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Bioaccumulation assessment

**Additional information related to assessment of bioaccumulation data
under Annex D of the Convention**

Note by the Secretariat

The Committee has been provided with a note by the Secretariat (UNEP/POPS/POPRC.3/2) with information provided by Japan related to possible approaches to assessing bioaccumulation under Annex D of the Convention when the quantitative criteria listed in subparagraph 1 (c) (i) of Annex D are not fully met. The annex to the present note contains a detailed dossier prepared by Japan with analyses of past use of bioaccumulation data reviewed by the Committee. The annex is being circulated as submitted and has not been formally edited by the Secretariat.

* UNEP/POPS/POPRC.3/1/Rev.1.

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Annex

Discussion Paper on Bioaccumulation Evaluation

Masaru Kitano, Meiji University

1. Background

The bioaccumulation criteria in Annex D of the Stockholm Convention are as follows:

“(c) *Bio-accumulation:*

- (i) *Evidence that the bio-concentration factor or bio-accumulation factor in aquatic species for the chemical is greater than 5,000 or, in the absence of such data, that the log Kow is greater than 5;*
- (ii) *Evidence that a chemical presents other reasons for concern, such as high bio-accumulation in other species, high toxicity or ecotoxicity; or*
- (iii) *Monitoring data in biota indicating that the bio-accumulation potential of the chemical is sufficient to justify its consideration within the scope of this Convention”.*

Among those criteria, (i) is quantitative and less ambiguous for its application. However, (ii) and (iii) are not quantitative and it is unclear how to apply these criteria. Because of such uncertainty, especially for those chemicals that do not fulfil (i), bioaccumulation has been seriously discussed; a common understanding has not yet been achieved. (See Appendix 1: Bioaccumulation data on existing POPs and POPs candidates.)

This paper considers how to apply bioaccumulation criteria (ii) and (iii) when the criterion (i) is not fulfilled.

2. Evidence of bioaccumulation in past POPRC and grouping

(1) Evidence of bioaccumulation in past POPRC

So far, for five chemicals it has been concluded that they fulfil the screening criteria despite their low BCF (<5,000). The important bases of POPRC evaluations are as follows. (See Appendix 2-1: Evidence of bioaccumulation in past POPRC meetings; and Appendix 2-2 Evidence of bioaccumulation of POPs candidates under (ii) and (iii))

PFOS:

- (i) BCFs(ss) 240–1,300, BCFs are not good predictors of bioaccumulation
- (ii) Very low elimination rates and developmental effects in mammals at low levels (NOAEL value of 0.1 mg/kg body weight/day in rats in a two-generation study) and (iii) biomagnification

Lindane:

- (i) BCFs 13 to 1,240 (EHC), 327 to 893 (Japan), 43 to 4,240 (other),
- (ii) High toxicity (NOAELs as low as 0.3 mg/kg body weight/day) – and ecotoxicity (NOEC below 1 µg/l) (Refs. 5 and 6), measured field levels in earthworms (0.3 mg/kg for a soil containing 80 µg/kg) against mammalian toxicity data
- (iii) Reported in seabirds, fish and mammals in the Arctic. Concentrations in marine mammals are equivalent to or higher than PCBs and DDT reported in human breast milk among Inuit in the Arctic and in marine mammals.

Alpha-HCH:

- (i) BCFs are 60 to 2,750 (whole body, dry weight basis), 313–2,400 (wet weight basis) (Refs. 8 and 9),
- (ii) and (iii): The biomagnification factors for different trophic levels (zooplankton, invertebrates, fish, and mammals) are in the range of 1–16. Field studies in Arctic marine food webs shows that alpha-HCH stereoselectively bioaccumulates in marine species and has the ability to biomagnify to a greater extent than gamma-HCH, for which values of up to 4,220 have been reported; detected in blood and adipose tissue in humans. Detected in breast milk and placenta tissue, thus exposing offspring in critical periods of development; information suggests that the food chain bioaccumulation of alpha HCH is higher than for lindane.

Beta-HCH:

- (i) BCFs 250–1,500 (whole body dry weight basis)
- (ii) and (iii) Field studies in Arctic marine food webs have demonstrated that beta-HCH can bioaccumulate in upper trophic levels. Beta-HCH appears to be persistent in investigated species. Biomagnification factors for beta-HCH in marine food webs were mostly in the range of 1–18 (with a maximum value of 280). In birds and marine mammals in particular, beta-HCH can accumulate to higher levels than the other isomers. In the terrestrial Arctic food chain, beta-HCH can also biomagnify in mammals. Detected in adipose tissue and in breast milk in humans. Detected in placenta tissue exposing offspring at critical periods of development; information confirms that the potential for bioaccumulation of beta-HCH is higher than that for lindane.

OctaBDE:

- (i) High BCFs of homologues in commercial mixture
- (ii) and (iii) Concentrations of 220–270 ng/g lipid weight in eggs of the peregrine falcon in northern Sweden and Greenland; the estimated half-life in humans is 100 days, the soil organism accumulation factor for octabromodiphenyl ether 197 has been calculated as 2.

(2) Grouping of evidence

The results of grouping the above evidence of bioaccumulation are as follows:

BCFs are not applicable:

PFOS

Long half-life:

PFOS and OctaBDE

High Toxicity/High Ecotoxicity:

PFOS and Lindane

Biomagnification:

PFOS, Alpha-HCH and Beta-HCH

Detections in Biota :

Lindane, Alpha-HCH, Beta-HCH and OctaBDE

Detections in Human Body (blood, milk, fat tissue):

Lindane, Alpha-HCH and Beta-HCH

Exposure in Development Stage:

Alpha-HCH and Beta-HCH

3. Existing guidance for bioaccumulation evaluation

Several guidance documents for bioaccumulation evaluation are available that include viewpoints not covered in (i). For example, an EU guidance document mentions how to evaluate scientific evidence equivalent to “B” (Bioaccumulation) criteria of PBT and vPvB substances (BCF =2,000 for PBT, 5,000 for vPvB). And Japan has bioaccumulation criteria to determine bioaccumulation property under the Chemical Substance Control Law, which covers how to deal with cases where BCFs are less than 5,000. (See Appendix 3: The importance of biological half-life for the evaluation of bioaccumulation; and Appendix 4: Utilization of monitoring data for the evaluation of bioaccumulation.)

(1) EU guidance document (guidance for the preparation of an Annex XV dossier on the identification of substances of very high concern: extract)

- a) *Uptake and metabolism data from laboratory studies on other species, including mammalian species*
- b) *Processes other than fat partitioning*
- c) *Use of monitoring data*

Measured data in biota provide a clear indicator that the substance is taken up by an organism. However, the analytical detection of substances in organisms is not in itself always an indicator that significant bioconcentration or bioaccumulation has occurred or is occurring that would lead to effects in biota.

