UNITED NATIONS

UNEP

RC

UNEP/FAO/RC/CRC.6/INF/8

Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade

Distr.: General
1 February 2010

English only

Chemical Review Committee
Sixth meeting
Geneva, 15–19 March 2010
Item 5 (b) (iii) of the provisional agenda*

Listing of chemicals in Annex III to the Rotterdam Convention: review of notifications of final regulatory actions to ban or severely restrict a chemical: endosulfan

Risk profile on endosulfan

Note by the Secretariat

The annex to the present note contains a risk profile on endosulfan adopted by the Persistent Organic Pollutants Review Committee at its fifth meeting, in October 2009. The risk profile has been reproduced as received.

* UNEP/FAO/RC/CRC.6/1.

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Annex

ENDOSULFAN

RISK PROFILE

Adopted by the Persistent Organic Pollutants Review Committee
at its fifth meeting

October 2009

Annex

Table of Contents

Executive summary

Endosulfan is a synthetic organochlorine compound consisting of two isomers (α and β). It is commonly used as an agricultural insecticide. Technical endosulfan is a 2:1 to 7:3 mixture of the α- and β-isomers.

Endosulfan has been sold from the mid 1950s but it is now banned in at least 60 countries with former uses replaced and its production is decreasing. However, endosulfan is still used in different regions of the world.

Endosulfan aerobic transformation occurs via biologically mediated oxidation. The main metabolite formed is endosulfan sulfate. This compound is slowly degraded to the more polar metabolites endosulfan diol, endosulfan lactone, endosulfan ether. The combined median half-life DT_{50} measured in laboratory studies for α and β endosulfan and endosulfan sulfate, was selected as a relevant parameter for quantifying the persistence, it ranges typically between 28 and 391 days. In the aquatic compartment, endosulfan is stable to photolysis; a rapid hydrolysis is only observed at high pH values, and it is non-readily biodegradable. In water/sediment systems, DT_{50} > 120 d was demonstrated. There is a uncertainty on the degradation rate of endosulfan in the atmosphere, however it is expected that the half life exceeds the 2 days threshold.

The bioconcentration potential of endosulfan in aquatic organisms is confirmed by experimental data. The validated bioconcentration factor (BCF) values range between 1000 and 3000 for fish, from 12 to 600 for aquatic invertebrates; and up to 3278 in algae. Thus, reported BCFs are below the criterion of 5,000; and the log Kow is measured at 4.7, which is below the criterion of 5. However, ***measured BAF and BMF in Arctic organisms show*** that endosulfan has an inherent high ***bioaccumulation and*** biomagnification potential. Additionally, endosulfan was detected in adipose tissue and blood of animals in the Arctic and the Antarctic. Endosulfan has also been detected in the blubber of minke whales and in the liver of northern fulmars. Therefore, there is sufficient evidence that endosulfan enters the food chain and that it bioaccumulates and has the potential to biomagnify in food webs.

The potential of endosulfan for long range transport (LRT) has been confirmed from three main information sources: the analysis of the endosulfan properties, the application of LRT models, and the review of existing monitoring data in remote areas.

LRT has been confirmed by the presence of endosulfan in air and biota from remote areas. Most studies measure α- and β-endosulfan, and in some cases, endosulfan sulfate. Other endosulfan metabolites are only rarely quantified. The presence of endosulfan in remote areas, far away from intensive use areas, in particular, the Arctic and Antarctica has been confirmed. The potential for LRT, seems to be mostly related to ***volatilization following by*** atmospheric transfer; deposition at high altitude mountain areas has been also observed.

The toxicity and ecotoxicity of endosulfan is well documented. Endosulfan is highly toxic for humans and for most animal taxa, showing both acute and chronic effects at relatively low exposure levels. Acute lethal poisoning in humans and clear environmental effects on aquatic and terrestrial communities has been observed under standard use conditions when the risk mitigation measures have not been followed. Several countries have found that endosulfan poses unacceptable risks, or has caused unacceptable harm, to human health and the environment, and have banned or severely restricted it. However, the information on its genotoxicity and its potential for endocrine disruption is not fully conclusive. Finally, the role of endosulfan metabolites other than endosulfan sulfate has received limited attention. Endosulfan lactone has the same chronic NOEC value as the parent endosulfan isomers. ***The assessment of the POP characteristics of endosulfan, including endosulfan sulfate, confirms the concern regarding endosulfan and its main metabolite; it should be also considered that other metabolites, formed through both environmental and biota transformations, maintains the chemical structure and in some cases have significant toxicity.***

Based on the inherent properties, and given the widespread occurrence in environmental compartments and biota in remote areas, together with the uncertainty associated with the insufficiently understood role of the metabolites which maintain the endosulfan chemical structure, it is concluded that endosulfan is likely, as a result of its long-range environmental transport, to lead to significant adverse human health and environmental effects, such that global action is warranted.]

1. Introduction

Endosulfan is a synthetic organochlorine compound. It is commonly used as an agricultural insecticide. It has been sold from the mid 1950s and it is still contained in pesticide products in some countries worldwide. Technical information about (eco)toxicity, environmental fate, residues in food and feedstuff, environmental concentrations, etc. of endosulfan is widely available from different sources around the world. Various reviews have been published during the last decade regarding every aspect related to our environment.

1.1 Chemical identity

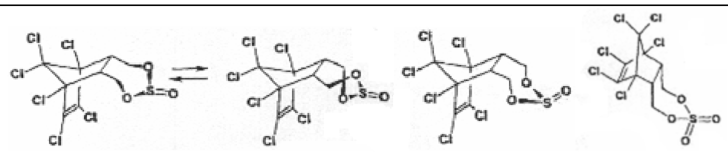
Names and registry numbers

Common name	Endosulfan	
IUPAC Chem. Abstracts	6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathiepin-3-oxide 6,9-methano-2,4,3-benzodioxathiepin-6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9-hexahydro-3-oxide	
CAS registry numbers	alpha (α) endosulfan	959-98-8
	beta (β) endosulfan	33213-65-9
	technical endosulfan *	115-29-7
	Endosulfan sulfate: * stereochemically unspecified	1031-07-8
Trade name	Thiodan® , Thionex, Endosan, Farmoz, Endosulfan, Callisulfan	

* Technical endosulfan is a 2:1 to 7:3 mixture of the α- and the β-isomer.

Technical grade endosulfan is a diastereomeric mixture of two biologically active isomers (α- and β-) in approximately 2:1 to 7:3 ratio, along with impurities and degradation products. The technical product must contain at least 94% endosulfan in accord with specifications of the Food and Agricultural Organization of the United Nations (FAO Specification 89/TC/S) with content of the α-isomer in the range of 64-67% and the β-isomer of 29-32%. The α-isomer is asymmetric and exists in two twist chair forms while the β-form is symmetric. The β-isomer is easily converted to α-endosulfan, but not vice versa (INIA, 1999).

Structures

Molecular formula	$C_9H_6Cl_6O_3S$	$C_9H_6Cl_6O_4S$
Molecular mass	406.96 g·mol^{-1}	422.96 g·mol^{-1}
Structural formulas of the isomers and the main transformation product	 α-endosulfan β-endosulfan endosulfan sulfate	

Physical and chemical properties of endosulfan isomers and of endosulfan sulfate

	α isomer	β isomer	Technical mixed isomers	sulfate
Melting point, ºC	109.2	213.3	70-124	181 - 201
Solubility in water pH 5, at 25ºC, mg/L	0.33	0.32	0.05-0.99 Recommended value: 0.5	0.22
Vapour Pressure, Pa, at 25ºC	1.05 E-03	1.38 E-04	2.27E-5 – 1.3E-3 Recommended value: 1.3E-3	2.3 E-05
Henry's Law Constant Pa m^3/mol, at 20ºC	1.1	0.2	1.09-13.2, recommended value: 1.06	0.041
logarithm of octanol-water partition coefficient (Log Kow) at pH 5.1	4.7	4.7	3.6	3.77
Dissociation constant	n.a. (no acidic protons)	n.a. (no acidic protons)	n.a. (no acidic protons)	n.a. (no acidic protons)

1.2 Conclusion of the Review Committee regarding Annex D information

The Committee evaluated Annex D information at its fourth meeting held in Geneva, from October 13th to 17th 2008, and decided that "it is satisfied that the screening criteria have been fulfilled for endosulfan" and concluded that "endosulfan met the screening criteria specified in Annex D".

1.3 Data sources

The primary source of information for the preparation of this risk profile was the proposal submitted by the European Community and its member States that are Parties to the Convention, contained in document UNEP/POPS/POPRC.4/14, and additional information submitted for Annex D evaluation. In particular:

- INIA 1999-2004. Monograph prepared in the context of the inclusion of the following active substance in Annex I of the Council Directive 91/414/EEC. Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (I.N.I.A.) including addenda.

In addition the following parties and observers have answered the October 2008 request for information specified in Annex E of the Convention: Albania, Australia, Bahrain, Bulgaria, Canada, China, Congo (RDC), Costa Rica, Croatia, Czech Republic, Ecuador, Egypt, Ghana, Honduras, Japan, Lithuania, Mali, Mauritius, Mexico, New Zealand, Nigeria, Norway, Romania, Slovakia, Switzerland, Togo, United States of America, Makteshim-Agan Industries (MAI), CropLife, Indian Chemical Council (ICC), Pesticide Action Network (PAN) International and the International POPs Elimination Network (IPEN). A more elaborated summary of the submissions is provided as separate informal document. *Summary of data submitted by Parties and observers for information specified in Annex E of the Convention.*

1.4 Status of the chemical under international conventions

Endosulfan is subject to a number of regulations and action plans:

- In March 2007 the Chemical Review Committee (CRC) of Rotterdam Convention on the Prior Informed Consent Procedure (PIC) for Certain Hazardous Chemicals and Pesticides in International Trade decided to forward to the conference of the parties of the Convention (COP) a recommendation for inclusion of endosulfan in Annex III. Annex III is the list of chemicals that are subject to the PIC procedure. Listing in Annex III is based on two notifications from different regions of regulatory action banning or severely restricting the use for health or environmental reasons that were found to meet the criteria listed in Annex II of the Convention. The COP in 2008 was not yet able to reach consensus on inclusion of endosulfan and decided to further consider the draft decision at the next COP. Meanwhile, the CRC has been evaluating further notifications of endosulfan.
- Endosulfan is recognized as one of the twenty-one high-priority compounds identified by UNEP-GEF (United Nations Environment Programme – Global Environment Facility) during the Regional Evaluation of Persistent Toxic Substances (STP), 2002. These reports have taken into account the magnitude of usage, environmental levels and effects for human beings and for the environment of this compound.
- The Sahelian Pesticides Committee (CSP) has banned all formulations containing endosulfan. The CSP is the structure for the approval of pesticides for CILSS member States (Burkina Faso, Cap Verde, Chad, Gambia, Guinea Bissau, Mali, Mauritania, Niger and Senegal). The deadline set for termination of the use of existing stocks of endosulfan was 31/12/2008.
- The UN-ECE (United Nations Economic Commission for Europe) has included endosulfan in Annex II of the Draft Protocol on Pollutant Release and Transfer Registers to the AARHUS Convention on access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters.
- UN-ECE task force concluded in June 2009 that endosulfan should be considered as POP. UNECE (2009)
- The OSPAR Commission has included endosulfan in the List of Chemicals for Priority Action (update 2002)
- In the Third North Sea Conference (Annex 1A to the Hague Declaration), endosulfan was agreed on the list of priority substances.

