別添6

クロルデコンの危険性の概要

分解性	蓄積性	人健康影響	動植物への影響
【生分解性・加水分解性】 水生環境中であるいは土壌中で、生分解又は加水分解するとは予測されない。 【光分解性】 大気中で直接的光分解を受けることは考えられないと結論している。 ・利用可能な全てのﾃﾞｰﾀに基づき、ｸﾛﾙﾃﾞｺﾝは環境中で高い残留性を示すと考えられる。	【ｵｸﾀﾉｰﾙ/水分配係数】 logKow=4.50-5.41 【BCF（経鰓的生物濃縮係数）】 ・藻類：BCF=6000 ・無脊椎生物：BCF=21600 ・魚類：BCF=60200 【BMF（経口的生物濃縮係数）】 ・ほとんど又は全く代謝浄化せず、水生の食物連鎖において生物濃縮の可能性がある。 ・食物連鎖の研究において、藻からｶｷへの移動は非常に低かったが、ｴﾋﾞからｱﾐ、ｱﾐからｽﾎﾟｯﾄへの明白な栄養段階を通じた移動があることが示された。	【反復投与毒性】 ラット（2 年）：NOAEL 0.05mg/kg/day 0.25mg/kg/day で腎臓影響（蛋白尿、重篤な糸球体硬化） ラット（経口 21 ヶ月）：LOAEL 0.07mg/kg/day 肝細胞の病理組織学的変化、甲状腺ろ胞サイズ、コロイド含量低下、甲状腺ろ胞上皮細胞の高さの増加 ラット（経口 3 ヶ月）：LOAEL 1.17mg/kg/day 肝の巣状（限局性）壊死、副腎肥大、振戦、多動性、過剰驚愕反応等 【生殖毒性】 ラット（3 ヶ月）：NOAEL 0.25mg/kg/day 精巣萎縮 ラット（90 日）：LOAEL0.83mg/kg/day で精子の運動性・生存率低下、精子数減少、1.67mg/kg/day で性嚢、前立腺重量低下 マウス（160 日）：LOAEL 2mg/kg/day で排卵停止、膣発情持続、ラット妊娠 14-20 日に母体経由で 15mg/kg/day 投与した雌児動物においても同様の報告	【慢性毒性】 ミジンコ *Daphnia magna* ：21dNOEC=0.0283 mg/L（繁殖），21dNOEC=0.025 mg/L（成長） ミシッドシュリンプ *Americamysis bahia* ：28dMATC=0.000026-0.00034 mg/L（成長） ユスリカ *Chironomus tentans* ：14dNOEC=17.9 mg/kg sediment（発達）

		【催奇形性】 ラット（経口）：LOAEL　2mg/kg/day で胎児体重低下、骨化度低下、10mg/kg/day で脳水腫、停留精巣、腎盂肥大、脳室肥大 【発がん性】 ラット（80 週）：LOAEL　1.2mg/kg/day 肝細胞がん IARC グループ2B（possibly carcinogenic to human） 【その他】 職業ばく露で振戦、情緒不安定、視力障害、筋力低下、歩行運動失調等、実験動物で、脾臓、胸腺重量、好中球数、NK 活性低下、 EU-Strategy for Endocrine Disruptors 優先化学物質（無処置動物の少なくとも一種類において内分泌かく乱活性を示す科学的根拠がある）に分類	

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Report of the Persistent Organic Pollutants Review Committee on the work of its third meeting

Addendum

Revised risk profile on chlordecone

At its third meeting, the Persistent Organic Pollutants Review Committee revised and adopted the risk profile on chlordecone, on the basis of the draft contained in document UNEP/POPS/POPRC.2/17/Add.2. The text of the risk profile, as amended, is set out below. It has not been formally edited.

K0763736 141207

CHLORDECONE

RISK PROFILE

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

November 2007

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Executive summary

The European Community and its member states being parties to the Stockholm Convention have proposed chlordecone to be listed in the Convention. The Persistent Organic Pollutants Review Committee concluded in its meeting in November 2005 that the substance complies with the screening criteria set out in Annex D of the Convention and that a draft risk profile should be prepared to review the proposal further.

Chlordecone is a synthetic chlorinated organic compound, which has mainly been used as an agricultural insecticide, miticide and fungicide. It was first produced in 1951 and introduced commercially in the United States in 1958 (trade names Kepone® and GC-1189). It was available in the United States until 1976. In France, chlordecone was marketed with a trade name Curlone from 1981 to 1993. Historically, chlordecone has been used in various parts of the world for the control of a wide range of pests. It has been used extensively in banana cultivation against banana root borer, as a fly larvicide, as a fungicide against apple scab and powdery mildew and to control the Colorado potato beetle, rust mite on non-bearing citrus, and potato and tobacco wireworm on gladioli and other plants. Given the specific pesticidal uses of chlordecone, it can be expected that all amounts manufactured are ultimately released to the environment.

Chlordecone is not expected to hydrolyse or biodegrade in aquatic environments, nor in soil. Direct photodegradation is not significant. Therefore, chlordecone is considered to be highly persistent in the environment. With BCF-values in algae up to 6,000, in invertebrates up to 21,600 and in fish up to 60,200 and documented examples of biomagnification, chlordecone is considered to have a high potential for bioaccumulation and biomagnification.

