# Toxic Substances Management Policy

## Scientific Justification

## POLYCHLORINATED BIPHENYLS

### Candidate Substance for Management Under Track 1 of the Toxic Substances Management Policy

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**Confirmation of "Track 1 Substance" Status Under the Toxic Substances Management Policy**

This document was originally released for public consultation purposes on March 22, 1997. After careful consideration of the comments received during the public consultation period, it was concluded that the evidence presented did not affect the assessment of 12 candidate substances as meeting the criteria for Track 1 substances under of the Toxic Substances Management Policy. A notice was published in the Canada Gazette, Part 1, on July 4, 1998, confirming the "Track 1 substance" status of these substances: Aldrin, Chlordane, DDT, Dieldrin, Endrin, Heptachlor, Hexachlorobenzene, Mirex, PCBs, Polychlorinated dibenzo-p-dioxins, Polychlorinated dibenzofurans, and Toxaphene. Comments on the thirteenth substance, Short-chain chlorinated paraffins, are still under consideration.
The federal government is engaging stakeholders involved in the generation or use of confirmed Track 1 substances to take domestic and international actions to protect the Canadian environment from these substances.

For additional information, consult the Environment Canada Green Lane web site at http://www.ec.gc.ca/cceb1/ , or contact:
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## Synopsis

Polychlorinated biphenyls (PCBs) were assessed against the criteria for Track 1 management of the Toxic Substances Management Policy (TSMP). This policy provides a framework based on two key objectives for managing toxic substances: virtual elimination from the environment of toxic substances that are persistent, bioaccumulative, and primarily the result of human activity (Track 1); and life-cycle management of other toxic substances and substances of concern to prevent or minimize their release into the environment (Track 2).

Commercial, manufacturing and processing uses of PCBs were restricted in Canada in 1980. These restrictions brought an end to the manufacture of new PCBs equipment and to the refilling of existing equipment resulting in a dimninishing use of PCBs through attrition.

The information reviewed for this assessment indicates that PCBs occur in the Canadian environment exclusively as a result of human activity, are bioaccumulative and persistent. PCBs are specified on the List of Toxic Substances in Schedule I to the Canadian Environmental Protection Act.

**Based on these considerations, it is concluded that the substance, polychlorinated biphenyls, meets all the criteria for management under Track 1 of the Toxic Substances Management Policy and that it should be virtually eliminated from the environment.**

**Any person may file a submission presenting scientific evidence objecting to or supporting whether the criteria for management under Track 1 of the policy are satisfied. All such submissions must be sent to the Director, Commercial Chemicals Evaluation Branch, Department of the Environment, Ottawa, Ontario, K1A 0H3 within 60 days of publication of the notice in the Canada Gazette, Part 1, announcing the availability of this report.**

The Canada Gazette Notice announcing the availability of this document was published on March 22, 1997. Comments received before May 22 1997 will be considered in the context of the public consultation period.

# 1 Introduction

The Toxic Substances Management Policy (TSMP) outlines the federal government's approach to the management of toxic substances (Government of Canada, 1995a). The policy presents a management framework based on two key objectives: virtual elimination from the environment of toxic substances that are persistent, bioaccumulative and primarily the result of human activity (Track 1); and life cycle management of other toxic substances and substances of concern to prevent or minimize their release into the environment (Track 2).

In developing the criteria for the TSMP, the federal government considered data for substances whose environmental or health risks had been previously assessed, including those under the *Canadian Environmental Protection Act* [CEPA] Schedule I, the CEPA Priority Substances List [PSL] toxic substances, the Accelerated Reduction / Elimination of Toxics [ARET] List A, the International Joint Commission Critical Pollutants List, and the Ontario Ministry of the Environment and Energy Primary List for Bans and Phase Outs) (Government of Canada, 1995b).