2. Summary information relevant to the risk profile

2.1 Sources

2.1.1 Production, trade, stockpiles

Endosulfan is synthesized via the following steps: Diels-Alder addition of hexachloro-cyclopentadiene and cis-butene-1,4-diol in xylene. Reaction of this cis-diol with thionyl chloride forms the final product.

Endosulfan was developed in the early 1950s. Global production of endosulfan was estimated to be 10,000 tonnes annually in 1984. Current production is judged to be significantly higher than in 1984. India is regarded as being the world's largest producer (9900 tonnes per year (Government of India 2001-2007)) and exporter (4104 tonnes in 2007-08 to 31 countries (Government of India)); followed by Germany (approximately 4000 tonnes per year); Production stopped at 2007 but export could continue until the end of 2010); China (2400 tonnes), Israel, Brazil and South Korea.

2.1.2 Uses

Endosulfan is an insecticide used to control chewing, sucking and boring insects, including aphids, thrips, beetles, foliar feeding caterpillars, mites, borers, cutworms, bollworms, bugs, white fliers, leafhoppers, snails in rice paddies, earthworms in turf, and tsetse flies.

Endosulfan is used on a very wide range of crops. Major crops to which it is applied include soy, cotton, rice, and tea. Other crops include vegetables, fruit, nuts, berries, grapes, cereals, pulses, corn, oilseeds, potatoes, coffee, mushrooms, olives, hops, sorghum, tobacco, and cacao. It is used on ornamentals and forest trees, and has been used in the past as an industrial and domestic wood preservative.

As recently as 2006 the US EPA has approved and registered the use of Endosulfan as a veterinary insecticide to control ectoparasites both in beef and lactating cattle. It is used as an ear tag in cattle.

The use of Endosulfan is now banned in at least 60 countries[1] with former uses replaced by less hazardous products and methods. More detailed information on current uses as informed by countries is provided as separate informal document. *Summary of data submitted by Parties and observers for information specified in Annex E of the Convention.*

Other countries are using of Endosulfan, including USA, Australia, Argentina, Brazil, Cameroon, Canada, Chile, Costa Rica, Ghana, Guatamala, India, Iran, Israel, Kenya, Madagascar, Mali, Mexico, Mozambique, China, Paraguay, Pakistan, Sierra Leone, South Africa, South Korea, Sudan, Tanzania, Uganda, Venezuela, Zambia, Zimbabwe.

Endosulfan is widely used in India for the last several years.

2.1.3 Releases to the environment

As a result of the use of endosulfan as an insecticide, endosulfan is released to the environment. No natural sources of the compound are known. From the manufacturing and formulation operations, local scale environmental releases to the air, waste water, or surface waters may also occur.

Global usage and emission of endosulfan, and the relationship between global emissions and the air concentration of endosulfan in the Canadian Arctic were reported in Li and MacDonald (2005). Cumulative global use of endosulfan for crops is estimated to be 338,000 tonnes. The average annual endosulfan usage in the world is estimated to have been 10,500 tonnes from 1980 to 1989 and 12,800 tonnes from 1990 to 1999. The general trend of total global endosulfan use increased continuously since the first year this pesticide was applied until at least the late 1990s. No recent figures, updated after the recent banning in at least 60 countries, are available. India is the world's largest consumer of endosulfan with a total use of 113,000 tonnes from 1958 to 2000. Total global endosulfan emissions have also increased continuously since the year when this pesticide was first applied presently amounting to an estimated total emission around 150,000 tonnes. Recent data on endosulfan usage and emissions in China indicate a total endosulfan usage of 24,000 t in the period from 1994 to 2004 and total endosulfan emissions of 1100 t (Jia et al. 2009a, 2009b). From 1998 to 2004, usage was about 2700 t/a and emissions were 1250 t/y; before 1998, values were lower.

A time trend of α-endosulfan air concentration at Alert, Canada between 1987 and 1997 (Li and MacDonald (2005)), compiled from several sources (Patton et al., 1989, Halsall et al., 1998 and Hung et al., 2002), shows this to be one of the few organochlorine pesticides with concentrations that were stable or were increasing slightly in Arctic air over the 1987-1997 time period. The data for emissions of α-endosulfan exhibit high variability but demonstrate a generally increasing trend at least up until the late 1990s. Canadian Arctic air sampling data similarly exhibits high variability but the few available data are not inconsistent with the emission data, suggesting the atmosphere is an important transporting medium. More recently, the long-term trend of endosulfan in arctic air - derived using Digital Filtration, a statistical time-series model that filters out regular seasonal fluctuations to reveal the underlying trend - does not show a decline over the period 1993 to 2006, unlike other OC pesticides (e.g.,γ-HCH and p,p'-DDT) (Hung et al., 2009).

1 Austria, Bahrain, Belgium, Belize, Benin, Bulgaria, Burkina Faso, Cambodia, Cape Verde,Chad, Colombia, Cote d'Ivoire, Croatia, Cyprus, Czech Republic, Denmark, Egypt, Estonia, Finland, France, Gambia, Germany, Greece, Guinea Bissau, Hungary, Indonesia, Ireland, Italy, Jordan, Kuwait, Latvia, Lithuania, Liechtenstein, Luxembourg, Malaysia, Mali, Malta, Mauritania, Mauritius, Netherlands, New Zealand, Niger, Nigeria, Norway, Oman, Poland, Portugal, Qatar, Romania, Saudi Arabia, Senegal, Singapore, Slovakia, Slovenia, Spain, Sri Lanka, St Lucia, Sweden, Switzerland, Syria, the United Arab Emirates, United Kingdom.

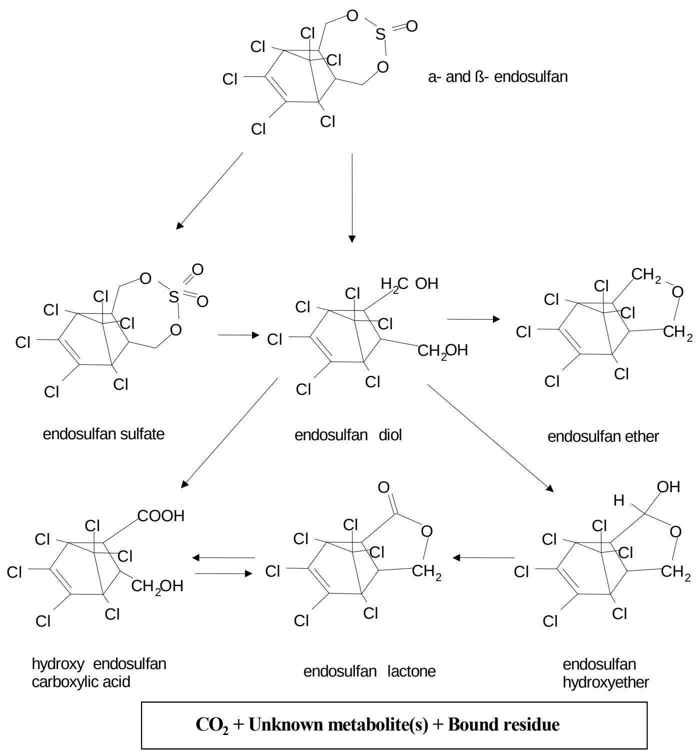
2.2 Environmental fate

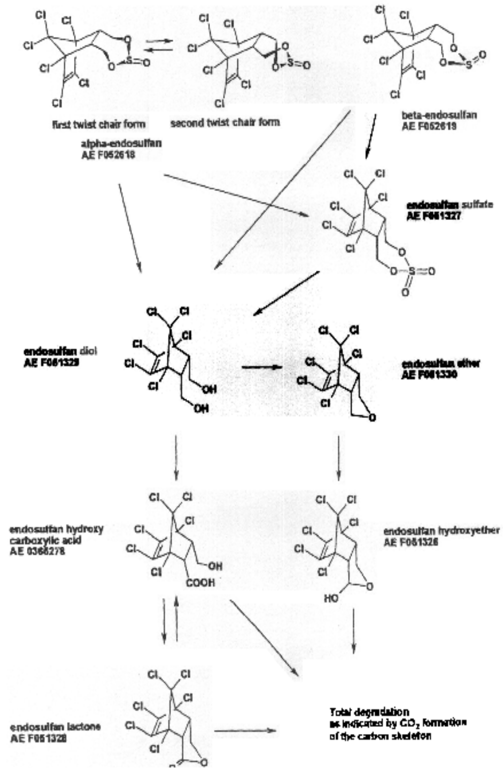
2.2.1 Persistence

Endosulfan aerobic transformation occurs via biologically mediated oxidation. The main metabolite formed is endosulfan sulfate. This compound is slowly degraded to the more polar metabolites endosulfan diol, endosulfan lactone, endosulfan ether. Formation of endosulfan sulfate is mediated essentially by micro-organisms, while endosulfan-diol was found to be the major hydrolysis product. Microbial mineralisation to carbon dioxide under laboratory conditions at 20ºC was 1.01 – 13.08% after 100 days for the parent endosulfan and for endosulfan sulphate 1.01 – 13.08% at 120 days and 5 – 35% at 365 days is in a range of depending on the type of soil..