Useful in this respect are data representing different trophic levels within a single food chain, where relative differences in concentration between the various levels can often provide useful information on the bioaccumulation potential.

An important factor to take into account with regard to monitoring data is the quality of the data. Many substances with PBT-type properties are difficult to analyse at low concentrations and the use of poor-quality data may lead to erroneous conclusions being drawn.

Another factor to take into account when considering the available data (from both certain laboratory studies and field data) is that the accumulation seen in any given situation can depend to a large extent on the lipid content of the species in question.

In terms of assessing whether the substance has a bioaccumulation potential that is equivalent to the B-criterion, a weight of evidence approach should be taken, drawing together the available data. Part of this assessment could include consideration of the degree to which the substance fails to meet the actual B or vB criteria if BCF data are available. It should be stressed that the equivalence of concern here is in relation to bioaccumulation potential and not solely occurrence in biota.

(2) Japan (Bioaccumulation criteria to determine Class 1 monitoring chemicals under CSCL)

- a) *Highly Bioaccumulative*
BCF value is higher than 5,000
- b) *Not Highly Bioaccumulative*
BCF value is less than 1,000 or Kow is less than 3.5.
Kow is not applicable for surface reactive substances, mixtures with molecular weight distributions, organic metal compounds, low-purity samples (except HPLC method) and inorganic compounds
- c) *If BCF values are between 1,000 and 5,000, the following test result should be considered if necessary to determine bioaccumulation potential.*
 - *Elimination test*
 - *BCF of fish parts (edible parts)*

4. Other indicators

(1) Bioconcentration factor and bioaccumulation factor

The relationships between BCF and BAF are examined. In general, high BCF POPs shows high BAF. However, the correlation between BCF and BAF is not clear. (See Appendix 5: The interrelation between BCFs and BAFs data of existing POPs and POPs candidates)

It is noted that BCFs are reliable because test methods are well established. But careful considerations on BAFs are needed because those data are derived from monitoring data.

(2) Koa

Koa is discussed as an indicator of potential bioaccumulation of terrestrial animals. However, only Koa values of limited chemicals that show bioaccumulation are discussed at this stage, and a relationship between Koa and bioaccumulation of terrestrial animals is not clearly indicated. Furthermore, there are no cases of using Koa as an indicator of bioaccumulation. (See Appendix 6: The biological half-life data of existing POPs and POPs candidates)

5. Discussions based on guidance documents

Based on guidance documents, evidence of bioaccumulation in past POPRC evaluation are reviewed as follows:

BCFs are not applicable

The EU guidance document points out a bioaccumulation mechanism other than fat partitioning. As protein binding is considered for PFOS, the mechanistic explanation may be useful to determine the bioaccumulation property when the (i) criterion is not fulfilled.

Long half- life

Japan's criteria include this concept and this is also considered to be included in the EU document as "uptake and metabolism." Information on half-life is useful to determine the bioaccumulation property when the (i) criterion is not fulfilled. It should be noted that both guidance place limits on test data for consideration.

High Toxicity /High Ecotoxicity

This is not mentioned in the guidance documents. Since the Annex D (d) criterion directly covers adverse effects, it should be considered that Annex D (c) covers the relative relationship between the monitored level and the (eco) toxicity level.

Biomagnification

The EU guidance document mentions biomagnification as data representing different trophic levels within a single food chain but quantitative criteria do not appear. Biomagnification data come from field monitoring data, thus careful consideration is needed such as the reliability and lipid content of the species in question. Consideration on differences in the metabolism of marine species and terrestrial animals may also be needed.

Detections in Biota, Detections in Human Body (blood, milk, fat tissue)

The EU guidance document states “the analytical detection of substances in organisms is not in itself always an indicator that significant bioconcentration or bioaccumulation has occurred or is occurring that would lead to effects in biota.” Thus detection data in biota or human body itself would not be regarded as direct evidence of bioaccumulation. However, especially in case the monitoring data reveals the increasing of the level by age or detection in various species, such data should be carefully considered.

Exposure in Development Stage

This is not mentioned in guidance documents and this information is not direct evidence of bioaccumulation like Detection in Human Body (blood, milk, and fat tissue) is. However, this situation indicates the need for careful consideration.

6. Conclusions

Based on the review of past POPRC evaluation and consideration of existing guidance documents, the following approach is considered appropriate.

(1) Important evidence

For the evaluation of the bioaccumulation property of those chemicals that do not fulfill the (i) criterion, the following information is considered important evidence which fulfill (ii) or (iii) criteria. The proposal submission for listing chemicals in Annexes A, B and C should indicate which criteria is met by the data of that chemical.

Certain level of BCF

A certain level of BCF such as 1,000 or 2,000 may indicate good reason for careful consideration of the bioaccumulation property of a chemical which does not fulfill the (i) criterion.

Long half- life, unique mechanism of Bioaccumulation

A long half-life and a mechanistic explanation on why the (i) criterion is not applicable may indicate good reason for careful consideration of the bioaccumulation property of a chemical which does not fulfill the (i) criterion.

Differences in concentration between trophic levels (biomagnification)

Differences in concentration between trophic levels suggest bioaccumulation through the food chain and may indicate good reason for careful consideration of the bioaccumulation property of a chemical which does not fulfill the (i) criterion. It should be noted that the source data come from monitoring, thus careful consideration on the use of monitoring data such as reliability may be needed.

High Toxicity /High Ecotoxicity

A comparison of the detected level in the environment and the strength of (eco) toxicity is needed. If these levels are close, it may indicate good reason for careful consideration. For this information, consideration of the use of monitoring data such as reliability may also be needed.

Detections in Biota, Detections in Human Body (blood, milk, fat tissue), Exposure in Development Stage
It should be taken into account that the detection of a substance in organisms is not in itself always an indicator of bioaccumulation and the lower detection limit is due to the improved analytical method. Relatively higher detection level and often detection comparing to past release into the environment and comparison with detection level with existing POPs may suggest appropriate level to trigger careful consideration.

(2) Weight of Evidence

In case (i) is not fulfilled, the weight of evidence approach should be considered for all available information. If much of the important evidence listed in (1) suggests bioaccumulation, this evidence persuasively indicates bioaccumulation.