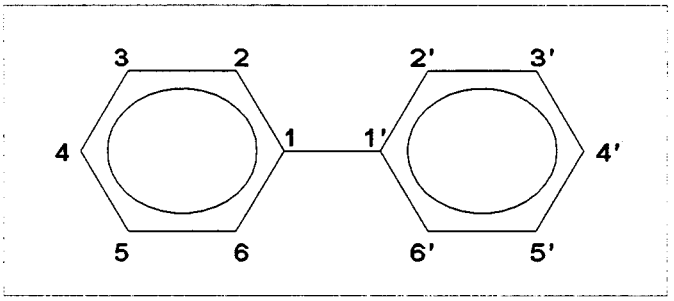
The analysis presented in this report is based on the information summarized in recent reviews and in the primary scientific literature. The synopsis summarizes the findings of the assessment. A brief background on PCBs is presented in Section 2. The assessment of whether PCBs meet the criteria for management under Track 1 is in Section 3. Expert judgement was used to analyse the scientific and technical evidence available for this substance, and a conclusion was drawn using the accumulated weight of evidence to establish whether the criteria of the TSMP have been met. In releasing this report, the federal government is offering interested parties the opportunity to comment on the analysis conducted and the conclusions presented herein.

# 2 Background Information

**Reviews**. PCBs are a class of substances that have been reviewed extensively in the scientific literature. Major recent reviews on PCBs include ATSDR (1995), WHO (1993), MBR (1995), Delzell *et al.,* (1994), Safe (1984; 1994) and Mackay *et al.,* (1992) to name a few.

**Identity**. Polychlorinated biphenyls (PCBs) are a group of synthetic organic chemicals. The general structure of the chlorinated biphenyl molecule is shown in Figure 1. PCBs are formed when chlorine atoms replace hydrogen atoms in the biphenyl structure. There are 10 possible locations for substitution; 2 through 6 and 2' through 6'. The conventional numbering of substitution positions is shown in Figure 1. The chemical formula can be expressed as $C_{12}H_{10-n}Cl_n$, where n, the number of chlorine atoms in the molecule, can range from 1 to 10.

**Figure 1: General molecular structure of polychlorinated biphenyls**




There are 209 possible PCB compounds or congeners, based on the degree of chlorination. These range from three monochlorinated isomers (1 chlorine) to the fully (10 chlorines) chlorinated decachlorobiphenyl isomer. According to the International Union of Pure and Applied Chemistry (IUPAC) system of nomenclature, the 209 PCB congeners are arranged in ascending numerical order, based on chlorine substitution, and assigned numbers from 1 to 209. Of the theoretical 209 congeners, only about 130 are likely to be found in commercial mixtures (Safe, 1990).

The 209 PCB congeners are grouped according to the degree of chlorination of the molecule. For PCBs, the mono-, di-, tri-, tetra-, penta-, hexa, hepta-, octa-, nona-, and deca-chlorobiphenyl congeners can exist in 3, 12, 24, 42, 46, 42, 24, 12, 3 and 1 isomeric forms respectively.

The Chemical Abstract Services Registry number of PCBs as a group is 1336-36-3. The Toxic Effects Registry Number is TQ 1350000. Separate CAS numbers are available for 70 of the individual congeners plus several of the commercial mixtures such as Aroclor 1016, 1221, 1232, 1254, 1260.

**Physical and Chemical Properties**. PCBs are highly stable under most environmental conditions. However, individual PCBs differ widely in terms of their vapour pressures, water solubilities and susceptibility to degradation, which influence their environmental fate (Coulston and Kolbye, 1994). These differences in physicochemical behaviours are determined by the number and pattern of chlorine substitutions in the individual congeners (Mackay *et al.*, 1992). Some fundamental chemical properties of PCB congener groups are summarized in Table 1.

Pure PCB congeners are colourless compounds. However, PCB mixtures are usually light-coloured liquids that feel like thick, oily molasses. Some PCB compounds form sticky, yellow liquids or a brittle gum ranging in colour from amber to black. Their density is higher than 1.0 due to chlorine atoms in the molecule and therefore they sink in water.

PCBs are soluble in most organic solvents but are almost insoluble in water as demonstrated by there relatively high log $K_{ow}$ (octanol/water partition coefficient) values. Generally, the solubility in water decreases as the number of chlorine substitutions increases. Similarly, the vapour pressure of individual PCBs decreases as chlorine substitutions increase. The environmental fate and behaviour of PCBs is largely governed by the degree of chlorination.