Endosulfan sulfate also has insecticidal activity. Given the comparable toxicity of the sulfate metabolite a number of authors make use of the term "endosulfan (sum)" which includes the combined residues of both parent isomers and endosulfan sulfate. However, this term does not consider that in reality all the metabolites of endosulfan retain the backbone of the structure with the hexachloronorbornene bicycle.

The following degradation patterns for soil (right figure) and water (left figure) are proposed in the European Union risk assessment. In both cases, the parent isomers are transformed in endosulfan diol, either directly or through endosulfan sulfate. Endosulfan diol is then degradated into a set of related metabolites, including endosulfan ether, endosulfan hydroxyether, endosulfan carboxylic acid, and endosulfan lactone.





This environmental fate complicates the assessment of persistence as DT_{50} values. Most studies suggest that α-endosulfan has a faster degradation than β-endosulfan, and that endosulfan sulfate is much more persistent (INIA, 1999-2004). There is high variability in the reported DT_{50} values for these substances. The aerobic soil degradation studies reported in the EU assessment covered a range of soil types (sandy loam, loamy sand, clay and silt loam soils, pH ranging from 4.7 to 7.4, organic carbon ranging from 0.5 to 2.9%, and between 30 and 50% maximum water holding capacity) and were conducted following the USEPA or the Biologische Bundesanstalt (BBA) guidelines at 20ºC., The reported DT_{50} for aerobic soil degradation under laboratory conditions, ranged from 25 to 128 days for the α + β isomers, and from 123 to 391 days for endosulfan sulfate. The rapid field dissipation of endosulfan following its application under normal conditions is mostly related to volatilisation and varies largely; the European Union assessment reported, for the temperate regions, field DT_{50s} ranging from 7.4 to 92 days for the α + β isomers. A fast dissipation has been observed for tropical climates; volatilization, particularly for the α and β isomers, is considered the major process for endosulfan dissipation in tropical environments (Ciglasch et al., 2006; Chowdhury et al., 2007). In field studies conducted in India, the reported dissipation half lives ranged from 3 days (isomer not reported) (Raikwar, et al., 2003) to 100 and 150 days for α- and β-endosulfan respectively (Jayashree and Vasudevan 2007). Field aging increases the persistence in soil and is particularly relevant for endosulfan, with a 3-fold increase in the apparent organic carbon partition coefficient K_{OC} within 84 days in a tropical fruit orchard under natural weather conditions (Ciglasch et al., 2008).

At POPRC 4, the combined DT_{50} measured in laboratory studies for α and β endosulfan and endosulfan sulfate, was selected as a relevant parameter for quantifying the persistence of endosulfan. A large variability in the rate of this degradation has been observed. The estimated combined half-life in soil for endosulfan (α, β isomers and endosulfan sulfate) ranges typically between 28 and 391 days; but higher and lower values are reported in the literature under specific conditions.

In the aquatic compartment, endosulfan is stable to photolysis. A rapid hydrolysis is only observed at high pH values, and it is non-readily biodegradable. In water/sediment systems (Jones, 2002; 2003 reported in the EU dossier) DT_{50}s for the alpha, beta isomers and endosulfan sulfate ranging between 3.3 and 273 days, were presented. These specific values were not validated but DT_{50} > 120 d was demonstrated. Endosulfan diol, maximum 63.5%, and under acidic conditions (pH= 4.5 in water and 4.9 in sediment) endosulfan lactone, maximum 14.8%, were also observed.

There is a high uncertainty regarding the degradation rate of endosulfan in the atmosphere. Buerkle (2003) has presented a set of estimations based on Structure Activity Relationship and experimental values. A half life estimation in atmosphere using the Atkinson method was conducted in 1991, resulting in a value of 8.5 d. Experimental figures are presented for α-endosulfan (27 d at 75ºC for gas phase reaction with OH radicals generated by flash photolysis) and β-endosulfan (15 d based on the reaction with OH radicals in liquid Freon-113). The AOPWIN calculation method indicates a half life of 47.1 hours assuming a constant diurnal OH concentration of 5 x10^5 cm^{-3}. It should be noted that for complex molecules like endosulfan, AOPWIN tends to under estimate the atmospheric half-life according to OH radical degradation (Atkinson et al., 1999)

It is concluded that, considering endosulfan and its related transformation products, the persistence of endosulfan in soil, sediments and air is confirmed.

2.2.2 Bioaccumulation

Three complementary sources of information have been analysed for assessing the bioaccumulation and biomagnification potential of endosulfan and its degradation products: the screening assessment based on physical-chemical properties, the analysis of experimental data, including bioconcentration, bioaccumulation and toxicokinetic studies, and the analysis of field collected information. The key elements of these assessments are presented below.

Screening assessment based on physical-chemical properties

The reported log K_{ow} for α- and β-isomers and endosulfan sulfate range between 3 and 4.8. New studies (Muehlberger and Lemke 2004) using the HPLC-method indicates a log K_{ow} of 4.65 for α-endosulfan, 4.34 for β-endosulfan and 3.77 for endosulfan sulfate. The other metabolites included in the K_{ow} determination have lower K_{ow} than endosulfan sulfate. These values indicate potential for bioconcentration in aquatic organisms, although they are below the screening trigger of 5 for the Stockholm Convention.

Recently, the role of the octanol/air partition coefficient (K_{oa}) for the screening assessment of the biomagnification potential of POPs in terrestrial food chains is receiving significant attention. Kelly & Gobas (2003) and Kelly *et al.* (2007) have proposed that the biomagnification of endosulfan in the terrestrial food chain is particularly relevant, because it has a high log K_{oa}. A high K_{oa} causes slow respiratory elimination. The proposed log K_{oa} for α- and β-endosulfan is 10.29; and for endosulfan sulfate is 5.18. Although there are no specific screening thresholds for the K_{oa} the authors suggests that chemicals with a log K_{ow} higher than 2 and a log K_{oa} higher than 6 have an inherent biomagnification potential in air-breathing organisms of terrestrial, marine mammalian, and human food chains provided that chemical metabolic transformation rates are not extensive. Endosulfan α- and β isomers clearly fall within this category; its primary metabolite endosulfan sulfate is very close. However, reservation ***was made by a few members*** on the use of log K_{oa} values for the purpose of biomagnification assessment ***as it was their view that*** this parameter is not included in the convention.

Bioconcentration and bioaccumulation studies in aquatic organisms

The reported BCF values for fish ranged from approximately 20 to 11,600 (L kg^{-1} wet wt.); however, the 11,600 value (Johnson and Toledo, 1993) is considered of low reliability because the elimination half-life derived from K2 is not consistent with observed data and therefore the Kinetic-based BCF is questionable. A 21-d BCF (ratio method) of 5670 is calculated based on total endosulfan (α, β, sulfate). A BCF of 5,670 has been proposed from the US-EPA re-evaluation of this study, but the uncertainty is still high and the data should not be considered as reliable. The USEPA re-evaluated in 2007 the bioconcentration studies (U.S.EPA 2007). The two highest quality studies indicate that the BCF range for fish is 1,000 (striped mullet; Schimmel et al. 1977) to 3,000 (sheepshead minnow; Hansen and Cripe 1991). Depuration half-lives in fish for α- and β-endosulfan and endosulfan sulfate were 2–6 days. Bioconcentration studies were available for five species of invertebrates in which BCF ranged from 12 to 600. An average BCF of 2,682 and 3,278 (dry weight) was determined for freshwater green algae and *Daphnia magna*, respectively (DeLorenzo et al. 2002). It should be noted that *D. magna* neonates accumulated little endosulfan when exposed via the ingestion of contaminated phytoplankton.

Weber et al. (2009) have published new information for Arctic food chains. Bioaccumulation factors (BAFs) and biomagnifications (BMFs) was limited to endosulfan results determined by GC-MS only, to avoid uncertainties associated with different analytical techniques (e.g. GC-ECD vs GC-MS). BAFs for endosulfan were estimated using concentrations measured by GC-MS in Arctic char, salmon, arctic cod, ringed seals and beluga coupled with concentrations measured in seawater or lake water (char). Wet weight BAF (ww) values for sum-endosulfan in char, cod, and salmon ranged from 1690 to 7280. Given the uncertainty of endosulfan measurements at low levels in biota and the possible spatial and temporal variation in water concentrations of endosulfan species, these BAFs should be viewed with caution. However, it is appropriate to evaluate the BAFs based on the sum-endosulfan concentrations since some of the body burden in these biota could be due to biotransformation to endosulfan sulfate. The average BAFwws for sum-endosulfan in 3 species of fish (4080) do not exceed the 5000 criteria, however, BAFs for sum-endosulfan based on concentrations in beluga and ringed seal blubber (where BAFlw=BAFww) averaged 3.95×10^5. These elevated BAFs are mainly due to high β-endosulfan reported by Kelly (2005).

BMFs in selected predator/prey species are based on results from Kelly (2005) and Kelly et al. (2007) as these were the only published data for endosulfan in marine mammals based on GC-MS analysis. BMFs > 1 were apparent for sum-Endosulfan for beluga (Delphinaterus leucas) preying on arctic cod (Arctogadus glacialus) and on salmon (Salmo sp), resulting in an overall mean BMF of 1.5 for fish to marine mammals.

The assessment of parent and metabolite bioconcentration is particularly relevant. The study by Pennington et al., (2004) offers a good example of the complexity of these estimations. Oysters were exposed to endosulfan in an estuarine mesocosm for 96h. Within this short exposure period, a significant bioaccumulation of α- and β-endosulfan in oysters is observed, but the quantification, even under mesocosm controlled conditions, is very different depending on how the water and organisms concentrations are compared. The authors suggest BCF values between 375 and 1766 (dry weight) for total (α-, β- and endosulfan sulfate). An outdoor aquatic microcosms study has been presented in the CropLife dossier (Schanne, 2002). The study was conducted outdoors in order to simulate the conditions in natural systems as closely as possible. For that purpose, sediment, water and other biota were collected from a large, shallow water natural reserve area of the Austrian side of Lake Constance. Concentrations of radio-labelled endosulfan lactone, and two unknown metabolites, M1 and M4, in water increased constantly during the study, whereas endosulfan sulfate was more or less constant at a low level or slightly decreasing at both entry routes. The total radioactive sediment residue was increasing during the study to maximum 13.8 µg radioactivity equivalents/kg. The total radioactive residue in macrophytes increased with time reaching a maximum of 2236 µg radioactivity equivalents kg^{-1} fresh weight. Like for macrophytes, the total radioactive residue in surviving fish reached a maximum of 3960 µg radioactivity equivalents kg^{-1} fresh weight.