The available data are not conclusive when it comes to long-range atmospheric transport of chlordecone in gaseous form. However, atmospheric transport of particle-bound substances and transport of sediment particles in ocean currents as well as biotic transport could also contribute to long-range environmental transport of chlordecone. Due to lack of monitoring data on chlordecone, the assessment of the potential for long-range transport of chlordecone was based on physico-chemical properties and application of long range transport models.

Chlordecone is readily absorbed into the body and accumulates following prolonged exposure. The pesticide is both acutely and chronically toxic, producing neurotoxicity, immunotoxicity, reproductive, musculoskeletal and liver toxicity at doses between 1 - 10 mg/kg bw/day in experimental animal studies. Liver cancer was induced in rats at a dose of 1 mg/kg body weight per day, and reproductive effects are seen at similar dose levels. The International Agency for Research on Cancer has classified chlordecone as a possible human carcinogen (IARC group 2B). Moreover, chlordecone is very toxic to aquatic organisms, with the most sensitive group being the invertebrates.

Based on the available evidence, chlordecone 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

The European Community and its member states being parties to the Stockholm Convention have proposed chlordecone to be listed in Annex A to the Convention (UNEP/POPS/POPRC.1/6).

This risk profile has been prepared following the decision of the Persistent Organic Pollutants Review Committee at its first meeting in November 2005 to establish an ad hoc working group to review the proposal further (UNEP/POPS/POPRC.1/10).

In this document all data are presented according to the International System of Units (SI) and, therefore, many have been recalculated from other units in the data sources. Furthermore, all concentrations are presented based on kg or L (*e. g.* µg/kg or mL/L).

1.1 Chemical Identity of the proposed substance

Chlordecone is a synthetic chlorinated organic compound, which has mainly been used as an agricultural insecticide, miticide and fungicide.

1.1.1 Names and registry numbers

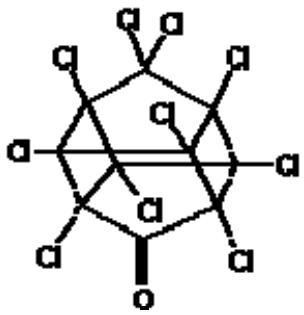
CAS chemical name:
1,1a,3,3a,4,5,5,5a,5b,6-decachloro-octahydro-1,3,4-metheno-2H-cyclobuta-[cd]-pentalen-2-one

Synonyms:
Decachloropentacyclo-[5,2,1,$0^{2,6}$,$0^{3,9}$,$O^{5,8}$]-decan-4-one,
Decachlorooctahydro-1,3,4-metheno-2H,5H-cyclobuta-[cd]-pentalen-2-one
Decachloroketone

Trade names:
GC 1189, Kepone, Merex, ENT 16391, Curlone

CAS registry number:
143-50-0

1.1.2 Structure



Source: **http://webbook.nist.gov**, as quoted in http:// ecb.jrc.it

Chlordecone is chemically closely related to mirex, a pesticide which is already listed under the Stockholm Convention. The chemical structure of chlordecone differs from mirex in that the oxygen of the keto group in chlordecone is replaced by two chlorine atoms in mirex.

1.1.3 Physical and chemical properties

The physical and chemical properties of chlordecone are listed in Table 1.1. It demonstrates that the variation is high between data sources for physical properties like vapour pressure and water solubility. This is confirmed by the fact that the Henry's Law Constant varies by one order of magnitude, depending on the type of data used for the calculation. The source of used data are generally considered to be reliable; the data quality have been assessed in the (inter)national consensus documents (IARC, IPCS HSG, IPCS EHC and US ATSDR) and the quality of the data published by Hansch *et. al.* and Howard has been evaluated (Pedersen *et. al.*, 1995).

Table 1.1 Physical and chemical properties of Chlordecone.

Property	Unit	Value	Reference
Molecular formula		$C_{10}Cl_{10}O$	
Molecular weight	g/mole	490.6	
Appearance at normal temperature and pressure		Tan-white crystalline solid	IARC, 1979[1]
Vapour Pressure	Pa	$3.0x10^{-5}$ (25 °C) $< 4.0x10^{-5}$ (25 °C) $4.0x10^{-5}$ (25 °C)	Kilzer, l *et. al.*, 1979[2] IARC, 1979[1] HSG 41, IPCS, 1990
Water solubility	mg/L	0.35-1.0x 1-2 2.7 (25 °C) 3.0	HSG 41, IPCS, 1990 EHC 43, IPCS, 1990 Kilzer, l *et. al.*, 1979[2] Kenaga, 1980
Melting point	°C	350; (decomposes)	IARC, 1979[1]
Boiling point	°C	No data	
Log K_{OW}		4.50 5.41	Howard, 1991[1] Hansch *et. al.*, 1995[2]
Log K_{aw}		-6.69	Scheringer *et. al* ., 2006
Log K_{oc}		3.38-3.415	Howard, 1991[1]
Henry's Law Constant	Pa m^3/mol	$5.45x10^{-3}$, (25 °C) $2.53x10^{-3}$ (20 °C) $4.9x10^{-3}$ $2.0x10^{-2}$	Calculated[2] Howard, 1991[1] Calculated[3] Calculated[4]
Atmospheric OH Rate Constant	cm^3/molecule-sec	≈ 0 (25 °C)[j]	Meylan & Howard, 1993[2]

* It is likely that the 0.35 number is an outlier. The source (HSG 41 by IPCS) did not provide the reference so it is impossible to track where this number came from. The more robust EHC 43 by IPCS did provide a reference and used 1-2 mg/l. This is in the same range with the other values in peer reviewed articles. ATSDR quotes a value of 3 mg/l from Kenaga.