Appendix 1: Bioaccumulation data on existing POPs and POPs candidates

Chemical name	Aquatic species		BAF (BSAF)	Other species BAF (BSAF)	Biological half-life (d)	log K _{oa} ⁵⁾ (-)	Mechanism
	BCF						
	METI method ¹⁾	Others					
<i>Aldrin</i>	1,550 - 20,000	5,500 - 11,700 ²⁾				8.08	
<i>Dieldrin</i>	4,860 - 14,500	8,910 - 9,770 ²⁾			100 - 592 ⁴⁾	8.90	
<i>Endrin</i>	2,360 - 12,600	5,890 - 7,410 ²⁾			2 - 4 ⁴⁾	8.13	
<i>Chlordane</i>	13,000 - 27,900	19,500 - 20,900 ²⁾			<1 - 140 ⁴⁾	8.92	
<i>DDT</i>	5,100 - 25,900	2,880 - 91,200 ²⁾	4,680 - 4,170,000 ²⁾		0.2 - 428 ⁴⁾	9.82	
<i>HCB</i>	6,000 - 30,000	3,720 - 245,000 ²⁾	1,200 - 550,000 ²⁾		12 - 1,095 ⁴⁾	7.38	
<i>Heptachlor</i>	2,020 - 17,300	8,710 - 10,000 ²⁾				7.64	
<i>Mirex</i>		20,400 - 41,700 ²⁾	224,000 - 5,750,000 ²⁾		1.6 - 364 ⁴⁾		
<i>Toxaphene</i>					1 - 19.3 ⁴⁾		
<i>PCBs</i>	600 - 21,900	2,690 - 933,000 ²⁾	11,000 - 32,400,000 ²⁾		0.3 - 1,020 ⁴⁾		
<i>PCDDs</i>		36,300 - 38,900 ²⁾			<7 - 4,125 ⁴⁾		
<i>PCDFs</i>		2,570 - 6,030 ²⁾			0.001 - 1,168 ⁴⁾		
<i>PeBDE</i>			17,700 ³⁾	1.8 ³⁾ BSAF = 11 - 34 ³⁾			
<i>PFOS</i>	200 - 1,500	240 - 3,100 ³⁾			13.6 - 1,428 ^{3),4)}		bound to blood protein
<i>HeBB</i>	4,700 - 16,000	4,700 - 18,100 ³⁾			22 - 35,405 ^{3),4)}		
<i>Chlordecone</i>		6.2 - 60,200 ³⁾			8.5 - 165 ⁴⁾		
<i>Lindane</i>	327 - 893	3 - 20,000 ³⁾	10 - 12,600 ^{2),3)}		0.71 - 2 ^{3),4)}	7.85	slow elimination via air-respiration
<i>α-HCH</i>		60 - 13,000 ³⁾			1.6 - 6.9 ⁴⁾	7.61	slow elimination via air-respiration
<i>β-HCH</i>		250 - 1,500 ³⁾			2.5 - 154 ⁴⁾	8.88	slow elimination via air-respiration
<i>OcBDE</i>		<10 - 36 ³⁾	BSAF= 1(hexa)-3(hepta) ³⁾ BSAF= 9.1±1.1(hexa)		100 ³⁾		dietary absorption of large molecules
<i>SCCP</i>	2,500 - 11,000	<1 - 138,000 ³⁾	16,440 - 25,650 ³⁾	BSAF = 1.9 - 6.8 ³⁾	7.1 - 86.6 ³⁾		
<i>PeCB</i>		577 - 23,000 ³⁾	125 - 117,000 ^{2),3)}		53 ³⁾		

Reference

1) Chemical Risk Information Platform (CHRIP, Japan), 2) Arnot, JA et.al (2006) Supplementary information for "A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms", 3) Evaluation against Annex D and risk profile of candidate POPs, 4) Hazardous Substances Data Bank (HSDB, U.S.), 5) Shoeib, M. et al.(2002) Environ. Toxicol.Chem., 21, 5, 984-990

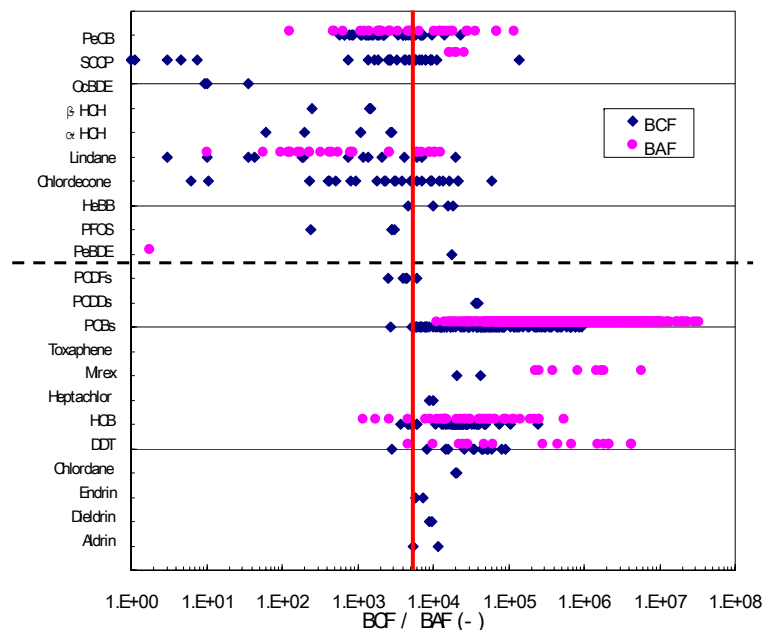


Figure 1. The interrelation between BCF and BAF data of existing POPs and POPs candidates

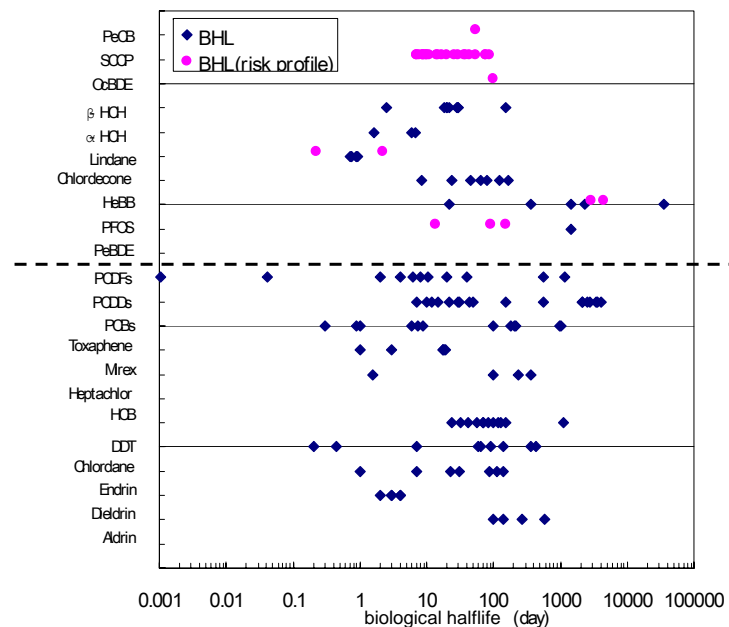


Figure 2. The biological half-life data of existing POPs and POPs candidates

Appendix 2-1: Evidence of bioaccumulation in past POPRC meetings (BCF<5,000)

