres, universities, hospitals, shopping malls, sports and leisure centers, hotels, swimming pools, car parks), dams, industries, power plants, military bases etc.

No immediate risk:

- Objects built after 1985

Potential risk:

- Interior: paint in good condition, but high PCB content may cause indoor air pollution
- Exterior: paint in good and poor condition may cause depletion into soils and waters

High risk:

- Paint in fire (formation of dioxins and furans)
- Flaking paint/plaster accessible to public
- Inexpert removal and inappropriate disposal

8.4 PCB in paints - indoor applications



Description:

Until the end of the 1970s, PCB were used as plasticisers and flame retardants in paints and varnishes. Products containing PCB were used to coat a very wide variety of surfaces. Detection of PCB is only possible by sampling and analyzing the material.

Applications:

Window and door frames, doors, radiators, pipes, steel constructions, etc.

Objects:

Houses, residential and public buildings (schools, kindergartens, theatres, universities, hospitals, shopping malls, sports and leisure centers, hotels, swimming pools, car parks etc.), industrial plants, power plants, military bases etc.

No immediate risk:

- Objects built after 1985
- Objects in good condition

Potential risk:

- Interior: paint in good condition, but high PCB content may cause indoor air pollution

High risk:

- Paint in fire (formation of dioxins and furans)
- Flaking paint accessible to public
- Inexpert removal and inappropriate disposal

8.5 PCB in surface coatings and industrial flooring - floors

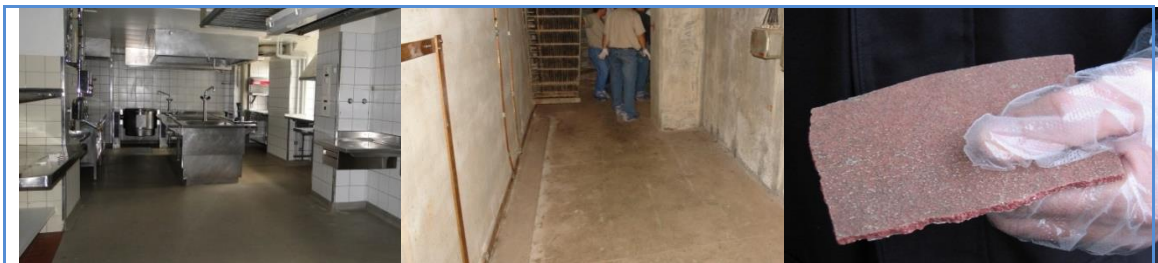


Photo: Miljökonsultgruppen in Stockholm

Description:

Until the end of the 1970s, PCB were used as plasticisers and flame retardants in paints and varnishes. Products containing PCB were used to coat a very wide variety of surfaces. Detection of PCB is only possible by sampling and analyzing the material.

Applications:

Concrete paints and coatings, emulsion priming and top coats for use on concrete or plasterwork, resistant industrial floors, seamless flooring (e.g. Acrydur»), highway marking paints, etc.

Objects:

Houses, residential and public buildings (schools, kindergartens, universities, hospitals, shopping centers, hotels, laundries, swimming pools, sports halls, car parks etc.), industrial plants, power plants, military bases, motorways etc.

No immediate risk:

- Objects built after 1985

Potential risk:

- Interior: paint in good condition, but high PCB content may cause indoor air pollution
- Exterior: paint in good and poor condition may cause depletion into soils and waters

High risk:

- Paint in fire (formation of dioxins and furans)
- Flaking paint/plaster accessible to public
- Inexpert removal and inappropriate disposal

8.6 PCB in anti-corrosion coatings - indoor applications



Description:

From 1947 to the end of the 1970s PCB were used as plasticisers in a variety of adhesives. Chlorinated rubber paints were primarily used in anti-corrosion coatings. Products containing PCB were used not only in priming coats but also in middle and top coats. Detection of PCB is only possible by sampling and analyzing the material.

Applications:

Steel supports, steel structures, radiators, pipes, oil fuel tanks, machines, devices, etc.

Objects:

Houses, residential and public buildings (schools, kindergartens, theatres, universities, hospitals, shopping malls, sports and leisure centers, hotels, swimming pools, car parks, etc.), industries, power plants, military bases etc.

No immediate risk:

- Objects built after 1985

Potential risk:

- Interior: coating in good condition, but high PCB content may cause indoor air pollution
- Exterior: coating in good and poor condition may cause depletion into soils and waters

High risk:

- Coating in fire (formation of dioxins and furans)
- Flaking coating accessible to public
- Inexpert removal and inappropriate disposal

8.7 PCB in anti-corrosion coatings - power plants and pipelines



Description:

From 1947 to the end of the 1970s, PCB were used as plasticisers in a variety of adhesives. Chlorinated rubber paints were primarily used in anti-corrosion coatings. Products containing PCB were used not only in priming coats but also in middle and top coats. Detection of PCB is only possible by sampling and analyzing the material.