1: Quoted from US ATSDR, 1995
2: Quoted from http://esc.syrres.com/interkow/webprop.exe
3: Calculated from maximum water solubility and minimum vapour pressure of this table
4: Calculated from minimum reliable water solubility (1 mg/L) and maximum vapour pressure of this table

1.2 Conclusion of the Persistent Organic Pollutants Review Committee on the Annex D information on Chlordecone

The POP Review Committee applied in its first meeting on 7–11 November 2005[1] the screening criteria specified in Annex D to the Stockholm Convention, and decided, in accordance with paragraph 4 (a) of Article 8 of the Convention, that it was satisfied that the screening criteria have been fulfilled for Chlordecone. It decided furthermore, in accordance with paragraph 6 of Article 8 of the Convention and paragraph 29 of decision SC-1/7 of the Conference of the Parties to the Stockholm Convention, to establish an ad hoc working group to review the proposal further and to prepare a draft risk profile in accordance with Annex E to the Convention. It invited, in accordance with paragraph 4 (a) of Article 8 of the Convention, Parties and Observers to submit to the Secretariat the information specified in Annex E of the Convention before 27 January 2006.

[1] See the meeting report at: www.pops.int/documents/meetings/poprc/

1.3 Data sources

This Risk Profile is mainly based on information from the following review reports:

- Environmental Health Criteria (EHC) 43: Chlordecone. IPCS International Programme on Chemical Safety. United Nations Environment Programme. International Labour Organisation. World Health Organization. Geneva 1990 (available at: http://www.inchem.org/documents/ehc/ehc/ehc43.htm)
- Health and Safety Guide No. 41, 1990. IPCS International Programme on Chemical Safety. United Nations Environment Programme. International Labour Organisation. World Health Organization. Geneva 1990 (available at: http://www.inchem.org/documents/hsg/hsg/hsg041.htm)
- Toxicological profile for Mirex and Chlordecone. U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry (ATSDR) August 1995 (available at: http://www.atsdr.cdc.gov/toxprofiles/tp66-p.pdf).

The above extensive review reports were used as the main source of information on this candidate POP chemical. Prior to the drafting of this risk profile, a detailed literature search was undertaken on Chlordecone which did not uncover any further assessment reports on this chemical, either international or at the level of individual countries. Where the reviews above have been cited, the text quoted (or quoted with modifications) includes the references cited in the original review. These references are not shown individually in the reference list.

Following the request of the POP Review Committee for additional information, as specified in Annex E of the Convention, on Chlordecone, information was provided, which was mainly based on the open literature. However, France provided a report prepared for the Assemblée Nationale describing the history of production and use of Chlordecone in Martinique and Guadeloupe (Beaugendre, 2005).

A search for more recent information included a literature search *via* the Danish Technical University Library and the data base FINDit (search terms: Chlordecone, kepone, merex) as well as a data base search in public data bases. The data bases include "Ecotox" (US-EPA, http://www.epa.gov/ecotox/), "NITE" (Japan, National Institute of Technology and Evaluation http://www.safe.nite.go.jp/english/db.html) BUA Reports (http://www.gdch.de/taetigkeiten/bua/berichte.htm) and Environmental Fate Data Base (http://www.syrres.com/esc/efdb.htm). This search was based on the search terms: Chlordecone, Kepone and the CAS number 143-50-0. In addition, the Arctic Monitoring and Assessment Programme[2] and the UNEP Regionally based assessment of Persistent Toxic Substances Global Report[3] were consulted. Most of these gave no further information regarding Chlordecone.

1.4 Status of the chemical under international conventions

Chlordecone is listed in Annex A of the Protocol to the Convention on Long-Range Transboundary Air Pollution (CLRTAP) on Persistent Organic Pollutants. The provisions of the Protocol oblige Parties (currently 25) to phase out all production and uses of Chlordecone. Chlordecone is included in the OSPAR convention as a substance of possible concern[4].

The proposal to include Chlordecone in the UNEP/FAO Rotterdam Convention was reviewed by the Chemical Review Committee (CRC) at its first meeting in February 2005. The CRC agreed that, on the basis of the information currently available, the notifications from Switzerland and Thailand had met all the criteria of Annex II with the exception of criterion (b) (iii)[5]. Accordingly, the CRC concluded that Chlordecone could not be recommended for inclusion in Annex III of the Rotterdam Convention at the current time.

[2] http://www.amap.no/

[3] http://www.chem.unep.ch/pts/gr/Global_Report.pdf

[4] The chemically related compound mirex is already included in the Stockholm convention. Both mirex and Chlordecone are included in the UNECE 1998 Aarhus Protocol on Persistent Organic Pollutants (POPs). Both are included in OSPAR as substances of possible concern.