**Table 1. Selected values for PCBs congeners groups (from Mackay, et al. 1992)**

| Congener Group | Mol. Weight (g/mol) | Vap. Pres. (Pa) | Water Solubility ($g/m^3$) | Log $K_{ow}$ |
|---|---|---|---|---|
| Monochlorobiphenyl | 188.7 | 0.9-2.5 | 1.21-5.5 | 4.3 - 4.6 |
| Dichlorobiphenyl | 223.1 | 0.008-0.60 | 0.06-2.0 | 4.9 - 5.3 |
| Trichlorobiphenyl | 257.5 | 0.003-0.22 | 0.015-0.4 | 5.5 - 5.9 |
| Tetrachlorobiphenyl | 292.0 | 0.002 | 0.0043-0.010 | 5.5 - 6.3 |
| Pentachlorobiphenyl | 326.4 | 0.0023-0.051 | 0.004-0.02 | 6.0 - 6.5 |
| Hexachlorobiphenyl | 360.9 | 0.0007-0.012 | 0.0004-0.0007 | 6.9 - 7.3 |
| Heptachlorobiphenyl | 395.3 | 0.00025 | 0.000045-0.0002 | 6.7 - 7.0 |
| Octachlorobiphenyl | 429.8 | 0.0006 | 0.0002-0.0003 | 7.1 - 7.4 |
| Nonachlorobiphenyl | 464.2 | -- | 0.000018-0.000079 | 7.2 - 8.16 |
| Decachlorobiphenyl | 498.7 | 0.00003 | 0.000001 | 8.26 |

**Production and Uses**. PCBs have been used extensively since 1930 in a wide range of industrial activities. Properties that made PCBs desirable for industrial and consumer products include: chemical inertness, resistance to heat, non-flammability, low vapour pressure and high dielectric constant. Therefore, PCBs were used as dielectrics in transformers and large capacitors, as heat exchange fluids, as paint additives, in carbonless copy paper and in plastics (Environment Canada, 1981; WHO, 1993). Consumer products that may contain PCBs include older-model fluorescent light ballasts fixtures, microscope immersion oil, electrical devices or appliances containing PCB capacitors, and old hydraulic fluids.

Approximately 40 000 tonnes of PCBs were imported into Canada prior to 1977. PCBs were never manufactured in Canada. Production of PCBs in the United States were halted in 1977 under the *Toxic Substances Control Act*. In Canada, PCBs were the first substances to be regulated under the *Environmental Contaminants Act* (1976). Their use as a constituent in new products manufactured in or imported to Canada was prohibited by *Chlorobiphenyl Regulations No. 1* (1977) and subsequent amendments (1980). All PCBs manufactured in North America were produced by the Monsanto Company in the United States under the trade name Aroclor (Environment Canada, 1981).

The production conditions determined the degree of chlorination which ranged from approximately 18.8 to 68% (Table 1). The resultant product was always a mixture of isomers and congeners with many impurities. Commercial mixtures were sold based on their physical properties and percent chlorine (cl) by weight. In the Aroclor series a 4-digit code is used: biphenyls are generally indicated by 12 in the first 2 positions, while the last 2 numbers indicate the percentage by weight of chlorine in the mixture. Thus, Aroclor 1248 is a PCB mixture containing 48% chlorine by weight. There were 7 principal Aroclors available with a range of chemical and physical properties. The proportions of PCBs with 1 to 9 substituents in the Aroclors are shown in Table 2 (Mackay *et al.*, 1992).

**Table 2 Approximate percentage (w/w) of Aroclors with different degrees of chlorination (WHO, 1993).**

| Compound | Chlorine weight (%) | Aroclor | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1221 | 1232 | 1016 | 1242 | 1248 | 1254 | 1260 |
| | 0 | 10 | | | | | | |
| Monochlorobiphenyl | 18.8 | 50 | 26 | 2 | 3 | | | |
| Dichlorobiphenyl | 31.8 | 35 | 29 | 19 | 13 | 2 | | |
| Trichlorobiphenyl | 41.3 | 4 | 24 | 57 | 28 | 18 | | |
| Tetrachlorobiphenyl | 48.6 | 1 | 15 | 22 | 30 | 40 | 11 | |
| Pentachlorobiphenyl | 54.4 | | | | 22 | 36 | 49 | 12 |
| Hexachlorobiphenyl | 59.0 | | | | 4 | 4 | 34 | 38 |
| Heptachlorobiphenyl | 62.8 | | | | | | 6 | 41 |
| Octachlorobiphenyl | 66.0 | | | | | | | 8 |
| Nonachlorobiphenyl | 68.8 | | | | | | | 1 |

As of December 1993, the national inventory of PCBs included: 11550 tonnes of PCBs in use in various electrical equipment, 15247 tonnes (gross weight) of waste PCBs and PCB equipment, 2161 tonnes of in-use PCB-contaminated mineral oil, 3787 tonnes (net weight) of waste PCB-contaminated mineral oil, and 107991 tonnes (gross weight) of PCB wastes (CCME, 1993).