	PFOS	Lindane	Alpha HCH	Beta HCH	Octa BDE
(i) Evidence that the bio-concentration factor or bio-accumulation factor in aquatic species for the chemical is greater than 5,000 or, in the absence of such data, that the log Kow is greater than 5;	Bioconcentration factor values for PFOS are lower than the screening criteria (in the range of 240–1,300 for steady-state conditions) and up to 2,796 using kinetic estimation) (Ref. 1); PFOS is a surface active substance and, as a result, octanol-water partition coefficient measurements are not relevant (Ref. 2). Bioconcentration factor values are not good predictors of bioaccumulation for this substance because food uptake has been demonstrated to be a relevant route for aquatic organisms (Ref. 3). Bioaccumulation is not related to lipophilicity and the accumulation does not primarily occur in lipid tissues;	Data found in Environmental Health Criteria 124 (Ref. 5) indicated that bioconcentration factors ranged from 13 to 1,240 . The bioconcentration factor values, obtained and peer-reviewed by Japan, were between 327 and 893, in accordance with OECD Test Guidelines. Other references provide measured bioconcentration factors in mussels, daphnia and fish species ranging from 43 to 4,240 , depending on the lipid content of the organism. Regarding the bioaccumulation factor, the only information provided was a value of 12,500 in the Mexican proposal, which may be based on the physico-chemical properties and environmental data for lindane. The log Kow value in the Mexican proposal is 3.5;	(i) The log Kow reported in the proposal is 3.8 (Ref. 1). Bioconcentration factors for invertebrates can reach values of 60 to 2,750 (whole body, dry weight basis) (Ref. 4). Bioconcentration factors for fish were in the range of 313–2,400 (wet weight basis) (Refs. 8 and 9);	The log Kow reported in the proposal is 3.7. The bioconcentration factor for fish was determined to be 1,460 . Other reported bioconcentration factors for fish were in the range of 250–1,500 on a whole body dry weight basis (Ref. 5);	The log Kow value for the commercial product has been determined to be around 6.29 (Ref. 3). Experimental results presented in the European Union risk assessment report indicate that octa and heptabromodiphenyl ethers have low bioconcentration factors (less than 10–36); these results have been confirmed by data presented and peer-reviewed by the Japanese Government. Nevertheless, other brominated diphenyl ethers present in commercial octabromodiphenyl ether have been found to have higher bioconcentration factors , for example, 11,700–17,700 for pentabromodiphenyl ethers (Ref. 3) and 1,000–5,600 for hexabromodiphenyl ethers (Ref. 3);
(ii) Evidence that a chemical presents other reasons for concern, such as high bio-accumulation in other species, high toxicity or ecotoxicity;	Toxicokinetic studies in aquatic and terrestrial vertebrates show very low elimination rates (Refs. 1 and 4). In addition, PFOS has shown developmental effects in mammals at low levels (no observed adverse effect level (NOAEL) value of 0.1 mg/kg body weight/day in rats in a two-generation study) (Ref. 1);	(i) The bioaccumulation of lindane has been observed for most taxonomic groups, from plants and algae to vertebrates . The environmental consequences of the combination of this bioaccumulation potential with a high toxicity – no observed-adverse-effect levels (NOAELs) as low as 0.3 mg/kg body weight/day – and ecotoxicity – aquatic ecosystem no-observable-effect concentration (NOEC) below 1 µg/l (Refs. 5 and 6) – should be considered. For example, when measured field levels in earthworms (0.3 mg/kg for a soil containing 80 µg/kg) are weighed against mammalian toxicity data (Ref. 5) using a realistic food intake ratio of 0.63 (Ref. 7), the comparison indicates an area of ecotoxicological concern which should be further explored;	The biomagnification factors for alpha-HCH for different trophic levels (zooplankton, invertebrates, fish, and mammals) are in the range of 1–16 . (Refs. 10 and 11). According to field studies in Arctic marine food webs, it has been demonstrated that alpha-HCH stereoselectively bioaccumulates in marine species and has the ability to biomagnify to a greater extent than gamma-HCH, for which values of up to 4,220 have been reported (Ref. 12); Alpha-HCH has been detected in blood and adipose tissue in humans (Ref. 13). It has also been detected in breast milk and placenta tissue , thus exposing offspring in critical periods of development (Refs. 14, 15 and 16); Available information suggests that the food chain bioaccumulation of alpha HCH is higher than for lindane (Ref. 12);	Field studies in Arctic marine food webs have demonstrated that beta-HCH can bioaccumulate in upper trophic levels (Ref. 1). Beta-HCH appears to be persistent in investigated species (Refs. 1, 6, and 7). Biomagnification factors for beta-HCH in marine food webs were mostly in the range of 1–18 (with a maximum value of 280). In birds and marine mammals in particular, beta-HCH can accumulate to higher levels than the other isomers (Refs. 1, 6 and 8). In the terrestrial Arctic food chain, beta-HCH can also biomagnify in mammals . Modelled biomagnification factors for wolves, depending on their age, ranged from 9 to 109 (Ref. 9); Beta-HCH has been detected in adipose tissue (Ref. 10) and in breast milk in humans (Refs. 11, 12 and 13). It has been detected in placenta tissue exposing offspring at critical periods of development (Ref. 14); In addition, available information confirms that the potential for bioaccumulation of beta-HCH is higher than that for lindane (Ref. 1).	Field data provide evidence for the potential for bioaccumulation of heptabromodiphenyl ether. Concentrations of 220–270 ng/g lipid weight in eggs of the peregrine falcon in northern Sweden and Greenland have been reported (Refs. 4 and 5). This evidence demonstrates that, despite its large molecular weight, the molecule is found in top predators at levels similar to those of bioaccumulable tetra and penta bromodiphenyl ether. In addition, the estimated half-life in humans is 100 days (Ref. 6), suggesting a potential for bioaccumulation. In soil biota, the soil organism accumulation factor for octabromodiphenyl ether 197 has been calculated as 2 (Ref. 2).
(iii) Monitoring data in biota indicating that the bio-accumulation potential of the chemical is sufficient to justify its consideration within the scope of this Convention;	Monitoring data confirm the bioaccumulation and biomagnification of PFOS in both terrestrial and marine mammals (Ref. 4);	(ii) Lindane has been reported in seabirds, fish and mammals in the Arctic (Ref. 1). Lindane concentrations in marine mammals are found at equivalent levels or even higher levels than some of the more hydrophobic contaminants such as polychlorinated biphenyls (PCBs) and DDT (Ref. 1). In addition, lindane has been reported in human breast milk among Inuit in the Arctic and in marine mammals (Ref. 8);			