Applications:

Natural gas pipelines, oil pipelines, high pressure water pipelines, weirs, sluice gates, bridges, steel supports, steel structures, pylons, masts, oil tanks, gas tanks, water storage tanks, etc.

Objects:

Industrial plants, power plants, nuclear power plants, waste water treatment plants, dam lakes, mines, military bases etc.

No immediate risk:

- Plants and machinery built after 1985

Potential risk:

- Interior: material in good condition, but high PCB content may cause indoor air pollution
- Exterior: material in good and poor condition may cause depletion into soils and waters

High risk:

- Coating in fire (formation of dioxins and furans)
- Flaking coating accessible to public
- Inexpert removal and inappropriate disposal

8.8 PCB in anti-corrosion coatings - transformers and machinery



Description:

From 1947 to the end of the 1970s, PCB were used as plasticisers in a variety of adhesives. Chlorinated rubber paints were primarily used in anti-corrosion coatings. Products containing PCB were used not only in priming coats but also in middle and top coats. Detection of PCB is only possible by sampling and analyzing the material.

Applications:

Turbines, motors, transformers, machines and devices, etc.

Objects:

Industrial plants, power plants, nuclear power plants, waste water treatment plants, mines, military bases etc.

No immediate risk:

- Plants and machinery built after 1985

Potential risk:

- Interior: material in good condition, but high PCB content may cause indoor air pollution
- Exterior: material in good and poor condition may cause depletion into soils and waters

High risk:

- Coating in fire (formation of dioxins and furans)
- Flaking coating accessible to public
- Inexpert removal and inappropriate disposal

8.9 PCB in anti-corrosion coatings and ASR - other industries



Description:

From 1947 to the end of the 1970s, PCB were used as plasticisers in a variety of adhesives. A content of up to 25 % pure PCB was added to some paints, and for example used for military, maritime, and aviation purposes. PCB were also used in the automotive industry, and can often be found in auto shredder residues (ASR). Detection of PCB is only possible by sampling and analyzing the material.

Applications:

Vessels, submarines, aeroplanes, cars, grain silos, window frames, valves, flanges etc.

Objects:

Harbours, airports, military bases, auto salvage yards, auto crushing, recycling sites (shredders), scrap dealers, landfills, industrial sites etc.

No immediate risk:

- Devices and vehicles built after 1985


Potential risk:

- Interior: paint in good condition, but high PCB content may cause indoor air pollution


High risk:

- Coating in fire (formation of dioxins and furans)
- Flaking coating accessible to public
- Inexpert removal and inappropriate disposal

8.10 PCB in adhesives

		
<p>Description: PCB were used as plasticisers in adhesives. In case of exposed concrete, PCB were added as adhesives. Detection of PCB is only possible by sampling and analyzing the material.</p> <p>Applications: Floor adhesives, adhesive in exposed concrete etc.</p> <p>Objects: Houses, residential and public buildings (schools, kindergartens, theatres, universities, hospitals, shopping malls, sports and leisure centers, hotels, swimming pools, car parks, etc.), industries, power plants, military bases etc.</p>		
<p>No immediate risk:</p> <ul style="list-style-type: none"> ▪ Objects built after 1985 ▪ Objects in good condition 	<p>Potential risk:</p> <ul style="list-style-type: none"> ▪ Interior: coating in good condition, but high PCB content may cause indoor air pollution ▪ Exterior: coating in good and poor condition may cause depletion into soils and waters 	<p>High risk:</p> <ul style="list-style-type: none"> ▪ Coating in fire (formation of dioxins and furans) ▪ Flaking coating accessible to public ▪ Inexpert removal and inappropriate disposal

8.11 PCB in cables and cable sheaths

		
<p>Description: PCB were added to cable sheaths as flame retardants, plasticisers and impregnation, for example in lead cables. The electrical cable itself can also contain PCB. Detection of PCB is only possible by sampling and analyzing the material.</p> <p>Applications: Electrical cables, both PVC and lead jacket, any kind of cable sheaths.</p> <p>Objects: Harbours, airports, military bases, auto salvage yards, auto crushing, recycling sites (shredders), scrap dealers, landfills, industrial sites etc.</p>		
<p>No immediate risk:</p> <ul style="list-style-type: none"> ▪ Cables manufactured after 1985 	<p>Potential risk:</p> <ul style="list-style-type: none"> ▪ Electric cable contains liquids or damp insulation 	<p>High risk:</p> <ul style="list-style-type: none"> ▪ Cables in fire (formation of dioxins and furans) ▪ Leaking cables ▪ Inexpert removal and inappropriate disposal

8.12 PCB as lubricating fluid in oils and grease



Description:

Prior to 1976 PCB were widely used in lubricating oils for electrical equipment and hydraulic systems because of their exceptional heat transfer characteristics. Detection of PCB is only possible by sampling and analyzing the material.

Applications:

Electrical equipment, air/gas compressors, natural gas turbine compressors, heat transfer, hydraulic systems, vacuum pumps, oil-impregnated gaskets/filters, brake linings, cutting oils, lubricating oils, optical oils, immersion oils etc.