# 3 Assessment against the Criteria for Track 1 Substances

The TSMP presents four criteria to be used in identifying substances for management under Track 1 (Appendix). The following analysis documents the evidence considered and whether the criteria are satisfied for PCBs.

## 3.1 Predominantly Anthropogenic

For a substance to be "predominantly anthropogenic", its concentration in the environment has to result largely from human activity. Since quantitative data describing the relative importance of anthropogenic and natural sources of a given substance are not always available, the assessment for this criterion is not based on a predetermined numerical parameter but on expert judgement using the weight of available evidence. There are no known natural sources of PCBs in the environment (ATSDR, 1995). Studies of sediment cores from Lake Ontario show that PCBs do not appear in lake sediments until after commercial production began in 1929 (Oliver *et al.,* 1989).

***Conclusion***

**On the basis of the available information, it is concluded that the concentration of PCBs in the environment is due largely to the quantities of this substance used or released as a result of human activity.**

## 3.2 Persistence

To be managed under Track 1, a substance must be determined to be persistent in at least one environmental medium. In assessing if a substance is persistent in the environment only transformation processes are taken into account; dilution or transportation to other media are not considered.

The scientific information regarding the fate of PCBs is abundant and of overall adequate quality. Persistence of PCBs in various environmental mediums (i.e., air, water, sediments, soil) depends on the physicochemical properties of the individual congeners. Generally, persistence increases as the number of chlorine atoms increases (Mackay *et al.,* 1992). Half-life "classes" for PCB isomer groups in air, water, sediments and soils as calculated by Mackay *et al.,* (1992) are in Table 3. The classes which are approximately equivalent to the persistence criteria for Track 1 substances are also identified in Table 3. In each compartment, all PCB isomer groups meet the criterion for inclusion as a Track 1 substance.

**Table 3 Suggested half-lives of polychlorinated biphenyls in various environmental compartments (Mackay *et al.*, 1992)**

| Compounds | Air | Water | Soil | Sediment |
|---|---|---|---|---|
| Monochlorobiphenyl | ~ 1 week | ~ 8 months | ~ 2 years | ~ 2 years |
| Dichlorobiphenyl | ~ 1 week | ~ 8 months | ~ 2 years | ~ 2 years |
| Trichlorobiphenyl | ~ 3 weeks | ~ 2 years | ~ 6 years | ~ 6 years |
| Tetrachlorobiphenyl | ~ 2 months | ~ 6 years | ~ 6 years | ~ 6 years |
| Pentachlorobiphenyl | ~ 2 months | ~ 6 years | ~ 6 years | ~ 6 years |
| Hexachlorobiphenyl | ~ 8 months | ~ 6 years | ~ 6 years | ~ 6 years |
| Heptachlorobiphenyl | ~ 8 months | ~ 6 years | ~ 6 years | ~ 6 years |
| Octachlorobiphenyl | ~ 2 years | ~ 6 years | ~ 6 years | ~ 6 years |
| Nonachlorobiphenyl | ~ 2 years | ~ 6 years | ~ 6 years | ~ 6 years |
| Decachlorobiphenyl | ~ 6 years | ~ 6 years | ~ 6 years | ~ 6 years |

**Air**. In air, PCBs exist primarily (>90%) in the vapour phase. The lower chlorinated PCBs have higher vapour pressures (Table 2), therefore, they tend to volatilize more than the higher chlorinated PCBs. In the presence of ultraviolet light, PCBs are susceptible to some photolysis which generally leads to the formation of other congeners. In general, PCBs in air are very stable. This is supported by the observation of PCBs being transported over thousands of kilometres in the atmosphere (Coulston and Kolbye, 1994; WHO, 1993). Removal from the atmosphere is primarily via association with airborne particulate matter and subsequent deposition.

There is relatively little data on actual persistence in air. Estimated half-lives for photochemical reduction of PCBs in air range from 10 days for monochlorobiphenyl to 1.5 years for a heptachlorobiphenyl (WHO, 1993).