Appendix 2-2: Evidence of bioaccumulation of POPs candidates under (ii) and (iii)

	PeBDE	PFOS	HeBB	Chlordecone	Lindane	α-HCH	β-HCH	OCBDE	SCCP	PeCB	
Bio-accumulation in other species					The bioaccumulation of lindane has been observed for most taxonomic groups, from plants and algae to vertebrates.		Modelled BMFs for wolves, depending on their age, ranged from 9 to 109.	In soil biota, the soil organism accumulation factor for octabromodiphenyl ether 197 has been			
Toxicity	High toxicity		Developmental effects in mammals at low levels (NOAEL = 0.1 mg/kg/day in rats in a two-generation study)		The environmental consequences of the combination of this bioaccumulation potential with a high toxicity (NOAELs 0.3 mg/kg/day) and ecotoxicity (NOEC <below 1 µg/l) should be considered.						
	High ecotoxicity										
	Toxicokinetics		Very low elimination rates (toxicokinetic studies in aquatic and terrestrial vertebrates) (*)	Toxicokinetic data in mammals and monitoring data in biota confirm the bioaccumulation potential. (*)		When measured field levels in earthworms (0.3 mg/kg for a soil containing 80 µg/kg)				Toxicokinetic data on domestic birds indicate accumulation during food exposure and a half-life for adipose tissue of 53 days. (*)	
Biological half-life	Human							The estimated half-life in humans is 100 days.			
	Animal		Very low elimination rates (toxicokinetic studies in aquatic and terrestrial vertebrates) (*)		An excretion half-life in mammals of several months					Toxicokinetic data on domestic birds indicate accumulation during food exposure and a half-life for adipose tissue of 53 days. (*)	
Monitoring data in biota	BMF or trophic transfer	Data from around the world demonstrate increasing levels of PentaBDE congeners with rising trophic position. Recent publications confirm food chain transfer in the Arctic. (*)	Monitoring data confirm the bioaccumulation and biomagnification of PFOS in both terrestrial and marine mammals. (*)				BMFs for α-HCH for different trophic levels (zooplankton, invertebrates, fish, and mammals) are in the range of 1-16. In Arctic marine food webs, it has been demonstrated that α-HCH stereoselectively bioaccumulates in marine species and has the ability to biomagnify to a greater extent than γ-HCH, for which values of up to 4,220 have been reported.	BMFs in marine food webs were mostly in the range of 1-18.			
	Detections in higher trophic levels		Monitoring data confirm the bioaccumulation and biomagnification of PFOS in both terrestrial and marine mammals. (*)		Detection of high levels of the chemical in fish and birds	Reported in seabirds, fish and mammals in the Arctic (*)		Field studies in Arctic marine food webs have demonstrated that beta-HCH can bioaccumulate in upper trophic levels. (*) In the terrestrial Arctic food chain, beta-HCH can also biomagnify in mammals. (*)	Despite its large molecular weight, the molecule is found in top predators at levels similar to those of bioaccumulable tetra and penta BDE. (*) Concentrations of 220-270 ng/g lipid weight in eggs of the peregrine falcon in northern Sweden and Greenland have been reported. (*)	Levels of short-chained chlorinated paraffins in marine mammals from various regions of the Arctic have been reported, as well as from Canada and Greenland. (*)	
	Detections in other species			Toxicokinetic data in mammals and monitoring data in biota confirm the bioaccumulation potential. (*)				β-HCH appears to be persistent in investigated species.	Field data provide evidence for the potential for bioaccumulation of heptabromodiphenyl ether.	There is also evidence of short-chained chlorinated paraffins accumulating in fish species from Lake Ontario, Canada.	
	Detections in remote areas of the Arctic	Recent publications confirm food chain transfer in the Arctic. (*)				Reported in seabirds, fish and mammals in the Arctic (*)		Field studies in Arctic marine food webs have demonstrated that beta-HCH can bioaccumulate in upper trophic levels. (*) In the terrestrial Arctic food chain, beta-HCH can also biomagnify in mammals. (*)	Despite its large molecular weight, the molecule is found in top predators at levels similar to those of bioaccumulable tetra and penta BDE. (*) Concentrations of 220-270 ng/g lipid weight in eggs of the peregrine falcon in northern Sweden and Greenland have been reported. (*)	Levels of short-chained chlorinated paraffins in marine mammals from various regions of the Arctic have been reported, as well as from Canada and Greenland. (*)	There is also a good amount of monitoring data in Arctic mammals, birds, fish, lake sediments and moss, in remote areas.
	Detections in breast milk					Reported in human breast milk among Inuit in the Arctic and in marine mammals	Detected in blood and adipose tissue in humans Detected in breast milk and placenta tissue, thus exposing offspring in critical periods of development	Detected in adipose tissue and in breast milk in humans Detected in placenta tissue, exposing offspring at critical periods of development.		Short-chained chlorinated paraffins have been detected in breast milk.	
	Comparative detection level of other POPs					Lindane concentrations in marine mammals are found at equivalent levels or even higher levels than some of the more hydrophobic contaminants such as PCBs and DDT.		In birds and marine mammals in particular, βHCH can accumulate to higher levels than the other isomers.			
	Others			Additional information from the Michigan incident	This bioaccumulation is a consequence of the lipophilic nature of the chemical, for which the log Kow value is 4.50-6.00.		Available information suggests that the food chain bioaccumulation of alpha-HCH is higher than for lindane.	Available information confirms that the potential for bioaccumulation of β-HCH is higher than that for lindane.	Despite its large molecular weight, the molecule is found in top predators at levels similar to those of bioaccumulable tetra and penta BDE. (*)		Pentachlorobenzene has been detected in the air in remote areas, including Arctic air, with a concentration range from 0.017 to 0.138

Entries with * fall under multiple categories.

Appendix 3: The Importance of biological half-life for the evaluation of bioaccumulation

1. Biological half-life data

Biological half-life is defined as time needed for the chemical to become half of its original amount by metabolism in and excretion from the body.

With rare exceptions, the resulting metabolites are more hydrophilic, such that they are excreted more rapidly than the parent substances. Therefore, half life is an important parameter for reducing the bioaccumulation potential.