[5] This requires that the documentation supplied demonstrates that the final regulatory action is based on a risk evaluation involving prevailing conditions within the Party taking the action.

2 Summary information relevant for the risk profile

2.1 Sources

2.1.1 Production

Chlordecone has been produced by reacting hexachlorocyclopentadiene and sulfur trioxide under heat and pressure in the presence of antimony pentachloride as a catalyst. The reaction product is hydrolyzed with aqueous alkali and neutralized with acid; Chlordecone is recovered *via* centrifugation or filtration and hot air drying (Epstein 1978) (Quoted from US ATSDR, 1995).

Chlordecone was first produced in 1951, patented in 1952, and introduced commercially in the United States by Allied Chemical in 1958 under the trade names Kepone® and GC-1189 (Epstein 1978; Huff and Gerstner 1978). The technical grade of chlordecone, which typically contained 94.5% chlordecone, was available in the United States until 1976 (IARC 1979). Chlordecone was also found to be present in technical grade mirex at concentrations up to 2.58 mg/kg and in mirex bait formulations at concentrations up to 0.25 mg/kg (EPA 1978b; IARC 1979a) (Quoted from US ATSDR, 1995).

2.1.2 Trade and stockpiles

Between 1951 and 1975, approximately 3.6 million pounds (1.6 million kg) of chlordecone were produced in the United States (Epstein 1978). (Quoted from US ATSDR, 1995) Chlordecone production was discontinued in the USA in 1976. However, a year later it was reported that a French company was considering the establishment of production facilities in France (Anonymous, 1978b), but no further information on this proposal is available. (Modified from EHC 43, (IPCS, 1984)).

No current data are available regarding import volumes of chlordecone. By 1976, technical chlordecone was not exported from the United States and the compound was no longer produced there. Diluted technical grade chlordecone (80% active ingredient) was exported to Europe, particularly Germany, in great quantities from 1951 to 1975 by the Allied Chemical Company (Epstein 1978) where the diluted technical product was converted to an adduct, Kelevan. Kelevan is a derivative of chlordecone and used for the same purposes. In the environment, it oxidizes to Chlordecone and could therefore also be considered with Chlordecone for listing in the Stockholm Convention. Approximately 90-99% of the total volume of Chlordecone produced during this time was exported to Europe, Asia, Latin America, and Africa. (DHHS 1985; EPA 1978b) (Modified from US ATSDR, 1995) There is no information, indicating that Kelevan is being produced or used at present.

Chlordecone was marketed in France as a formulation, Curlone, by De Laguarique from 1981 to 1993. The formulation was used in Martinique and Guadeloupe following hurricane Allen in 1979 and David in 1980 which led to considerable pest infestations. Chlordecone for this formulation was synthesised in Brazil. The authorisation for Curlone was withdrawn by the French Ministry of Agriculture in 1990. Use was continued until September, 1993. (Beaugendre, 2005) In Canada, no product containing Chlordecone has been registered as a pest control product since 2000.

2.1.3 Uses

Chlordecone has been used extensively in the tropics for the control of banana root borer (Anonymous, 1978a; Langford, 1978). This was its only registered food use. It is regarded as an effective insecticide against leaf-cutting insects, but less effective against sucking insects (Information Canada, 1973). Historically, Chlordecone has been used in various parts of the world for the control of a wide range of pests. It can be used as a fly larvicide, as a fungicide against apple scab and powdery mildew (Information Canada, 1973), and to control the Colorado potato beetle (Motl, 1977), rust mite on non-bearing citrus, and potato and tobacco wireworm on gladioli and other plants (Suta, 1978). Chlordecone has also been used in household products such as ant and roach traps at concentrations of approximately 0.125% (IARC 1979a). The concentration used in ant and roach bait was approximately 25%. (Epstein 1978) (Modified from EHC 43 (IPCS, 1984) and US ATSDR, 1995).

2.1.4 Releases to the environment

Given the specific pesticidal uses of Chlordecone, it can be expected that all amounts manufactured are ultimately released to the environment. The use of Chlordecone as a pesticide in Martinique and Guadeloupe until 1993 resulted in severe contamination of soil and surface water, which are being monitored at present. (Bocquene & Franco, 2005, Beaugendre, 2005).

Major releases of Chlordecone occurred to the air, surface waters, and soil surrounding a major American manufacturing site in Hopewell, Virginia. Releases from this plant ultimately contaminated the water, sediment, and biota of the James River, a tributary to the Chesapeake Bay (Quoted from US ATSDR, 1995).

2.2 Environmental fate

The partitioning of Chlordecone in the environment will be governed by its high log K_{ow} (5.41 or 4.50) and relatively low water solubility (1-3.0 mg/L) resulting in sorption to particulate matter (dust, soil and sediment) and organic material (living organisms).

The combination of these properties and the vapour pressure (3.0-4.0x10^{-5} Pa) of Chlordecone, results in a relatively low potential for volatilisation as the Henry's Law Constant is between 2.0x10^{-2} and 5.45x10^{-3} Pa m^3/mole (25 °C), depending on the type of data used for the calculation (Table 1.1.).