This study clearly demonstrates that endosulfan is found in the sediment, fish and macrophytes up to study termination and is also degraded to metabolites that maintain the chlorinated cyclic structure of endosulfan. These metabolites have the potential to bioaccumulate in fish and macrophytes, and some of them have demonstrated their potential for persistence in the environment. In addition to this, the study reveals that there are other unknown metabolites with the same potential for bioaccumulation. The bioaccumulation factors (BAF) for spray-drift and run-off routes were estimated as: BAF total radioactivity ca.1000; BAF endosulfan-sulfate 4600-5000 (spray-drift). It should be noted that these BAFs should be taken with care as the tested concentrations provoked clear effects on aquatic organisms or were too close to toxic concentrations; therefore, the estimated bioaccumulation potential could be different to that expected due to the toxic effects of the tested concentrations.

Toxicokinetic and metabolism studies

Following oral administration of endosulfan, either via single oral dose or dietary administration, elimination of the parent compound and its metabolites is extensive and relatively rapid in a range of species of experimental animals. The metabolites of endosulfan include endosulfan sulfate, diol, hydroxy-ether, ether, and lactone.

A physiologically based pharmacokinetic model for endosulfan metabolism in the male Sprague-Dawley rats has been developed by Chan et al. (2006). Recently, the accumulation and elimination kinetics of dietary endosulfan in Atlantic salmon has been published (Berntssen et al., 2008). Dietary β-endosulfan showed a higher biomagnification factor (BMF) (0.10 ± 0.026 vs. 0.05 ± 0.003, $p<0.05$) than α-endosulfan, with higher uptake ($41\pm8\%$ vs. $21\pm2\%$) and lower elimination ($26\pm2 \times 10^{-3}$ day^{-1} vs. $40\pm1 \times 10^{-3}$ day^{-1}) rate constants,. Endosulfan sulphate levels remained unchanged during the depuration period, whereas the parental isoforms were rapidly eliminated. Based on the decrease in diastereomeric factor over time, biotransformation was estimated to account for at least 50% of the endosulfan elimination. The formation of the metabolite endosulfan sulfate comprised a maximum 1.2% of the total accumulation of endosulfan. No other metabolites were measured, and therefore a BMF for endosulfan plus all metabolites cannot be estimated from this study.

Assessment of field data and biomagnification models

A large number of studies offering information on measured levels of endosulfan in biota all over the world are available. Endosulfan and its metabolite endosulfan sulfate are frequently found in crops and in the vicinity of treated sites, as well as in remote areas where the presence of this pesticide must result from medium and long range transport from those areas in which endosulfan has been used.

Quantitative estimates of biomagnification can be obtained through the use of mathematical models calibrated with field data (Alonso et al., 2008). Several published models indicate the potential biomagnification of endosulfan through the food chain. A model of the lichen-caribou-wolf food chain predicts biomagnification of β-endosulfan. The BMFs for wolf range from 5.3 to 39.8 for 1.5 to 13.1 year old wolves (Kelly et al. 2003).

A particularly relevant piece of information was published in 2007 (Kelly et al., 2007). The model predicts a significant BMF for β-endosulfan in air-breathing species, ranging from 2.5 for terrestrial herbivores to 28 for terrestrial carnivores; and BMF below 1 for water-respiring organisms.

Also in the Canadian Arctic concentrations of α-, and β-endosulfan and endosulfan sulfate in ice-algae, phytoplankton, zooplankton, marine fish and ringed seal have been presented. Concentrations ranged from 0.1 – 2.5 ng g^{-1} lipid. Calculated trophic magnification factors were less than 1, suggesting no biomagnification in the ringed seal food chain (Morris et al. 2008). However a trophic magnification factor >1 was calculated for the Southern Beaufort Sea and Amundsen Gulf food webs if marine mammals are included in the food web (Mackay & Arnold (2005).

The comparison of reported concentrations of endosulfan in biota, and particularly in top predators, with those observed in the same organisms and ecosystems for other POPs, also offer indirect indications of bioaccumulation potential. Although the numerical BCF threshold is not exceeded in the standard laboratory studies, there is information demonstrating that the bioaccumulation potential of endosulfan exists.

2.2.3 Potential for long-range environmental transport

The potential of endosulfan for long range transport can be evaluated from three main information sources the analysis of the endosulfan properties, the application of LRT models, and the review of existing monitoring data in remote areas.

Screening of physical-chemical properties

There is enough information on the volatility of α and β endosulfan to support the potential for atmospheric transport. Atmospheric transport over long distances requires a minimum level of persistence in the atmosphere; as presented above, there is uncertainty on the real degradation rate of endosulfan in the atmosphere but the threshold half life of 2 days seems to be exceeded. Taking into account the much lower temperatures of the troposphere, the environmental half-life of endosulfan under real situations is likely to be even longer. Therefore, it should be concluded that the combination of volatility and sufficient atmospheric persistence results in a significant potential for long range transport.

LRT model predictions

Several models have been developed for estimating this potential according to the characteristics of the POP candidates. Becker, Schenker and Scheringer (ETH, 2009 Swiss submitted information) have estimated the overall persistence (POV) and LRT potential (LRTP) of α- and β-endosulfan and two of their transformation products, endosulfan sulfate and endosulfan diol with two multimedia box models, the OECD POV and LRTP Screening Tool and the global, latitudinally resolved model CliMoChem. The OECD Tool yields POV and LRTP for each compound separately, whereas the CliMoChem model calculates the environmental distribution of the parent compounds and the formation and distribution of the transformation products simultaneously. Results from the CliMoChem model show that POV and LRTP of the endosulfan substance family (α, β and sulfate) are similar to those of acknowledged POPs, such as aldrin, DDT, and heptachlor. The results also show that POV and LRTP of the substance family, i.e. including the transformation product, are significantly higher than those of the parent isomers alone (430 d compared to 33 d (α-endosulfan individually) and 65 d (β-endosulfan individually) Becker et al. (2009)). Additional results obtained with the CliMoChem model (Scheringer et al. 2000) indicate that all latitudinal zones in the Northern hemisphere contribute to the presence of endosulfan found in the Arctic but with different shares. The contribution of the tropical region (0–20 °N) is approximately 2%, whereas this region accounts for 12% of the endosulfan emissions in 2000. The northern temperature zone (40–70 °N) contributes about 60% of the endosulfan found in the Arctic but represents only 16% of the emissions. The northern subtropical region (20–40°N), finally, has similar shares of emissions and contribution to endosulfan in the Arctic (35%). However, this model has not been validated for endosulfan ***specifically but for other comparable molecules, and one member is of the view that*** the predicted values may not be realistic.

The US (USEPA 2007) concludes that recent studies suggest that desorbed residues of endosulfan volatilize and continue to recycle in the global system through a process of migration and re-deposited via wet and dry depositions as well as air-water exchange in the northern hemisphere. Dust dispersion and translocation also contribute endosulfan into the atmosphere as adsorbed phase onto suspended particulate matter, but this process does not appear to be a major contributor like volatilization. Transport of endosulfan in solution and sediment bound residues also can potentially contribute in the long-range and regional distributions of endosulfan.

Brown and Wania (2008) have recently published a model based on two parallel screening methodologies: one methodology screens chemicals based on substance properties and the other screens chemicals based on a structural profile of known Arctic contaminants. According to the model, endosulfan was found to have high Arctic contamination and bioaccumulation potential and matched the structural profile for known Arctic contaminants. These results are in agreement with the empirical estimations of Arctic contamination potential reviewed by Muir et al (2004) which concluded that endosulfan is subject to LRT as predicted by models and confirmed by environmental measurements.

Confirmation based on measures in remote areas

This potential has been confirmed by monitoring data; there is a significant amount of information as endosulfan has been measured in combination with other organochlorine insecticides. Several publications indicate the potential for long-range transport of endosulfan residues, and report findings of endosulfan in the Arctic at increasing levels in water, air and biota.

2.3 Exposure

2.3.1 Environmental monitoring data

Although endosulfan has only recently been included in formal POP monitoring programs, the chemical is frequently measured in studies on organochlorine pesticides, and therefore there is abundant but highly variable information on measured levels of endosulfan in environmental samples. Most studies include α- and β-endosulfan, and in some cases, endosulfan sulfate is also measured. Other endosulfan metabolites are only rarely quantified. The information has been compiled in three main categories:

- Medium range transport: Collects the information in untreated areas in the vicinity of areas for which endosulfan has been used or has been potentially used (areas with intensive agricultural activity).
- Potential for long range transport: Collects information in areas at significant distance from use areas, where the presence of endosulfan can only be explained by atmospheric transfer and deposition; includes high altitude mountain areas.
- Long range transport: Collects information in remote areas, far away from intensive use areas, in particular, the Arctic and the Antarctic.

A summary of relevant monitoring values is presented below. This summary is mostly based on the recent reviews by the European Communities and the USA submitted within their information dossiers, and completed by additional information presented by other parties/observers and the review of recent literature data.