Mackay *et al.*, (1992) suggest that the half-life of a chemical depends not only on the intrinsic properties of the substance but also on the nature of the surrounding environment. A number of environmental conditions (e.g., temperature, sunlight intensity) affect the chemical's half-life so it is misleading to report a single half-life. Therefore, it is suggested that half-lives be reported as ranges or classified into groups (Table 3).

**Water**. In the aquatic environment, photolysis may be the only viable abiotic degradation process, with hydrolysis and oxidation not playing a significant role (WHO, 1993). PCBs are relatively insoluble in water and have a high octanol/water partition coefficient ($K_{ow}$). Therefore, PCBs readily adsorb to particulate matter and become incorporated into suspended particulates and bottom sediments when released into aquatic systems.

Relatively short half-lives are reported in surface waters for some PCB congeners. For example, Baily *et al.*, (1983) estimated the half-life of biphenyl (PCB-0) in river water to be 1.4 days. Similarly, Neely (1983) reported a half life of 1.4 days for 2-chlorobiphenyl (PCB-2) in Lake Michigan. These half-lives are likely influenced by transfer into other compartments (e.g., sediments). Mackay *et al.*, (1992) indicate that the minimum half-life for a PCB compound in water is eight months (Table 3). The half-lives increase with a higher degree of chlorination (Neely, 1983; Furukawa *et al.*, 1978a,b).

**Soils/Sediments.** Biodegradation of PCBs by microorganisms in sediments and soils has been reported (Coulston and Kolbye, 1994). Higher chlorinated PCBs (>5 chlorine atoms) are resistant to biodegradation under natural conditions (WHO, 1993). Oliver *et al.*, (1989) measured PCBs in sediment cores from Lake Ontario deposited over a period of over 30 years. Congener-specific analysis of the sediment cores showed that the percentage chlorine in the PCBs increased from near the top of the cores (most recent sediments) to the bottom of the cores (oldest sediments). However, the older sediments also contained traces of trichlorobiphenyls. Possible explanations for this observed pattern include a change in production/use to lower chlorinated mixtures as environmental concern with PCBs increased, or greater persistence of the higher chlorinated compounds relative to the less chlorinated groups. This trend is consistent with the classification scheme of Mackay *et al.*, (1992) that indicates the minimum half-life of PCBs in sediments or soils is about two years, with increasing persistence with a higher degree of chlorination (Table 3).

*Conclusion*

**On the basis of the available information, it is concluded that the higher chlorinated (Cl≥3) PCB congeners persist in the environment for many years. It is impractical to manage PCBs on a congener specific basis since all commercial mixtures contain various proportions of individual congeners with different levels of chlorination. PCBs as a class are considered to be persistent in the environment.**

## 3.3 Bioaccumulation

To be managed under Track 1 of the TSMP a substance must either have a bioaccumulation or a bioconcentration factor higher than 5000, or a log $K_{ow}$ (octanol/water partition coefficient) ≥ 5.0. Bioaccumulation refers to the uptake of a given substance directly from water or through the consumption of food containing the substance, while bioconcentration refers only to uptake from water. Bioaccumulation and bioconcentration factors are a ratio of the concentrations observed in biota with respect to concentrations in the exposure medium. For further detail on these terms, refer to Government of Canada (1995b).

Bio-concentration factors (BCFs) for PCBs have been well documented for a large number of species, at many different trophic levels and for a wide range of the PCB congeners. Table 4 presents values selected from IPCS, 1993).

**Table 4: Typical bioconcentration factors for PCB in a number of species (from IPCS, 1993).**

| PCB congener | Species example | Range of BCFs |
|---|---|---|
| mixture | Green Algae | 1600-5200 |
| HeCB | Algae: *Fragilari crotonensis* | 117,000- 313,000 |
| HeCB | Fungus: *Fusarium oxysporum* | 1327-1144 |
| Aroclor 1254 | Oyster: *Crassostrea virginica* | 89,00-165,000 |
| Aroclor 1254 | water flea: *Daphnia magna* | 47,000 |
| Aroclor 1254 | Grass shrimp: *Paleomonetes kadieknsis* | 12,300- 16,600 |
| Aroclor 1016 | sheepshead minnow: *Cyprinidon variegatus* | 22,000-54,000 |
| Aroclor 1254 | Atlantic salmon | 0.39 |
| Aroclor 1254 | mink | 16.5-28.5 |

**Octanol/Water Partition Coefficients (Log $K_{ow}$).** The log $K_{ow}$ for PCBs generally increases with a higher chlorination of the biphenyl molecule (Mackay *et al.,* 1992). Of the nine isomeric groups of PCBs only the monochlorobiphenyls have log $K_{ow}$ values less than 5. Log $K_{ow}$ values up to 11 have been examined for decabiphenyl (Appendix), but a value of 8.2 is most commonly used.