In the EHC 43 (IPCS, 1984), the volatilisation of Chlordecone is evaluated based on laboratory and field observations that indicate that Chlordecone does not volatilise to any significant extent (Dawson, 1978). However, the release of copious quantities of Chlordecone dust from production facilities has represented a major source of environmental and human contamination. Airborne Chlordecone has been known to spread 60 miles from a point source (Feldmann, 1976), and the potential exists for further dispersion of fine particles (Lewis & Lee, 1976 (Abbreviated from EHC 43 (IPCS, 1984).)

The US ATSDR (1995,), concluded that Chlordecone released to the environment partitions to soil and sediment. Small amounts may remain dissolved in water and Chlordecone released to the atmosphere is eventually deposited on soil or surface waters.

2.2.1 Persistence

In the EHC 43 (IPCS, 1984), early reports that did not include any evidence of Chlordecone degradation in the natural environment (Dawson, 1978; Geer, 1978) were quoted as well as a more recent study, in which microbial action had been shown to transform Chlordecone into monohydro- and possibly dihydrochlordecone (Orndorff & Colwell, 1980a).

EHC 43 (IPCS, 1984), concluded that Chlordecone is an extremely stable compound and is not expected to degrade in the environment to any significant extent. However, there have been reports of trace amounts of monohydrochlordecone being found (Carver *et. al.*, 1978, Orndorff & Colwell, 1980b), but the mechanism of its formation is not clear. Solar irradiation of Chlordecone in the presence of ethylenediamine results in 78% degradation after 10 days (Dawson, 1978) quoted from EHC 43 (IPCS, 1984). However, ethylenediamine is not usually present in the atmosphere, so at the time, there was no information available regarding the photolytic stability of Chlordecone under environmental conditions.

The more recent review (US ATSDR, 1995), concludes that Chlordecone is not expected to be subject to direct photodegradation in the atmosphere. Furthermore, it is concluded that Chlordecone is resistant to aerobic degradation, although some anaerobic biodegradation does occur and that Chlordecone is very persistent in the environment. Chlordecone will strongly bind to organic matter in water, sediment, and soil. When bound to organic-rich soil, Chlordecone is highly immobile; however, when adsorbed to particulate matter in surface water, Chlordecone can be transported great distances before partitioning out to sediment. The primary process for the degradation of Chlordecone in soil or sediments is anaerobic biodegradation (Abbreviated from US ATSDR, 1995) .

Information regarding the persistence of Chlordecone dating after 1995 is scarce, but the use of Chlordecone until 1993 in the Caribbean island of Martinique has resulted in severe contamination and monitoring studies have been initiated. Bocquene & Franco (2005) reported concentrations in samples from 2002 in water (particulate matter) and sediment in rivers of up to 57 µg/kg and 44 µg/kg, respectively. They quoted other investigations for reporting concentrations in river water, sampled in 2000-2001 in the range 1.20 - 2.13 µg/L.

Even though Chlordecone was prohibited from main land France, an exemption was granted that allowed the use of it in the French West Indies until September, 1993. A recent study showed that it is still detected in different ecosystems of Martinique (Coat, S. *et. al.*, 2006). Stocks of Chlordecone may have been used in Martinique after 1993, but it is expected that the use ceased several years ago. However, residues are still measurable in both river water and sediment, where the prevailing anaerobic conditions in the latter allow for the only known biotic degradation of Chlordecone. This is all the more remarkable as the climate in this area is optimal not only for crops and pests but also for biodegradation.

Conclusion

Chlordecone is not expected to hydrolyse or biodegrade in aerobic aquatic environments or in soil; however, there is some evidence of degradation under anaerobic condition. Direct photodegradation is not significant. Based on all available data Chlordecone is considered to be highly persistent in the environment.

2.2.2 Bioaccumulation

Because of the lipophilic nature of this compound (high octanol-water partition coefficient (log K_{ow} 4.50-5.41), Chlordecone has a potential for both bioaccumulation and, with little or no metabolic depuration, also biomagnification in aquatic food chains.

Table 2.1 summarises bioconcentration factors (BCF) selected from the US EPA database Ecotox (US EPA, 2006). The results included are based on measured concentrations and, for organisms different from algae, derived from tests based on flow through exposure. Thereby, the results should reflect the bioconcentration obtained under well defined, constant exposure concentrations. For fish, the results of a series of tests of four days duration were not included, because it is not considered to be likely that equilibrium had been reached[6]. Two additional studies from EHC 43 (IPCS, 1984) are also included.

Table 2.1 BCF values for Chlordecone.