POTENTIAL FOR LONG-RANGE TRANSPORT: MOUNTAINOUS REGIONS

The effect of "global distillation" is believed to account for transport of POPs whereby a compound volatilizes from warmer regions, undergoes long-range atmospheric transport, and subsequently re-condenses to an accumulation of these substances in the temperate, higher mountainous and Arctic regions. Wania and Mackay (1993) suggested that, through "global distillation" organic compounds could become latitudinally fractionated, "condensing" at different temperatures according to their volatility, so that compounds with relative low vapour pressures might accumulate preferentially in polar regions. Endosulfan was found in the atmosphere of European mountain areas (Central Pyrenees and High Tathras). Like hexachlorocyclohexane (HCH), endosulfan was found in higher concentrations in the warm periods (4-10 pg m^{-3}) in both the gasand particulate phase, reflecting its seasonal use pattern (van Drooge et al. 2004). Endosulfan was found, along with many other POP substances, in snowpack samples collected at different altitudes of mountains on western Canada. The levels of contaminants in snow and in snowpack increased with the altitude, showing a 60-100 fold increase in net deposition rates of contaminants to snowpack over a 2300 meter rise in elevation (Blais et al., 1998). The concentration range of α-endosulfan was 0.06–0.5 ng L^{-1} in the sampling altitude range of 700 – 3,100 m. Aerial transport also caused contamination of snow (Sequoia National Park) and water (Lake Tahoe basin) of the Sierra Nevada Mountains in California, a region adjacent to California's Central Valley which is among the heaviest pesticide use areas in the U.S. Levels of α-endosulfan found in rain were in a range of < 0.0035 ng L^{-1} to 6.5 ng L^{-1} while β-endosulfan was measured at concentrations of < 0.012 ng L^{-1} up to 1.4 ng L^{-1} McConnell et al. (1998). ***In 1997, LeNoir et al. (1999) reported concentrations of endosulfan (sum of alpha and beta isomers) measured in remote lakes of Sequoia National Park of California's Sierra Nevada Mountains. Specifically, concentrations in 3 lakes at elevations between 2,000 and 3,300 meters ranged from 1.3 to 120.3 ng/L. The maximum level (120 ng/L) levels exceed the chronic NOAEC for freshwater fish of 56 ng/L (Dionne 2002).*** Concentrations of 71.1 pg m^{-3} of α-endosulfan were measured in the Himalayas; backward trajectory analysis indicted that it arrived there from the Indian subcontinent on westerly winds, driven by the Asian monsoon (Li et al 2006).

However, ***one member is of the view that*** it is not clear whether some finger printing or source apportionment studies were carried out to reach this conclusion.

For mountain lakes in the Alps, Pyrenees (Estany Redò) and Caledonian Mountains (Øvre Neådalsvatn (Norway)), atmospheric deposition of endosulfan was estimated between 0.2 and 340 ng m^{-2} per month (Carrera et al., 2002). Unlike other chemicals, endosulfan showed a more uniform geographical distribution, the lakes in the South were much more exposed to endosulfan impact, reflecting the impact of agricultural activities in southern Europe. In the northern lakes only the more persistent endosulfan sulfate was measured. Endosulfan sulfate concentrations were 1000, 92 and 120 pg L^{-1} in the Pyrenees, Alps and Caledonian mountains respectively (Vilanova et al. 2001).

LONG-RANGE TRANSPORT: POLAR REGIONS

The US review summarizes information by GFEA (2007); Ngabe and Bidleman 2001, and Endosulfan Task Force (ETF) report MRID 467343-01.

Long range atmospheric transport of α- and β-endosulfan to the Arctic was first reported in 1986 (Patton et al. 1989). A "brown snow" event occurred in the central Canadian Arctic during the year 1988. The snow was coloured by dust that appeared to be transported from Asia. Endosulfan was detected in the dust at a maximum concentration of 22 pg L^{-1}. Since then endosulfan has been routinely found in the Canadian Arctic air monitoring program, from 1993 up to the present (Halsall et al., 1998; Hung et al., 2001). Extensive monitoring data on endosulfan from the Arctic are available for the atmosphere, snowpack, surface water and biota (Bidleman et al., 1992; De Wit *et al*., 2002; Halsall et al., 1998; Hobbs *et al*, 2003; Jantunen and Bidleman, 1998).

Long-range transport: Arctic Air

Endosulfan was reported as a widely distributed pesticide in the atmosphere of northern polar region. Unlike for most other organochlorine pesticides, the concentrations of which have declined average concentrations of endosulfan in the Arctic did not change significantly during the last 1990s (Meaking, 2000). Concentrations of α-endosulfan from Arctic air monitoring stations increased from early to mid-1993 and remained at roughly 0.0042-0.0047 ng m^{-3} through to the end of 1997. No clear temporal trends of endosulfan concentrations in the arctic atmosphere were observed (Hung et al., 2002). Measurements taken in air at Alert in Nunavut, Canada resulted in annual average concentrations between 3 and 6 pg m^{-3} during 1993 to 1997. Fluctuating values mirror the seasonal applications in source regions.

Concentrations of endosulfan in Arctic air were found to be exceeded only by those of ΣHCH-isomers and hexachlorobenzene (HCB) (Halsall et al., 1998). In comparison to monitored concentrations in the Great Lakes region, atmospheric levels in the Arctic were less dependent on temperature, although seasonal variations were apparent as well. For example α-endosulfan concentrations ranged by a factor of 3-5 from spring to fall periods. This infers a more blurred bimodal seasonal cycle with growing distance from areas of application. Hung et al. (2002) used temperature normalization, multiple linear regression, and digital filtration to analyze the temporal trends of an atmospheric dataset on organochlorine pesticides collected at the Canadian high Arctic site of Alert, Nunavut.

Seasonal variation of concentrations was also reported from Sable Island (240 km east of Nova Scotia, Canada, at 43°57´N, 60°00´W). In summer, aerial endosulfan concentrations (α- and β-isomers) were determined between 69 and 159 ng m^{-3} while for wintertime values dropped to 1.4-3.0 pg m^{-3} (only α–isomer) (Bidleman et al., 1992).

Similar data on α-endosulfan have been reported from Resolute Bay (Cornwallis Island, 75 N lat.) where air concentrations of approximately 4 pg m^{-3} have been measured (Bidleman et al., 1995) and from air samples taken on an iceberg that calved off the Ward Hunt Ice Shelf on the northern shore of Ellesmere Island, Canada, (approx. 81°N, 100°W). Mean concentration of α-endosulfan in summer 1986 and 1987 were 7.1 and 3.4 ng m^{-3}, respectively (Patton et al., 1989). Additional evidence for airborne long-range transport is provided by data from Newfoundland showing mean concentrations of 20 pg m^{-3} in summer 1977 (Bidleman et al., 1981).

Further air concentrations of endosulfan were reported from Amerma (eastern Arctic region of Russia) between 1–10 pg m^{-3} (De Wit et al., 2002; Konoplev et al., 2002). Endosulfan was detected in around 90% of all samples displaying a significant correlation with atmospheric temperature. Unlike other organochlorines where seasonal enhancements are hypothesized to be due to (re)volatisation from secondary sources, fresh applications were assumed to be responsible for endosulfan concentrations of 3.6 pg m^{-3} in winter and 5.8 pg m^{-3} in summer (mean values). Spatially, the annual concentrations at the various circumpolar sites did not show remarkable differences, indicating a degree of uniformity in contamination of the Arctic atmosphere.

Long-range transport: Arctic Freshwater

Endosulfan (isomer unspecified) was measured also at Amituk Lake on Cornwallis Island, NV, Canada. The ranges were (in ng L^{-1}) 0.135 – 0.466 in 1992, 0.095 – 0.734 in 1993, and 0.217 – 0.605 in 1994 (quoted in Ngabè and Bidleman 2001). Annual summertime peaks in endosulfan concentrations observed were attributed to fresh input from snow melt via influent streams.

Long-range transport: Arctic Freshwater Sediment

Laminated cores collected from Arctic Lake DV09 on Devon Island, in Nunavut, Canada, in May 1999 were analysed *inter alia* for endosulfan. Only α-endosulfan was present in the sediment of that lake. The concentration was highest at the sediment surface, and rapidly decreased to below detection limits in core slices dated prior to 1988.

Long-range transport: Arctic Seawater

Endosulfan was repeatedly detected in Arctic seawater during the 1990s. Mean concentrations were similar to those of chlordane and ranged from 2-10 pg L^{-1}. Seasonal trends displayed increasing concentrations during the open water season suggesting fresh input from gas exchange and runoff. This trend parallels seasonal trends observed in Arctic air and Amituk Lake (USEPA, 2007).

A survey of several pesticides in air, ice, fog, sea water and surface micro-layer in the Bering and Chukchi Seas in summer of 1993 (Chernyak et al., 1996) identified α-endosulfan in air and subsurface seawater at levels around 2 pg L^{-1}. In melted ice <9 pg L^{-1} and for the sea water surface micro-layer <40 pg L^{-1} were detected. For fog condensates from several sites of that region concentrations of <10 to <0.5 ng L^{-1} were reported. β-endosulfan was found in several atmospheric samples, e.g. from the Central Bering or Gulf of Anadyr at concentrations around 1 pg m^{-3}. Similar concentrations of endosulfan have been reported from seawater surface layer (40-60 m) collected in the Bering and Chukchi Seas, north of Spitzbergen and the Greenland Sea (Jantunen and Bidleman, 1998).

Arctic seawater concentrations of endosulfan were measured from 1990s to 2000 in different regions of the Arctic Ocean (Weber et al., 2006). Surface seawater concentrations for α- and β-endosulfan ranged from <0.1 to 8.8 pg L^{-1} and 0.1 to 7.8 pg L^{-1} respectively. Morris et al (2008) have reported α-endosulfan and endosulfan sulfate in Barrow Strait averaging 1.4 and 4.6 pg L^{-1} at 2m depth. Geographical distribution for α-endosulfan revealed the highest concentrations in the western Arctic, specifically in Bering and Chukchi Seas with lowest levels towards the central Arctic Ocean. The results of air-water fugacity ratio indicate that α-endosulfan has been undergoing net deposition to surface waters across all the regions of the Arctic Ocean since 1990s. The authors concluded that the net deposition through air-water transfer may be the dominant pathway into the Arctic Ocean for α-endosulfan, particularly during the ice free periods.

Long-range transport: Arctic Snow and Snowpack

Concentrations of α-endosulfan in snow samples collected in the Agassiz Ice Cap, Ellesmere Island, Canada in 1986 and 1987 ranged from 0.10 to 1.34 ng m^{-3} (Gregor and Gummer, 1989). The concentrations of α- endosulfan in snowpack in Agassiz Ice Cap were 0.288 ng L^{-1} in 1989 and 0.046 ng L^{-1} in 1992 (Franz et al., 1997). From measured snowpack concentrations and snowfall amounts, minimum winter deposition rates of 0.03 µg m^{-2} were estimated for the years 1986 and 1987 (Barrie et al., 1992).