**Bioaccumulation Factors.** Bioaccumulation factors (BAF) differ for individual PCBs depending on the degree of chlorine substitution and the substitution pattern. In general, PCBs with five to seven chlorine atoms are accumulated to the greatest extent (higher chlorinated PCBs are too large to pass through biological membranes) lower chlorinated PCBs are more rapidly metabolized (Coulston and Kolbye, 1994). Several studies of PCBs in the Great Lakes show that organisms from higher trophic levels accumulated more PCBs than would be predicted on the basis of their chemical properties (Oliver and Niimi, 1988; Rowan and Rasmussen, 1992; Thomann and Connolly, 1984; Haffner *et al.,* 1994). In the Lake St. Clair ecosystem, Haffner *et al.,* (1994) observed that total PCB concentrations increased from sediments (935 $\mu$g/kg), bivalves (1360 $\mu$g/kg), oligochaetes (7240 $\mu$g/kg) and up into various fish species. The highest mean PCB level (64 900 $\mu$g/kg) was measured in the predatory gar pike. With relatively low water BAF levels, the gar pike represented a BAF of $2.16 \times 10^{10}$.

PCBs do not tend to bioconcentrate to high levels in terrestrial animals with BCF values from feed to animals such as rats, cows and mink reported as less than 5 (Garten and Trabalka, 1983; Wren *et al.,* 1987).

*Conclusion*

**On the basis of the available information, it is concluded that polychlorinated biphenyls are bioaccumulative substances.**

## 3.4 CEPA-toxic or equivalent

PCBs are substances specified on the List of Toxic Substances in Schedule I to CEPA [Canada Gazette Part I, February 26, 1977]. They were originally prohibited for certain uses under the Environmental Contaminants Act, which was superceded by the Canadian Environmental Protection Act in 1988. Four regulations have been developed for these substances: *Federal Mobile PCB Treatment and Destruction Regulations* (Canada Gazette Part II, Vol. 124, No. 1); *PCB Waste Export Regulations* (Canada Gazette, Part II, Vol. 124, No. 17); *Chlorobiphenyls Regulations* (Canada Gazette Part II, Vol. 125, No. 6); and *Storage of PCB Material Regulations* (Canada Gazette Part II, Vol. 126, No. 19). On November 20, 1995, the Minister of the Environment made an Interim Order regarding the PCB waste export regulations (Canada Gazette, Part I, December 9, 1995).

*Conclusion*

**PCBs are on the List of Toxic Substances under CEPA and are therefore CEPA-toxic.**

# 4 Overall Conclusion

**On the basis of the information reviewed, it is concluded that PCBs are predominantly anthropogenic, persistent, bioaccumulative, and CEPA-toxic. PCBs satisfy all four criteria outlined in the Toxic Substances Management Policy to identify substances for management under Track 1. Therefore, PCBs are proposed for management under Track 1 of the Policy.**

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# Appendix Criteria for the Selection of Substances for Track 1 under the Toxic Substances Management Policy

| Persistence [1] | | Bioaccumulation [3] | Toxicity [4] | Predominantly anthropogenic [5] |
|---|---|---|---|---|
| Medium | Half-life | | | |
| Air | ³ 2 days [2] | BAF ³ 5,000 or BCF ³ 5,000 or log $K_{ow}$ ³ 5.0 | CEPA-toxic or CEPA-toxic Equivalent | Concentration in environment largely resulting from human activity |
| Water | ³ 6 months | | | |
| Sediment | ³ 1 year | | | |
| Soil | ³ 6 months | | | |

1 A substance is considered persistent when the criterion is met in any one medium.

2 A substance may be considered as persistent in air if it is shown to be subject to atmospheric transport to remote regions such as the Arctic.

3 Whole-body, wet weight basis. Bioaccumulation factors (BAF) are preferred over bioconcentration factors (BCF); in the absence of BAF or BC