Species	Test Duration	Exposure Concentration µg/L	BCF	Reference[1]
Green algae (*Chlorococcum sp., Dunaliella tertiolecta*)	24 h	100	230-800	Walsh *et. al.*, 1977
Green alga (*Chlorococcum sp.*)	48 h	40	6,000	Bahner *et. al.*, 1977
Diatoms (*Thalassiosira guillardii, Nitzschia sp.*)	24 h	100	410-520	Walsh *et. al.*, 1977
Crustacean (*Callinectes sapidus*)	96 h	110-210	6.2-10.4	Schimmel, 1977
Crustacean (*Palaemonetes pugio*)	96 h	12-121	425-933	Schimmel, 1977
Crustacean (*Palaemonetes pugio, Americamysis bahia*)	21-28 d	0.023-0.4	5,127-13,473	Bahner *et. al.*, 1977
Crustacean (*Palaemonetes pugio*)	16 d	0.041	12,094	Fisher & Clark, 1990
Oyster (*Crassostrea virginica*)	19-21 d	0.03-0.39	9,278-9,354	Bahner *et. al.*, 1977
Midge (*Chironomus tentans*)	14 d	11.8-169.2	21,600	Adams *et. al.*, 1985
Fish (*Brevoortia tyrannus*)	1-18 d	0.14-1.55	2,300-9,750	Roberts & Fisher, 1985
Fish (*Menidia menidia*)	1-28 d	0.08-0.8	21,700-60,200	Roberts & Fisher, 1985
Fish (*Cyprinodon variegatus*)	28 d	< 0.02-1.9	3,100-7,115	Bahner *et. al.*, 1977; Hansen *et. al.*, 1977
Fish (*Leiostomus xanthurus*)	30 d	0.029-0.4	2,340-3,217	Bahner *et. al.*, 1977
Fish (*Pimephales promelas*)	56 d	0.004	16,600	Huckins *et. al.*, 1982[2]
Fish (*Cyprinodon variegatus*)	Life cycle	0.041	1,800-3,900	Goodman *et. al.*, 1982[2]

1: All quoted from the Ecotox database (US EPA, 2006), except for two[2] quoted from EHC 43 (IPCS, 1984)

The information on bioaccumulation from food is limited, but the EHC 43 (IPCS, 1984) report includes two relevant studies; one on food exposure and the other on an estuarine food chain. When chlordecone was fed to juvenile spot for 28 days, the body burden of chlordecone increased additively and equilibrium was not attained (Stehlik & Merriner, 1983). The estuarine food chain study (Bahner *et al*., 1977) was composed of green algae, oysters, mysids, grass shrimps, sheepshead minnows and spot. The transfer from algae to oysters was very low; but a clear transfer from shrimp to mysids

[6] In OECD Test Guideline 305, the prescribed duration of the exposure phase is 28 days.

and from mysids to spot, indicated that much of the chlordecone was being transferred through the trophic levels. Clearance was slow in shrimp and fish, with tissue levels of chlordecone decreasing by 30-50% in 24-28 days.

US ATSDR (1995), described the bioaccumulation of chlordecone together with that of mirex, stating that they are both highly lipophilic and therefore, have a high bioconcentration potential. They bioaccumulate in aquatic food chains with virtually no degradation of the compounds by exposed organisms (de la Cruz and Naqui, 1973; Epstein, 1978; Huckins *et al.*, 1982; Huggett and Bender, 1980; Kenaga, 1980; Lunsford *et al.*, 1987; Naqvi and de la Cruz, 1973; Nichols, 1990; Oliver and Niimi, 1985 and 1988; Roberts and Fisher, 1985)[7].

Only limited information is available on uptake and bioaccumulation of chlordecone in terrestrial food chains (Naqvi and de la Cruz, 1973), and little uptake of chlordecone by plants was observed (Topp *et. al*., 1986).

Conclusion

With BCF-values of up to 6,000 in algae, of up to 21,600 in invertebrates and of up to 60,200 in fish, and with documented examples of biomagnification, chlordecone is considered to have a high potential for bioaccumulation and biomagnification.

2.2.3 Potential for Long-Range Environmental Transport

The potential for long-range environmental transport can be documented through monitoring data from remote regions (*e.g.* the Arctic) and/or through physical-chemical characteristics of the molecule, which are promoting such transport. The most well known mechanism of long-range transport is atmospheric transport of substances in the vapour phase. However, atmospheric transport of particle-bound substances and transport of sediment particles in ocean currents as well as biotic transport could also contribute (*e. g.* AMAP 2004).

One prerequisite for long-range atmospheric transport is persistence to degradation, and Chlordecone is considered to be highly persistent in the environment (see Section 2.2.1). Chlordecone does not volatilise to any significant extent (see section 2.2). The partitioning of Chlordecone in the environment will be governed by its high log K_{ow} (5.41 or 4.50) and relatively low water solubility (1-3.0 mg/L) resulting in sorption to particulate matter (dust, soil and sediment) and organic materials and living organisms. Therefore, the long range transport is expected to take place through these pathways.

The US ATSDR (1995), states that atmospheric transport of dust containing Chlordecone particles was reported during production years based on results from high volume air sample filters from Hopewell: At approximately 200 yards from the Chlordecon production plant, the contents ranged from 3.0-55 micrograms/m^3, depending on weather conditions and date of collection. At more distant sites in May 1975, levels ranged from 1.4-21 ng/m^3. Specifically, in South Richmond, 15.6 miles north west from Hopewell, the level was 1.41 ng/m^3. At Byrd airport, 14.12 miles north of Hopewell, the level was 1.93 ng/m^3. In Petersburg, 8.19 miles south west from Hopewell, the level was 20.7 ng/m^3. (Epstein, 1978). They conclude further, that airborne Chlordecone has been known to spread 60 miles from a point source (Feldmann, 1976), and that the potential exists for further dispersion of fine particles (Lewis & Lee, 1976) (US ATSDR, 1995).