Long-range transport: Arctic and Antarctic Biota

α-Endosulfan was found in 40% of samples of Antarctic krill. The geometric mean level detected was 418 pg g^{-1} lw, the maximum was 451 pg g^{-1} lw (Bengston et al., 2008).

Endosulfan (α- and β-isomer) was found in many different species in Greenland. The highest median and maximum concentrations in ng g^{-1} lw for various tissues and locations per species are summarized here: Terrestrial species: ptarmigan (median 1.9 and max 3.0 in liver), hare (median 0.55 and max 0.64 in liver), lamb (median n.d. and max 0.65 in liver), caribou (median 0.17 and max 0.39 in muscle), muskox (median 0.016 and max 1.8 in blubber). In freshwater fish: Arctic char (median 21 and max 92 in muscle tissue). In marine organisms: shrimp (median 3 and max 5.2 in muscle), snow crab (median 19 in muscle and max 95 in liver), Iceland scallop (median 0.36 and max 1.6 in muscle) capelin (median 50 ng g^{-1}). In seabirds: common eider (median 4.9 and max 8.6 in liver), king eider (median 3.7 in liver and max 10 in muscle), kittiwake (median 62 and max 130 in muscle), thick-billed murre (median 8.8 and max 15 in liver). In marine mammals: ringed seal (median 5.6 in liver at Qeqertarsuaq and max 25 in muscle at Ittoqqortoomiit), harp seal (median 12 and max 45 in blubber), minke whale (median 12 and max 29), beluga (median 45 and max 83 in skin), and narwhal (median 81 and max 120 in skin (Vorkamp et al., 2004).

Blubber samples from male beluga were collected over 20 years at five time points in Cumberland Sound, Canada. Only endosulfan sulfate was detected. But unlike other organochlorines, levels appear to have increased steadily (3.2 fold) over that 20 year time period from 1982 reaching ca. 14 ng g^{-1} lw in 2002 (USEPA 2007). α-endosulfan concentrations in blubber of minke whale populations from distinct parts of the North Atlantic were sampled in 1998 (Hobbs et al., 2003). The highest mean concentrations were found for minke whales in the North Sea/Shetland Islands (34 ng g^{-1} lipid for females and 43.0 ng g^{-1} for males), the Barents Sea (7.74 ng g^{-1} lw for females and 9.99 ng g^{-1} lw for males) and Norway's Vestfjorden/ Lofotes (4.51 ng g^{-1} lw for females and 9.17 ng g^{-1} lw for males). Lower concentrations of < 1 ng g^{-1} lw and 5 ng g^{-1} lw were reported for whales from Jan Mayen (territory of Norway) and Greenland. The differences were attributed to distinctions based on genetics, fatty acid profiles, etc.

Endosulfan was detected in adipose tissue and blood of polar bears from Svalbard (Norway). Mean values found for α-endosulfan were 3.8±2.2 ng g^{-1} wet weight (min-max: 1.3-7.8 ng g^{-1}) and 2.9 ± 0.8 ng $g^{-1}$for β-endosulfan (min-max: 2.2-4.3 ng g^{-1}). While the α-isomer was detectable in all samples (15/15) the β-isomer was found in just 5 out of 15 samples.

Alpha-endosulfan ranged between <0.1 and 21 ng g^{-1} wet weight fat, (<0.1-36 ng g^{-1}lw) in the fat of polar bears sampled along the Alaskan Beaufort Sea coast in spring, 2003 (Bentzen et al., 2008).

In liver of northern fulmar from Bjørnøja endosulfans were detected for just two individuals out of fifteen at low levels of 0.28 and 0.50 ng kg^{-1} lw (Gabrielsen, 2005).

Levels in murre eggs sampled in 2003 at St. Lazuria Island ranged from 3.04 to 11.2 ng g^{-1} (mean 5.89 ng g^{-1}) for β-endosulfan while and from 0.116 to 0.428 ng g^{-1} (mean 0.236 ng g^{-1}) for α-endosulfan. At Middleton Island in the Gulf of Alaska, measured levels in 2004 in murre eggs for β-endosulfan ranged up to 11.8 ng g^{-1} (mean of 6.74 ng g^{-1}). α-and β-endosulfan were also found in common murre eggs at East Anatuli Island, Duck Island, Gull Island, Cape Denbigh, Cape Pierce, Sledge Island, Bluff and Bogoslov Island (Roseneau et al., 2008).

Endosulfan levels in Chinook and sockeye salmon, Cook Inlet Alaska ranged from 252 to 1610 ng kg^{-1} (USEPA, 2003).

In ringed seals from Alaska, the highest levels were found in the western Arctic Ocean off Barrow (geometric mean in ringed seal blubber combined males and females of 22.6 ng g^{-1} α-endosulfan with the upper concentration at 43.39 ng g^{-1}) (Mackay and Arnold, 2005).

Endosulfan has been detected in biota in the Arctic (5 terrestrial, 1 freshwater and 13 marine species with maximum levels between 0.39 to 130 pg g-1 lw) and Antarctic (a seal species and krill with maximum levels of 451 pg g-1 lw). Monitoring data have detected endosulfan (and endosulfan sulphate) in the air, the freshwater, the marine water and the sediment of the Arctic and/or Antarctic regions. Therefore, there is evidence that endosulfan is transported at long distances and bioccumulates in biota in remote areas ***though one member considered the concentration encountered to be very low***.

2.4 Hazard assessment for endpoints of concern

Endosulfan is highly toxic for most invertebrates and vertebrates, including humans. The insecticidal properties are shared, with some differences in potency, by the α and β isomers and the metabolite endosulfan sulfate. The toxicity of endosulfan has been evaluated by several organizations, including among others JMPR in 1998 (FAO/WHO, 1998); ATSDR in 2000 (ATSDR, 2000); the EU in 1999 with addenda up to 2004 (EC dossier submitted as additional information); an EFSA Scientific Panel in 2005 (EFSA, 2005), Australia in 2005 (submitted as additional information), Canada in 2007 (PMRA's REV2007, submitted as additional information), US EPA in 2007 (submitted as additional information), and New Zealand in 2008 (submitted as additional information).

The toxicity of other endosulfan metabolites has also been demonstrated for different species including humans.

Adverse effects on aquatic organisms

Endosulfan α, β and sulfate are highly toxic to aquatic invertebrates and fish. Acute median lethal concentrations (LC_{50}s) for several species at levels below 1µg L^{-1} have been reported. Chronic no observed effect concentrations (NOECs) below 0.1 µg L^{-1} have been reported for fish and aquatic invertebrates. A significant toxicity for aquatic organisms has been also observed for other metabolites; unfortunately, no chronic aquatic toxicity data are available for these metabolites, but the acute LC_{50}s for endosulfan lactone and ether are lower than 1 mg l^{-1} (highly toxic to aquatic organisms according to the UN-GHS classification), with reported K_{ow} higher than the GHS trigger for chronic classification in the case of endosulfan ether, and are not expected to be readily biodegradable..

The NOEC for sediment dwelling organisms tend to be between 0.1 and 1 mg kg^{-1}, with equivalent pore water concentration of about 1µg L^{-1}. The dietary toxicity of endosulfan to fish has been studied in Atlantic salmon (*Salmo salar*) histopathological effects were observed after 35 d of exposure to a diet containing 4 µg kg^{-1} of endosulfan, and the condition factor was significantly reduced in fish exposed for 49 d to 500 µg kg^{-1} (Petri et al., 2006; Glover et al., 2007).

Additional sublethal effects of particular concern, including genotoxicity and endocrine disrupting effects have been reported. Associated genotoxic and embryotoxic effects have been observed in oysters exposed to endosulfan (Wessel et al., 2007). Endosulfan sulfate has been shown to be an anti-ecdysteroidal compound for *Daphnia magna* delaying the molting process (Palma et al., 2009). The ecdysteroid system is used by crustaceans and other arthropods as the major endocrine signalling molecules, regulating processes such as moulting and embryonic development. Neurotoxicity has been observed in common toad (*Bufo bufo*) tadpoles (Brunelli et al., 2009), and developmental abnormalities on anuran *Bombina orientalis* embryos (Kang et al., 2008). In ovum exposure at a critical period for gonadal organogenesis provoked post-hatching effects in *Caiman latirostris* (Stoker et al., 2008). Immunotoxicity has been observed in Nile tilapia (Tellez-Bañuelos et al., 2008; Girón-Pérez et al., 2008). Toxic effects have also been observed on non-animal species, including cyanobacteria (Kumar et al., 2008) and aquatic macrophytes (Menone et al., 2008).

Adverse effects on terrestrial organisms

In laboratory animals, endosulfan produces neurotoxicity effects, which are believed to result from over-stimulation of the central nervous system. It can also cause haematological effects and nephrotoxicity. The α-isomer was generally found more toxic than the β-isomer (ATSDR, 2000).

The lowest relevant NOEC for endosulfan in terrestrial vertebrates is 0.6 mg kg^{-1} bw day^{1} based on reduced body-weight gain, increased marked progressive glomerulonephritis, and blood vessel aneurysm in male rats at 2.9 mg kg^{-1} bw day^{-1}; the same value was reported in a 1-year dog study. Reproductive effects on mallard ducks (*Anas platyrhynchos*) where observed at low dietary levels, the reported NOEC was 30 ppm in the diet. The acute median lethal dose (LD_{50}) value in this species is of 28 mg kg^{-1} bw (see INIA, 1999).

Toxicity has been shown for bees, beneficial arthropods and soil dwelling invertebrates in the laboratory and field studies (i.e., INIA, 1999, New Zealand dossier, Vig et al., 2006; Bostanian and Akalach 2004).