Objects:

Industries, power plants, waste water treatment plants, mines, private and public buildings, natural gas pipelines, hospitals, laboratories, research departments etc.

No immediate risk:	Potential risk:	High risk:
<ul style="list-style-type: none"> ▪ Devices manufactured after 1985 	<ul style="list-style-type: none"> ▪ Devices contain viscous liquids and may cross-contaminate when released or leaking 	<ul style="list-style-type: none"> ▪ Devices in fire (formation of dioxins and furans) ▪ Leaking devices ▪ Inexpert removal and inappropriate disposal

8.13 PCB as flame retardant and impregnating agent



Description:

PCB were often used as flame retardants for wood and cardboard in indoor applications. Another application of PCB was textile coatings. Furthermore, PCB were often used for impregnating wood in outdoor as well as indoor applications. Detection of PCB is only possible by sampling and analyzing the material.

Applications:

Acoustic ceiling tiles, door and floor panels, treated timber, textile coatings (ironing board covers, polyamide yarns), wooden (telephone) poles, pallets, railway tracks, treated timber etc.

Objects:

Houses, residential and public buildings (schools, kindergartens, universities, hospitals, shopping centers, hotels, sports halls, theatres, concert halls), outdoor installations etc.

No immediate risk:	Potential risk:	High risk:
<ul style="list-style-type: none"> ▪ Objects built and installations erected after 1985 	<ul style="list-style-type: none"> ▪ Flame retardant in good condition, but high PCB content may cause indoor air pollution ▪ Impregnation in good and poor condition may cause depletion into soils and waters 	<ul style="list-style-type: none"> ▪ Materials in fire (formation of dioxins and furans) ▪ Flaking coating/impregnation accessible to public ▪ Inexpert removal and inappropriate disposal

8.14 PCB in small capacitors (ballasts) and small sized transformers



Description:

Typical fluorescent light ballasts contain a small capacitor. The PCB are found in the capacitor oil, the starter and often in the tar-like epoxy resin. The ballasts are normally mounted on the light fixture. Also, small motors often require starting devices that can contain PCB.

Applications:

Fluorescent light ballasts, small motors (for example in washing machines, televisions, dishwashers, fridges, and other household machines), street lamps, electro locomotives in industries, specifically in underground mines etc.

Objects:

Residential, public and industrial buildings, mining and other industries, military bases, manufacturing plants, storage halls etc.

No immediate risk:

- Mark saying "No PCB"
- Manufacture after 1979 (US) or 1985 (worldwide)

Potential risk:

- Non-labelled ballasts manufactured before 1980
- Capacitors marked "PCB" in good condition

High risk:

- Capacitors in fire (formation of dioxins and furans)
- Leaking capacitors
- Inexpert removal and inappropriate disposal

8.15 PCB and asbestos 'galbestos' in roofing and siding materials



Description:

PCB were used in galvanised steel applications called "Galbestos". These applications were coated with Asbestos. Galbestos is a type of asbestos-protected metal.

Applications:

Galvanised steel sheeting, galvanised corrugated siding panels etc.

Objects:

Airlines, railroads, chemical plants, steel mills, mines, industries, military bases etc.

Special:

Products also contain and release asbestos fibres.

No immediate risk:

- Objects and installations built after 1985
- Objects in good condition

Potential risk:

- Coating in good and poor condition may cause depletion into soils and waters

High risk:

- Coating in fire (formation of dioxins and furans)
- Flaking coating accessible to public
- Inexpert removal and inappropriate disposal

8.16 PCB and asbestos



Description:

PCB applications were often installed together with Asbestos materials. Typical examples are fluorescent lights (PCB ballast), with an Asbestos cardboard used as flame-retardant. Furthermore, plaster as well as adhesives can contain and release PCB and Asbestos fibres.

Applications:

Fluorescent light ballasts, plaster on walls and façades, floor adhesives etc.

Objects:

Houses, residential and public buildings (schools, kindergartens, theatres, universities, hospitals, shopping malls, sports and leisure centers, hotels, swimming pools, car parks, etc.), industries, power plants, military bases etc.

No immediate risk:

- Ballasts with mark saying “No PCB”
- Objects built after 1979 (US) or 1985 (worldwide)

Potential risk:

- Non-labelled ballasts manufactured before 1980
- Material in good and poor condition may cause diffusion into air, soils and water

High risk:

- Materials in fire (formation of dioxins and furans)
- Flaking coating accessible to public
- Inexpert removal and inappropriate disposal

9 PCB in combination with other hazardous substances

PCB were also mixed and combined with other hazardous substances and materials, in order to enhance the properties of a product.

On one hand, PCB were mixed with other hazardous substances, for example “Galbestos” metals were coated with a mix of Asbestos and PCB. On the other hand, PCB materials were used in combination with other hazardous products. A parallel installation of PCB containing small capacitors and Asbestos cardboard for fire protection reasons was very common.

Only experienced specialists may screen a site or a building professionally. Although some applications can be identified by visual inspection, random samples and analysis are usually necessary in order to correctly assess the situation.

10 Endnotes

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