Transport in aquatic environments is illustrated by results of measurements in clams and oysters from the James River at sampling locations from 8-64 miles from Hopewell, Virginia that contained 0.2-0.8 mg/kg of Chlordecone (Epstein, 1978).

However, no records are available regarding concentrations of Chlordecone in areas at long distances from sites of production or use. Therefore, the assessment of the potential for long-range transport of Chlordecone must be based on physical properties. For this - apart from persistence - the vapour pressure and the Henry's Law Constant are considered to be the most relevant properties. For a comprehensive evaluation of the potential for long-range atmospheric transport, knowledge of the vapour pressure at high as well as at low temperatures (*e. g.* 25 °C and 0 °C) is required. This information is, however, available for only a few substances (AMAP, 2004), so the vapour pressure at 25 °C is used as a measure of the volatility of the substance.

As a rule of thumb, substances with vapour pressures $>1.33 \times 10^{-2}$ Pa will be entirely in the vapour phase and substances with vapour pressures $<1.0 \times 10^{-4}$ Pa will be particulate (US ATSDR, 2004).

A way of evaluating the characteristics and effects of a substance for which not enough information exists is to compare it with better known substances of similar characteristics. This approach (known as "the benchmark approach") was proposed by Scheringer (1997) and Beyer *et. al.,* (2000), has been recently used in some recent studies concerning persistence and environmental transport of pollutants (see, *i. e.* Vulykh *et. al.,* 2006, and Klasmeier *et. al.,* 2006). As a measure of values of properties that would qualify for long-range atmospheric transport, the currently listed POPs are used. However,

[7] These references describe both Mirex and Chlordecone.

information regarding physical-chemical properties for chemicals often varies widely between sources and the quality of data cannot be compared without specific review of the individual studies. This is demonstrated by the available data on the physical-chemical properties of Chlordecone presented in Table 1.1. The two values for the vapour pressure are rather uniform (0.3 and $0.4x10^5$ Pa) but the water solubility found in literature varies by an order of magnitude (0.35–3.0 and the lowest value is considered to be unreliable.[8]

The comparison of Chlordecone with already listed POPs is presented in Table 2.2. As a starting point for this comparison, the highest and lowest values for Chlordecone (Table 1.1) were used. For already listed POPs, information was sought on the UNEP-POPs homepage. Among the currently listed POPs, most of the relevant properties were available for aldrin, chlordane, dieldrin, DDT, hexachlorobenzene, mirex, toxaphene, endrin and heptachlor. Missing information (water solubility of mirex) was sought in US ATSDR (1995) and AMAP (2004). The US ATSDR (1995), quotes values of 0.2 and 0.6 mg/L, while the AMAP (2004), quotes Mackay for very low water solubility: $6.5x10^{-5}$ mg/L. In order to avoid introduction of what seems to be an outlier in the comparison, the value for water solubility of mirex from US ATSDR (1995) was used.

The water solubility and vapour pressure as well as Henry's Law Constants calculated from these values of the currently listed POPs are summarised in Table 2.2 together with information on Chlordecone from Table 1.1.

Table 2.2 Water solubility (WS), vapour pressure (VP) and (calculated) Henry's Law Constant (HLC) (at 25°C) for Chlordecone and currently listed POPs.

Substance	WS mg/L	VP Pa	HLC Pa m^3/mol
Chlordecone-min	1.0	0.00003	0.0049[1]
Chlordecone-max	3.0	0.00004	0.02[2]
POP-min	0.0012 (DDT)	0.000025 (DDT)	0.04 (endrin)
POP-max	3.0 (toxaphene)	27 (toxaphene)	3726 (toxaphene)
POP-2nd max	0.5 (dieldrin)	0.04 (heptachlor)	267 (heptachlor)

1: Calculated from maximum water solubility and minimum vapour pressure
2: Calculated from minimum reliable water solubility and maximum vapour pressure

Table 2.2 shows that the water solubility of Chlordecone is at the level of the most water soluble among the currently listed POPs (toxaphene and dieldrin), while the vapour pressure is comparable to that of DDT. The highest of the two Henry's Law Constants that were calculated for Chlordecone is of the same order of magnitude as that of endrin. It should be noted that in presenting the data in table 2.2 it is not inferred that a chemical (in this case Chlordecone) is considered to meet the long range environmental transport criterion just because it fits within the range of values of currently listed POPs.

Further to this, it should be mentioned that the latest AMAP report on POPs (AMAP, 2004) describes the possibilities of particle borne transport for substances, which have Henry's Law Constants (HLC) close to that of Chlordecone (HLC = 0.0049 or 0.056). Based on HLC-values from AMAP (2004), it is concluded that semi-volatile compounds such as lindane (γ-HCH) (HLC = 0.000149) and chlordane (HLC = 0.342) are distributed between airborne particles and the gaseous phase, depending on the temperature. These can be washed out *via* precipitation and temporarily deposited in seawater or soil and can absorb to water, plant and soil surfaces from the gaseous phase. During favourable warm weather conditions, these compounds evaporate again into the atmosphere and undergo further atmospheric transport. This remobilization is also called the 'grasshopper effect'. The role of stormy weather situations in remobilization of semivolatile compounds into the atmosphere is obvious but still scarcely investigated (AMAP, 2004).