Adverse effects on human health

Endosulfan is highly acutely toxic via oral, dermal and inhalation routes of exposure and it is associated to human poisoning (Moon and Chun, 2009; Satar et al., 2009). Exposure through certain conditions of use (e.g. lack of protective equipment), and 'bystander' exposure has been considered a risk (Beauvais et al., 2009) and has been linked to congenital physical disorders, mental retardations and deaths in farm workers and villagers in developing countries in Africa, Asia and Latin America (Kishi 2002; NIOH 2003; Wesseling et al 2005; Glin et al 2006). A survey conducted by PAN Africa in Mali in 2001 of villages in 21 areas of Kita, Fana and Koutiala found a total 73 cases of pesticide poisoning and endosulfan was the main pesticide identified (Glin et al 2006). Endosulfan was found among the most frequently reported unintentional intoxication incidents, adding further evidence to its high toxicity for humans (Glin et al 2006).

The primary effect of endosulfan, via oral and dermal routes of exposure, is on the central nervous system (CNS). Effects in laboratory animals as a result of acute, subchronic, developmental toxicity and chronic toxicity studies indicate that endosulfan causes neurotoxic effects, particularly convulsions, which may result from over stimulation of the CNS. Possible mechanisms of neurotoxicity include (a) alteration of neurotransmitter levels in brain areas by affecting synthesis, degradation, and/or rates of release and reuptake, and/or (b) interference with the binding of neurotransmitters to their receptors. Additional effects were noted in the liver, kidney, blood vessels and haematological parameters following repeated exposure to endosulfan. The evaluation by the USEPA (2006) of a rat developmental neurotoxicity study conducted by Gilmore et al in 2006, indicates a LOAEL for developmental effects of 3.74 mg kg-1 day-1 based on decreased pup weight and deceased weight gain, no NOAEL for pups could be established in that study. No neurotoxic effects were observed at doses below 10 mg kg-1 day-1 . Only minor effects were observed in the dams. ***An Australian study indicated that endosulfan is not genotoxic (Australia (1998)).***

Acute exposure to high doses of endosulfan results in hyperactivity, muscle tremors, ataxia, and convulsions. The LD_{50} of endosulfan varies widely depending on the route of administration, species, vehicle, and sex of the animal. Female rats are clearly more sensitive to endosulfan than male rats, and, on the basis of a single study, this sex difference appears to apply to mice also. The lowest oral LD_{50} value is 9.6 mg kg^{-1} bw in female Sprague-Dawley rats (*Ratus norvegicus*), and the lowest inhalation LC_{50} is 0.0126 mg L^{-1} (2.13 mg kg^{-1} bw) in female Wistar rats (*R. norvegicus*). The lowest relevant NOAEL for endosulfan in laboratory animals is 0.6 mg kg^{-1} bw day^{-1}.

Regarding the metabolites, a particularly relevant study is the 90d toxicity study in rat dietary exposure on endosulfan-lactone, conducted by Langrand-Lerche (2003) and included in the EU dossier. The NOEC reported in this study is 0.6 mg kg^{-1} bw day^{-1}, although mild effects in liver and kidney were observed at this dose.

Evidence regarding genotoxicity is inconclusive. The assessments conducted by the EU, Canada or the USA concluded that endosulfan is not carcinogenic. However, Bajpayee et al., (2006) found that exposure to sublethal doses of endosulfan and its metabolites induce DNA damage and mutation. Although the contribution of the metabolites to the genotoxicity of the parent compound in bacteria *(Salmonella spp.)* and mammalian cells was unclear, and the pathways leading to bacterial mutation and mammalian cell DNA damage appeared to differ.

Contradictory opinions on the potential for endocrine disruption have been presented. Recent information indicates that endosulfan mimics non-uterotrophic E(2) actions, strengthening the hypothesis that endosulfan is a widespread xenoestrogen (Varayoud et al., 2008), acts via a membrane version of the estrogen receptor-α on pituitary cells and can provoke Ca^{++} influx via L-type channels, leading to prolactin (PRL) secretion (Watson et al., 2007), and is also anti-progestative (Chatterjee et al., 2008).

It should be noticed that the toxicological reviews have been mostly conducted in the framework of the pesticides registrations in various countries. As a consequence, some specific issues, of particular relevance in the long-term exposure assessment of POP related characteristics received little attention. For example, in the rat chronic study, females from the high dose group had a reduced survival rate after 26 weeks (93% in controls, 74% in high dose) and 104 weeks (88% in controls, 46% in high dose). The deaths were predominantly associated with respiratory infections. This effect could be associated to the potential immunotoxicity of endosulfan that has been hypothesized in some studies. As the study was not designed for the specific assessment of these endpoint, relevant effects at low doses could remain unobserved and only dramatic effects (over 50% mortality was observed in this case) are evidenced.

In some chronic toxicity studies, the concentrations of endosulfan and its metabolites were measured at the end of the study, but the limit of detection levels were too high and only endosulfan sulfate and occasionally endosulfan lactone, were above the quantification level. These limitations increase the uncertainty in the comparison of measured values in biota with the reported toxicological information.

Weber et al., 2009, have recently compared measured biota data in the Artic with toxicity endpoints. The maximum measured concentrations of α- and β-endosulfan for several species were just within one order of magnitude of the lowest valid mammalian NOAEL. These results ***add to the concern*** for adverse effects. It should be noted, that the role of metabolites is not considered in these calculations. Endosulfan sulfate and other metabolites have been detected in some mammalian toxicity studies, unfortunately, the limit of detection employed in these studies were too high, and do not allow the estimation of relevant internal concentrations to be compared to measured data.

There are toxicity and ecotoxicity data available for both endosulfan isomers and several metabolites. Endosulfan is a very toxic chemical for many kinds of biota. Metabolism occurs rapidly, but the oxidised metabolite endosulfan sulfate shows an acute toxicity similar to that of the parent compound. Endosulfan may cause endocrine disruption in both terrestrial and aquatic species. Degradation studies indicate that endosulfan is degraded into a large number of other metabolites, all of them retaining the endosulfan structure, and some of them showing significant toxicity while others do not. Therefore, there is sufficient evidence that endosulfan causes adverse effects to human health and the environment.

As additional information, a benchmark approach has been performed with lindane having similar toxicity than endosulfan. This approach show that lindane and endosulfan are found in similar concentration in remote area biota.

Table: Comparative analysis of the toxicity and biota monitoring data in the remote areas for endosulfan and lindane.The NOEC and NOAEL for endosulfan can be found in the document UNEP-POPS-POPRC-END-08-EU-V1-1.

COMPARISON OF THE TOXICITY OF ENDOSULFAN AND LINDANE			
TOXICITY TO AQUATIC ORGANISMS	Lowest aquatic NOEC (fish)	Endosulfan : 0.05 µg/l (Knacker et al., 1991)	Lindane: 2.9 µg/ l (lindane risk profile)
TOXICITY TO MAMMALS	Lowest NOAEL for mamals	Endosulfan 0.6 mg/kg bw day Rats (Ruckman et al., 1989) Dogs (Brunk 1989-1990)	Lindane: 0.8 mg/kg bw day Rabbit (lindane risk profile)
COMPARISON OF MEASURED CONCENTRATIONS IN ARTIC AND ANTARCTIC BIOTA (for endosulfan: ∑ = α-endosulfan+ β-endosulfan + endosulfansulfate; sum of indicated isomers in other cases)			
Reference & Location	**Organism (tissue)**	**Endofulfan Mean (range)**	**Lindane Mean (range)**
Bengtson Nash et al 2008. Antarctica	Invertebrate: Antarctic krill	∑ 419 (<LOQ-451) pg/g lw	127 (<LOQ-127) pg/g lw
EPA 910-R-01-003. 2003 Alaska	Fish: Chinook salmon Fish: Chum salmon Fish: Sockeye salmon	∑ (<273-780) ng/kg ∑ (<273)ng/kg ∑ (<273-1610) ng/kg	(<124-203) ng/kg (<124-186) ng/kg (<124-793) ng/kg
Bentzen et al 2008 Alaska	Mammal: Polar Bear (fat)	α+ β 8 ng/g lw	8 ng/g lw
Roseau et al. 2008 Alaska	Bird: Common murre (eggs)	∑3.15 ng/g ww	0.19 ng/g ww

Miranda-Filho et al.2007 Antarctica	Marine mammals: elephants seals: Adult males Adult females Juveniles Pups	 ∑ 3.02 ng/g lw ∑ 2.68 ng/g lw ∑ 1.99 ng/g lw ∑ 0.90 ng/g lw	 1.04 ng/g lw 0.65 ng/g lw 0.34 ng/g lw 0.28 ng/g lw
Hobbs et al 2003 North Atlantic	Marine Mammals minke whales (blubber)	α (<1 -33.6) ng/g lw	(<1 - 86.6) ng/g lw

3. Synthesis of information

The potential health and environmental risks of endosulfan associated with its use as a pesticide are well documented and have resulted in banning the compound or imposition of use restrictions in many countries around the world. Human fatality and chronic poisoning cases, and severe environmental problems have been reported (Durukan et al., 2009; Jergentz et al., 2004). ***The assessment of the POP characteristics of endosulfan, including endosulfan sulfate, confirms the concern regarding endosulfan and its main metabolite; it should be also considered that other metabolites, formed through both environmental and biota transformations, maintains the chemical structure and in some cases have significant toxicity***.

The persistence of endosulfan should be assessed in terms of a dual evaluation. First, the persistence of the "active" molecules, with insecticidal activity: the isomers α- endosulfan and β-endosulfan, and the main metabolite endosulfan sulfate. Second, the overall persistence of the number of transformation products which maintain a similar chemical structure with the hexachloronorbornene bicycle: endosulfan diol, endosulfan lactone, endosulfan ether; endosulfan hydroxyether; endosulfan carboxylic acid.

This environmental fate complicates the assessment of persistence using DT_{50} values. At POPRC 4, the combined DT_{50} measured in laboratory studies for α and β endosulfan and endosulfan sulfate, was selected as a relevant parameter. A large variability in the rate of this degradation has been observed. The estimated combined half-life in soil for endosulfan (α, β isomers and endosulfan sulfate) ranges typically between 28 and 391 days; but higher and lower values are reported in the literature under specific conditions. In the field, volatilization from soil and plant surfaces is expected to be a main dissipation route.