2. Importance of biological half-life data

Example 1: Guidance on identification of SVCH (substances of very high concern)

The European Chemical Agency (2007) has published guidance on identification of SVCH. With respect to the bioaccumulation criterion, the BCF in aquatic organisms is used as an indicator of the bioaccumulation potential of the substance. Data that could also be used to demonstrate or support a high bioaccumulation potential in relation to equivalent concern include half life data: "Uptake and metabolism data from laboratory studies on the other species, including mammalian species"

Example 2: The evaluation of bioaccumulation potential using log Kow

For lipophilic substances, correlations are assumed to exist between log Kow and BCF values. However it is apparent that there are significant discrepancies between measured and calculated BCF values, which become more pronounced with increasing log Kow (United Nations (2005)).

The reasons for these discrepancies are attributed to reduced membrane permeation kinetics, reduced biotic lipid solubility for large molecules, experimental artifacts such as equilibrium not being reached, and analytical errors.

The metabolism is also considered as one of these reasons. Fish are able to metabolize many different classes of xenobiotics and some of the enzymes catalyzing these reactions have been identified and characterized. A metabolite, which is the product of a biotransformation reaction, has different physical and chemical properties to its parent substance. Bioaccumulation potential may be reduced by altering a substance to a more hydrophilic derivative.

Example 3: The evaluation of biomagnification potential

Refer to □ Utilization of monitoring data for the evaluation of bioaccumulation □

3. Factors affecting biological half-life data

In fish bioconcentration tests, estimates of half life can be calculated on the basis of a change in chemical concentration, or a change in chemical content (body burden) per unit time. The difference between the two units of calculation is due to an increase in body weight, or "growth dilution," during the study. Growth can become an important factor in studies on persistent chemicals where levels are monitored over a long period (Niimi, A.J. (1987)).

Furthermore, factors such as interspecies differences, the time interval between cessation of chemical exposure and first sample interval, the use of radiolabeled compounds, and the use of first- and multi-order kinetics could influence half life estimates.

In toxicokinetics study, half life data are usually derived from plasma concentrations. Urinary, biliary or fecal excretion can also be measured. Lipophilic chemicals are at first eliminated into feces, and so half life may appear to be short. However, the portion that is taken up by the body can remain in the lipid tissue for a long time, resulting in much longer half life.

References:

European Chemicals Agency (2007) Guidance for the preparation of an Annex XV dossier on the identification of substances of very high concern.

Niimi, A.J. (1987) Biological half-lives of chemicals in fishes, *Reviews of Environmental Contamination and Toxicology*, 99, 1-46.

United Nations (2005) Globally harmonized system of classification and labelling of chemicals (ghs), Annex 9 Guidance on hazards to the aquatic environment.

Appendix 4: Utilization of monitoring data for the evaluation of bioaccumulation

1. Utilization of monitoring data

Care must be taken in using monitoring data for the evaluation of bioaccumulation potential. European Chemical Agency (2007) has published guidance with regard to using monitoring data from field studies.

“Measured data in biota provide a clear indicator that the substance is taken up by an organism. However the analytical detection of substances in organisms is not in itself always an indicator that significant bioconcentration or bioaccumulation has occurred or is occurring that would lead to effects in biota.

The interpretation of such data in terms of actual bioaccumulation or biomagnification factors can be especially difficult when the sources and levels of the exposure (for example through water as well as food) are not known or cannot be estimated reasonably.”

2. Consideration in using monitoring data for the evaluation of bioaccumulation

a) Biomagnification factor (BMF) by foodweb transfer

Although there are various definitions for biomagnification, it was described in POPRC1 (2005) as

“Biomagnification is the process by which chemical concentrations are normally expressed on a lipid normalized basis. Biomagnification results from the trophic level transfer of a chemical through the diet from a lower to a higher trophic level.

Given the great variability in approaches to calculating the biomagnification factor (BMF), the potential for biomagnification should be used instead of BMF for the evaluation of the bioaccumulation criterion. If a biomagnification potential is identified, it should be considered as a specific concern in the evaluation of criteria 1 (c) (ii) and (iii).”

Lipid based concentration should be used in comparing the concentration between trophic levels by BMF. BMF values based on whole body weight tend to be lower than lipid based BMFs.

$BMF = \text{lipid based concentration of the chemical in an organism} / \text{lipid based concentration of the chemical in food}$

Schwarzenbach, R.P. (2003) reported some examples of specific organochlorine compound concentrations in organisms forming simple food chains or food webs. When $BMF > 1$, transfer to higher level predator is considered to have occurred. However, metabolism and depuration rates in microorganisms such as planktons are fast, so disequilibrium between trophic levels is hard to be established.

BMF tends to increase as the lipid solubility of the chemical increases. This is generally due to slow elimination process. For chemicals with relatively low lipid solubility such as HCH ($K_{ow} = 3.8$), elimination process is faster and so potential for biomagnification decreases.

BMF can be lower than 1 in high level predators that are capable of metabolizing the chemicals. For example, birds can biotransform HCH more readily than its prey, and so BMF of HCH in seabirds is 0.3.

b) Time trend of the monitoring data

Time trend data can also provide very useful information in terms of whether the levels of the substance is building up over time in the environment, although again the interpretation of such data may not always be straightforward.

c) Comparison with the measured concentrations of existing POPs

Comparison with the measured concentrations of highly bioaccumulative substances such as existing POPs can provide benchmarks for potential to bioaccumulate.

However, the measured concentrations of POPs to be compared with are not necessary so high. Furthermore, since accumulated concentrations do not correspond to toxic effect concentrations, comparison should be made between body burden and toxicity level at the site where toxic effects are expressed.

d) Sample data detected at high levels

Although organic compounds are generally accumulated in liver or lipid tissue, data detected in other parts of the body (e.g. blood protein) can help to identify chemical's specific accumulation behaviour and to interpret the mechanism of accumulation.

While BCFs are usually derived from the experiments with aquatic organisms, data detected at high levels in other organisms (e.g. terrestrial organisms) can help to find organisms susceptible to bioaccumulation and to interpret the mechanism of accumulation.

3. Evaluation of the quality of monitoring data

An important factor to take into account with regard to monitoring data is the quality of the data. Many substances with POP properties are difficult to analyze at low concentrations and the use of poor quality data may lead to erroneous conclusions being drawn. The Arctic Monitoring and Assessment Programme (AMAP, 2001) has published recommendations with regard to assessing the quality of monitoring data for use in determining spatial and temporal trends and other types of data interpretations. The following four categories of data are proposed, based on quality assurance considerations.

- a) Evidence of certification or documented quality assurance on all stages of the data gathering process.
- b) Some parts of QA/QC process can be documented (but may not be fully described in e.g. published reports).
- c) No data available on QA/QC procedures, but results are consistent with other reports concerning the same sample types.
- d) No evidence of QA or of data compatibility with the certified data flux.