In the aquatic compartment, endosulfan is stable to photolysis; a rapid hydrolysis is only observed at high pH values, and it is non-readily degradable. The dissipation of endosulfan and the abundance of one or other degradation products is influenced by the pH and other properties of the water/sediment system. The accumulation of endosulfan sulfate in the sediment and of endosulfan hydroxy carboxylic acid in water has been seen throughout the studies. The degradation rate could not be estimated, but DT_{50} > 120 d has been demonstrated. Under acidic conditions endosulfan lactone seems to accumulate in the sediment not reaching a plateau after one year. The persistence of endosulfan and other pesticides in aquatic ecosystems of the tropics is not substantially lower than during summer in temperate regions.

There is a high uncertainty on the degradation rate of endosulfan in the atmosphere. However, there is enough information on the volatility of α and β endosulfan, and therefore the persistence in the atmosphere is essential for supporting the potential for atmospheric transport. The atmospheric transport at long distances requires a minimum level of persistence in the atmosphere; despite the uncertainty on the real degradation rate of endosulfan in this compartment the threshold half life of 2 days seems to be exceeded. Therefore, it should be concluded that the combination of a high volatility and sufficient atmospheric persistence may result in a significant potential for long range transport.

Several models have been developed for estimating this potential according to the characteristics of the POP candidate molecules. Results from the CliMoChem model show that POV and LRTP of the endosulfan substance family are similar to those of acknowledged Persistent Organic Pollutants, such as aldrin, DDT, and heptachlor. The results also show that POV and LRTP of the entire substance family, i.e. including the transformation products, are significantly higher than those of the parent compounds alone. However, this model has not been validated for endosulfan ***specifically but for other comparable molecules, and one member is of the view that*** the predicted values may not be realistic.

Several authors have suggested that endosulfan is subject to LRT as predicted by models and posses a high arctic contamination and bioaccumulation potential; matching the structural profile for known arctic contaminants. The US concludes that desorbed residues of endosulfan volatilize and continue to recycle in the global system through a process of migration and are re-deposited via wet and dry depositions as well as air-water exchange in the northern hemisphere.

These suggestions are confirmed by measured data. The presence of endosulfan in remote areas, including the Arctic and Antarctic, confirms that endosulfan has enough persistence and transport potential to move around the planet, representing a potential concern at the global level.

Three complementary information blocks have been analysed for assessing the bioaccumulation and biomagnification potential of endosulfan and its degradation products: the screening assessment based on physical-chemical properties; the analysis of experimental data, including bioconcentration, bioaccumulation and toxicokinetic studies; and the analysis of field collected information.

The reported log K_{ow} for α- and β-isomers and endosulfan sulfate range between 3 and 4.8. These values indicate potential for bioconcentration in aquatic organisms, although are below the screening trigger of the Stockholm Convention. Recently, the role of the octanol/air partition coefficient K_{oa} for the screening assessment of the biomagnification potential of POPs in terrestrial food chains is receiving significant attention. Although there are no specific screening thresholds for the K_{oa}, the authors suggest that organic chemicals with a log K_{ow} higher than 2 and a log K_{oa} higher than 6 have an inherent biomagnification potential in air-breathing organisms of terrestrial, marine mammalian, and human food chains. ***However, reservation was made by a few members on the use of log K_{oa} values for the purpose of biomagnification assessment as it was their view that this parameter is not included in the convention.*** Endosulfan clearly falls within this category along with other known POPs such as beta-hexachlorocyclohexane, dieldrin, hexachlorobenzene, mirex and pentachlorobenzene.

The bioconcentration potential of endosulfan in aquatic organisms is confirmed by experimental data. The validated BCF values range between 1000 and 3000 for fish; from 12 to 600 for aquatic invertebrates; and up to 3278 in algae. These values, measured in conventional studies, are in line with those expected from the K_{ow}, indicating a clear bioconcentration potential but below the screening trigger of 5000. However, due to the complex degradation and metabolism pattern of endosulfan, the potential for bioconcentration requires additional considerations.

The data obtained in the estuarine and freshwater microcosm experiments confirms that the assessment of parent and metabolite bioconcentration is particularly relevant. In the short-term estuarine experiment, the authors suggest BAFs between 375 and 1776 for total (α-, β- and endosulfan sulfate); but BAFs over 5000 could be obtained for α-endosulfan based on the concentrations measured at the end of the experiment. An outdoor aquatic microcosms study estimated bioaccumulation factors of about 1000, based on total radioactivity but up to 5000 for endosulfan sulfate. A similar situation is observed in the dietary exposure experiments with aquatic organisms. The initial "standard" assessment indicates a low bioaccumulation from food in cladocerans exposed to contaminated algae and in fish exposed to contaminated food. However, an in-depth analysis of the results in terms of the comparative assessment of the long-term toxicokinetics of endosulfan and its degradation products reveal some concerns, for example, the endosulfan concentrations in the fish exposed to endosulfan in the diet were low but remained unchanged during the whole depuration phase.

The biomagnification potential of endosulfan has been recently associated with its high K_{oa}, and model estimations, based on measured concentration of key elements from remote Arctic food chains, indicates a significant biomagnification of endosulfan in terrestrial ecosystems. ***However, reservation was made by a few members on the use of log K_{oa} values for the purpose of biomagnification assessment as it was their view that this parameter is not included in the convention.***

This complex situation has been confirmed by the presence of endosulfan in biota from remote areas. Most studies include α- and β-endosulfan, and in some cases, endosulfan sulfate is also measured. Other endosulfan metabolites are only rarely quantified. The presence of endosulfan in biota including top predators has been confirmed for situations representing medium range transport; potential for long range transport, including atmospheric transfer and deposition at high altitude mountain areas; and in remote areas, far away from intensive use areas, in particular, the Arctic and the Antarctic.

Regarding the potential of endosulfan for producing adverse effects, the toxicity and ecotoxicity of this pesticide is well documented. Endosulfan is highly toxic for humans and for most animal groups, showing both acute and chronic effects at relatively low exposure levels. Acute lethal poisoning in humans and clear environmental effects on aquatic and terrestrial communities have been observed under standard use conditions when the risk mitigation measures have not been followed. A large number of countries have found that endosulfan poses unacceptable risks, or has caused unacceptable harm, to human health and the environment, and as a result have banned or severely restricted it.

Regarding environmental exposure, the potential risk of endosulfan is not limited to zones in the vicinity of the areas with extensive use. Concentrations of potential concern have been observed in areas at significant distances, due to medium-range atmospheric transport.

As expected for a currently used pesticide, the concentrations in remote areas tend to be orders of magnitude below those predicted/observed in crop areas. However, the assessment of POP and POP-like chemicals requires a very specific evaluation, which strongly differs from that employed in the local risk assessment employed by regulatory bodies for supporting the registration of pesticides. Regulatory risk assessments for pesticides focus on the health and environmental consequences of local episodic exposures, consider the expected benefits of the application, and the acceptability criteria differ dramatically from those relevant for assessing persistent pollutants. POPs have potential for distributing around the world, reaching remote areas, and bioconcentrating along the food-chain resulting in a long term exposure of human and wildlife populations. Thus, concentrations assumed to be acceptable at the local level in pesticide regulatory programmes should not be considered acceptable in a POP assessment. Such an assessment should be conducted based on the scientific evidences on the potential adverse effects to human health or to the environment resulted by long-range transport of the chemical.

The long-term concern for chemicals with POP characteristics is associated with its distribution to remote areas, which obviously are expected to lead to low but potentially relevant concentrations, followed by biologically dominated concentration processes through specific ecological pathways (biomagnification). Although traditionally it has been considered that these processes are dominated by the fugacity potential associated with very high lipophilicity and very low aquatic solubility, it is now clear that there are other mechanisms and routes which may lead to equivalent health and environmental concerns, as demonstrated for other POP candidates such as PFOS or HCH isomers.

Additional information on the likelihood of endosulfan for causing environmental effects in remote areas has been obtained through two complementary methods: benchmarking with related POPs and comparison of measured biota concentrations with endpoints of ecotoxicological concerns. Lindane has been selected for benchmarking, due to the similarities in terms of toxicity (being endosulfan slightly more toxic) and marketing (only recently identified as a POP). Monitoring endosulfan data show biota concentrations in several Arctic and Antarctic species in the same range than those observed for lindane, suggesting similar levels of concerns regarding health and environmental adverse effects. In addition, the upper range of the measured data for several species is within one order of magnitude when compared to the validated mammalian NOAEL; adding to the potential risk associated to long-range transport of endosulfan.

Finally, the role of endosulfan metabolites other than endosulfan sulfate has received limited attention. Endosulfan lactone has the same chronic NOEC value as the parent endosulfan isomers. The lactone is produced from the degradation of the carboxylic acid and/or the hydroxyether. If the toxicity of each metabolite is integrated into the degradation/metabolism process, the result is a biphasic curve. The initial degradation step, to endosulfan sulfate, increases the bioaccumulation potential and maintains or slightly reduces the toxicity; the further degradation steps provoke a clear reduction in the toxicity and bioaccumulation potential, but then further steps, with the formation of the lactone, increase again the toxicity and the bioaccumulation potential.

4. Concluding statement

Endosulfan has been banned or restricted in a number of countries but it is still extensively used in other countries.

Endosulfan has been reported ***throughout the*** atmosphere of northern Polar Regions. Concentrations of endosulfan (isomers unspecified) from Arctic air monitoring stations increased from early to mid-1993 and remained at that level through the end of 1997. Unlike most other organochlorine pesticides that have decreased over time, average concentrations of endosulfan in the Arctic have not changed significantly during the last five years.

The rapid field dissipation of the endosulfan isomers is related to volatility and it is then subject to atmospheric long-range transport. Persistence, in particular in colder regions, and bioaccumulation potential are confirmed through the combination of experimental data, models and monitoring results. Endosulfan is highly toxic to the environment and there is evidence suggesting the relevance of some effects on humans. However, the information on its genotoxicity and potential for endocrine disruption is not fully conclusive. Based on the inherent properties, and given the widespread occurrence in environmental compartments and biota in remote areas, together with the uncertainty associated with the insufficiently understood role of the metabolites which maintain the endosulfan chemical structure, it is concluded that endosulfan is likely, as a result of its long-range environmental transport, to lead to significant adverse human health and environmental effects, such that global action is warranted]

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