AMAP recommend that only data in categories A or B should be accepted for investigation of spatial and temporal trends or other types of basic data interpretations. Category C data can be used to show relative trends, assuming that they are internally consistent. Category D data should not be used in the assessment process.

4. Factors for monitoring data variabilities

There are many factors that could affect monitoring data and some of these factors are closely related to each other. Borga et al. (2004) suggested implications of those factors as summarized below:

Lipid

Lipid content of an organism varies with environmental factors such as seasonality as well as individual factors such as the age, sex, body size and reproductive stage. Although lipid normalized concentrations are used in bioaccumulation studies to account for the variation, the influence of those factors should be considered.

Organisms living in cold temperature areas such as the Arctic tend to accumulate large amount of lipid in their body to store energy as a strategy for survival in cold climate. Most of the POPs are highly lipid soluble, and partition into lipid phase, so they are detected at high levels in arctic biota.

Seasonality

In the Arctic, seasonal changes in solar irradiation intensity affect accumulation of POPs.

Formation and melting of ice, or change in the organic matter content of the water due to seasonal increase or decrease in primary production influence bioavailability of POPs in the water column.

Increased primary production results in abundance of food that leads to increased body size and /or lipid content of the organisms. The increased lipid enables increased storage of lipophilic chemicals.

Life cycle

For pelagic organisms, increase in body size reduces relative surface area and thus reduces elimination through body surface.

For growing organisms, especially birds and mammals, apparent concentration of POPs decrease with the increase in body size (growth dilution).

For mature organisms, the concentrations of POPs tend to increase with age because many of these substances are recalcitrant and eliminated very slowly.

Changes in diet or habitat by age can alter the POPs' accumulation and/or elimination process.

Female mammals at reproductive stage eliminate POPs accumulated in their body through fetus and milk.

Habitat

Habitats vary in characteristics such as the composition of the aquatic system (e.g. depth of water column and sediment) and partitioning of the chemical between compartments.

POPs tend to adsorb to particles and deposit into sediment, and so they are found to be higher in benthic organisms than in pelagic organisms at the same trophic level. The deep-sea fish living in habitats with more interactions between sediment and water accumulate more POPs than surface-water fish.

Organisms that migrate are exposed to various levels of POPs during their lifetime depending on regional differences.

Metabolism (Biotransformation)

The rate of metabolism rather than uptake determines the chemical's potential to bioaccumulate and biomagnify

High bioaccumulation factor does not necessary suggest high potential for biomagnification if the chemical can be metabolized.

The ability of an organism to metabolize is highly chemical-specific and differs among species, age, body size, sex, etc.

There is a possibility that metabolites are more persistent, bioaccumulative and/or toxic than the parent compound.

Trophic position

When an organism at higher trophic position consumes its prey, chemicals accumulated by prey taken up from food

For persistent and bioaccumulative substances like POPs, slow elimination from the body of the organisms at each trophic level results in increased concentration in the organisms at next level.

BMFs tend to increase with the rise in trophic level But, metabolic transformation of the chemical in the predator causes the predator to achieve a concentration lower than that in its prey (Trophic dilution).

References:

AMAP (2001) Guidelines for the AMAP Phase 2 Assessments. Arctic Monitoring and Assessment Programme. AMAP Report 2001:1.

Borga, K., Fisk, A.T., Hoekster, P.F., and Muir, D.C.G. (2004) Biological and chemical factors of importance in the bioaccumulation and trophic transfer of persistent organochlorine contaminants in arctic marine food webs. *Environ. Toxicol. Chem.*, 23, 10, 2367–2385.

European Chemicals Agency (2007) Guidance for the preparation of an Annex XV dossier on the identification of substances of very high concern.

Schwarzenbach, R.P., Gschwend, P.M., Imboden, D.M. (2003) *Environmental Organic Chemistry* second edition. Wiley-interscience.

UNEP (2005) Definitions of bioconcentration, bioaccumulation and biomagnification, Persistent Organic Pollutants Review Committee, First meeting.

Appendix 5: Relationships between BCFs and BAFs

1) Bioconcentration factors (BCF)

- Measured in laboratory experiments under controlled conditions.
- Exposure solely from water - applicable to aquatic species only.
- Net result of uptake via respiratory surface (e.g. gill membrane in fish) vs. depuration through respiration, fecal elimination, biotransformation, etc.
- Generally calculated as the ratio of the chemical concentration in the organism to that in the water at a steady state. Kinetic method is used when a steady state is not reached.

2) Bioaccumulation factors (BAF)

- Measured in laboratory (model ecosystem) experiments or field studies.
- Exposure from ambient media (air, water, sediment, soil) and diet – also applicable to non-aquatic species.
- Net result of uptake via both routes (respiratory surface and food) vs. depuration.
- Calculated as the ratio of the chemical concentration in the organism to that in the ambient medium.
- BAF of benthic organism is expressed as biota-sediment accumulation factor (BSAF).
- Ratio of the chemical concentration in the organism to that in its food (prey) is expressed as biomagnification factor (BMF).
- Results of dietary bioaccumulation experiments (feeding studies) are expressed in BMFs.

3) Correlation between BCF (bioconcentration factor) and BAF (bioaccumulation factor) values

- BAFs tend to be higher than BCFs for many chemicals possibly because of the increased routes of exposure.
- Table 1 lists summary statistics for five chemicals selected as a case study to compare BCFs and BAFs for the same chemical in fish species (Arnot, J.A. et al. (2006)). For chemicals that are known to biomagnify in food webs, field BAFs can be up to almost 2 orders of magnitude greater than the BCFs from laboratory experiments. But certain chemicals are observed to have greater BCFs than BAFs.

Table 1. A case study comparison of acceptable fish bioconcentration factor (BCF) and bioaccumulation factor (BAF) values for 5 chemicals. (Arnot, J.A. et al. (2006))

Chemical (endpoint)	Log K_{ow}	<i>n</i>	Range log values (SD)	Median log value	Mean log value (SE)
Chlorobenzene (BCF)	2.84	2	1.13–1.34 (0.15)	1.24	1.24 (0.11)
Chlorobenzene (BAF)	2.84	3	1.81–2.88 (0.55)	2.09	2.26 (0.32)
Lindane (BCF)	3.72	33	2.16–3.32 (0.35)	2.84	2.80 (0.06)
Lindane (BAF)	3.72	4	3.43–3.97 (0.25)	3.90	3.80 (0.13)
Hexachlorobenzene (BCF)	5.73	21	3.57–4.70 (0.32)	4.26	4.12 (0.07)
Hexachlorobenzene (BAF)	5.73	26	3.91–5.74 (0.48)	4.75	4.74 (0.09)
<i>p,p'</i> -DDT (BCF)	6.91	5	4.17–4.72 (0.27)	4.65	4.48 (0.12)
<i>p,p'</i> -DDT (BAF)	6.91	7	5.84–6.62 (0.27)	6.33	6.31 (0.10)
DEHP (BCF)	7.73	6	2.43–2.98 (0.18)	2.79	2.76 (0.07)
DEHP (BAF)	7.73	2	1.86–2.83 (0.69)	2.35	2.35 (0.49)

Note: *n*, number of observations; SD, standard deviation; SE, standard error of the mean; *p,p'*-DDT, 1,1-(2,2,2-trichloroethylidene)bis(4-chlorobenzene); DEHP, 1,2-Benzenedicarboxylic acid, bis(2-ethylhexyl) ester.

4) Uncertainties in assessing field-derived BAF values

- Historical background concentration is unknown.
- Bioavailability of the chemical depends on site-specific conditions (temperature, organic carbon content...)
- Influence of temporal and spatial factors (seasonality, geographical characteristics, etc.)
- Variation among species (diet, trophic position, habitat, metabolism, etc.)
- Variation in the status of individual organism (age, sex, reproductive stage, body size, lipid content, etc.).
- Difficulties in measurement of the chemical in the ambient medium when the concentration is extremely low (i.e. near the detection limit).
- Influence of combined exposure with other chemicals.

References:

Arnot, J.A. and Gobas, F.A.P.C (2006) Review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. *Environ. Rev.* 14:257-297.

Appendix 6: Octanol/air partition coefficient and bioaccumulation

1. Introduction

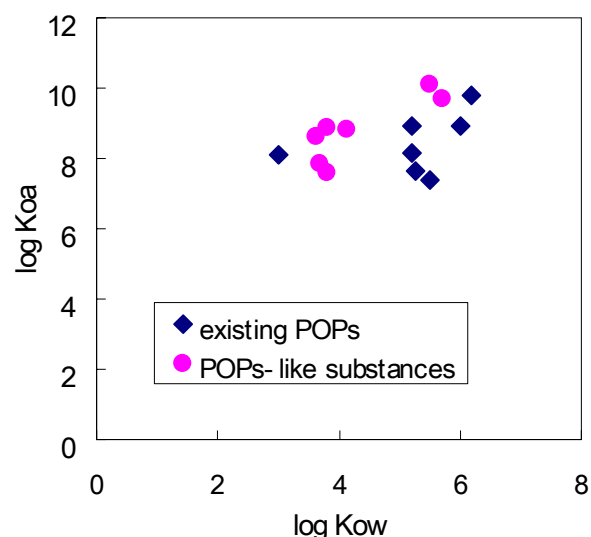
Since POP-like substances have the tendency to partition into lipid rather than water phase, the octanol-water partition coefficients (K_{ow}) have been used as an indicator of bioaccumulation potential. Chemicals with low K_{ow} have been judged to have low bioaccumulation potential in aquatic organisms because they are easily eliminated into the water. However, it was reported that for terrestrial organisms that breathe air instead of water, chemicals with high K_{oa} can have high bioaccumulation potential despite low K_{ow} values because they are not easily eliminated into the air.

2. Log K_{oa} and bioaccumulation

According to Kelly et al. (2007), substances with relatively low K_{ow} values such as HCH ($K_{ow}=10^{3.8}$), tetrachlorobenzenes ($K_{ow}=10^{4.1}$) and endosulfan ($K_{ow}=10^{3.8}$) which did not biomagnify in the aquatic food web showed a high degree of biomagnification in the terrestrial food web or in air-breathing organisms of the marine mammalian food web. Similar findings were also reported for PFOS ($K_{ow}<10^5$). This may be due to high K_{oa} ($\geq 10^6$) causing slow respiratory elimination coupled with not so low K_{ow} ($>10^2$) causing slow elimination in urine or nitrogenous wastes in air-breathing organisms.

The analysis by the same authors showed that air-breathing organisms exhibit higher BMFs than those in water-respiring organisms because of their greater ability to absorb and digest their diet, which is related to differences in digestive tract physiology and body temperature.

	log K_{ow}	log K_{oa}
<i>Aldrin</i>	3.01	8.08
<i>Dieldrin</i>	5.2	8.9
<i>Endrin</i>	5.2	8.13
<i>cis-Chlordane</i>	6	8.92
<i>p,p'-DDT</i>	6.19	9.82
<i>HCB</i>	5.5	7.38
<i>Heptachlor</i>	5.27	7.64
<i>Lindane</i>	3.7	7.85
α -HCH	3.81	7.61
β -HCH	3.8	8.88
δ -HCH	4.14	8.84
<i>Endosulfan</i>	3.62	8.64
<i>p,p'-DDE</i>	5.7	9.68
<i>p,p'-DDD</i>	5.5	10.1



Log K_{ow} and Log K_{oa} of existing POPs and POPs-like substances

3. Measurement of Koa

Shoeib et al. (2002) measured Koa of 19 organochlorine pesticides.

Nitrogen gas (flow rate: 200–300mL/min.) was saturated with octanol by sparging through a column approximately 20cm in height, and then passed through a cooling coil to an octanol trap to ensure condensation of excess octanol before reaching the generator column.

The cooling coil, octanol trap, and generator column were all submerged in a thermostat-controlled (± 0.1 °C) water bath that was always at least 10 °C cooler than the octanol used to saturate the gas stream.

The generator column consisted of glass beads coated with 300 μ l of the sample mixed octanol solution. Equilibrated gas-phase chemicals in the gas stream exiting the generator column were collected on an adsorbent trap, which contained approximately 20 g of C18-bonded silica.

Flow rates were measured at the outlet of the adsorbent trap to determine total sample volumes.

Traps were extracted with 15 ml of 50:50 hexane: dichloromethane (v/v) and then reduced in volume to approximately 500 μ l with a gentle stream of nitrogen. Concentrated extracts were analyzed using gas chromatograph.

4. Other information on Koa

Kelly et al. (2007) reported that Koa of the HCHs vary greatly among isomers. Values of log Koa relative to α -HCH (assigned a value of 1) are 19, 1.7, and 22 for β -, γ - and δ -HCH isomers, respectively. Also, logarithmic relationship was found between Koa and reciprocal of the absolute temperature.

References:

Kelly et al. (2007). Food-web specific biomagnification of persistent organic pollutants. *Science*, 317, 236-239.

Shoeib et al. (2002). Using measured octanol-air partition coefficients to explain environmental partitioning of organochlorine pesticides. *Environmental Toxicology and Chemistry*, Vol. 21, No. 5, 984–990.