Besides, certain physical-chemical properties of Chlordecone, such as the partition coefficients log K_{ow} (octanol-water partition coefficient) and log Kaw (air-water partition coefficient), are similar to those of some toxaphene components which, added to its persistence in air and water, would mean that coupled long range transport in atmosphere and oceans may take place (*i. e.* the substance is exchanging between atmospheric gas phase and oceanic dissolved phase and can be

[8] Availability of high quality data regarding physical-chemical properties could support more firm conclusions.

transported in either phase). (Wania, F. 2006, personal communication). Chlordecone has a very low Henry's law constant and a high mass fraction is found in water, and therefore it can be inferred that transport with ocean currents contributes to the long-range transport of Chlordecone.

In a recent modeling study, Scheringer *et. al*.,(2006), investigated the persistence and long range transport potential of these potential POPs, including chlordecone and hexabromobiphenyl, using an OECD screening tool which based the evaluation of overall environmental persistence and transport potential on the results of several of the currently available multimedia environmental fate models (see also Klasmeier *et. al*., 2006, and Fenner *et. al*., 2005 for a more detailed explanation). They concluded that the four POP candidates have persistence and long range transport potential properties similar to those of several known POPs in this evaluation. Furthermore, they included the uncertainty regarding the data quality in an uncertainty analysis, which indicated that the result is valid although there are considerable uncertainties in the chemical properties of the four POP candidates. It should be noted that environmental fate modeling results strongly depend on the assumptions made, specifically when essential data such as environmental half-lives are not known. In addition, results for substances like Chlordecone, which are strongly bound to particles and are of very low volatility, are highly dependent on the medium to which they are emitted, i.e., to air, to water, or to soil. The emission to air scenario always yields the highest transfer efficiency, and that value is displayed in the Scheringer *et. al.*, (2006) plots. Transfer efficiency will likely differ by several orders of magnitude when evaluated under soil and water emission scenarios.

Conclusion

In summary, the above discussion shows that the available data on Chlordecone are not conclusive when it comes to long-range atmospheric transport in gaseous form. However, atmospheric transport of particle-bound substances and transport of sediment particles in ocean currents, as well as biotic transport, could also contribute to long-range environmental transport of Chlordecone Coupled atmosphere-ocean transport also seems quite possible.

Due to a lack of monitoring data on Chlordecone the assessment of the potential for long-range transport of Chlordecone must be based on physico-chemical properties and modelling data. The modelling study of Scheringer *et. al.*, 2006, shows clearly that long range environmental transport is possible (and possibly more than actually estimated), even considering the uncertainties surrounding the physico-chemical properties.

In accordance with paragraph 7 (a) of Article 8 of the Convention, and taking into account that a lack of full scientific certainty should not prevent a proposal from proceeding, Chlordecone 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.

2.3 Exposure

2.3.1 Environmental concentrations

The available information regarding environmental concentrations of Chlordecone is very limited and includes only areas in the vicinity of production (US) or use (Martinique).

The US ATSDR (1995), illustrates the presence of Chlordecone in the environment following production of the substance. In 1977, 12 years after production of Chlordecone began and 2 years after the production ceased, average concentrations of Chlordecone in estuarine water (dissolved) were <l0 ng/L (ppt) (Nichols 1990). In October 1981, 6 years after production ceased, Chlordecone water concentrations ranged from not detectable to 0.02 µg/L (ppb) (Lunsford *et. al.,* 1987). Groundwater monitoring data are lacking, but because Chlordecone binds tightly to organic matter in soil, leaching into groundwater is not expected to occur extensively (Abbreviated from US ATSDR, 1995).

Recent monitoring data from the United States demonstrate the persistence of Chlordecone, known as Kepone in the United States. The substance is included in the U.S. EPA National Lake Fish Tissue Study to estimate the national distribution of selected residues in fish tissue from lakes and reservoirs in the lower 48 states. There were a total of 881 samples collected and analyzed between 2000 and 2005. For Chlordecone, there were 152 hits (17.25%), ranging from 12.3 and 2008 ppb. (Jensen, 2006).

In Martinique, the widespread use of Chlordecone until 1993 has resulted in contamination of soils and surface water in most of the island (Bocquené & Franco, 2005). These authors reported an investigation from 2002 of the presence of a series of pesticides in the water at the mouth of seven rivers. They measured Chlordecone in particulate matter or sediment of six of the seven rivers at concentrations up to 57 µg/kg in particulate matter, and up to 44 µg/kg in sediment.

Bocquené & Franco (2005), quoted other investigations in which concentrations of Chlordecone in the range 1.20 to 2.13 µg/L were measured in rivers of Martinique in 2002-2001. They also stated that Chlordecone was "ubiquitous" in river water used for drinking water.

Further to this, the report prepared for L'Assemblée Nationale (Beaugendre, June 2005), described the history of the use of Chlordecone in Guadeloupe and Martinique, and mentioned several monitoring programmes which are expected to result in reports at the end of 2005. However, these reports have not been available when drafting this document.

2.3.2 Human exposure

In the US ATSDR (1995), the experience from production of Chlordecone is summarised as follows: Chlordecone has not been detected in human adipose tissue or in blood samples from the general population, although historically it was detected in human milk samples collected in the south-eastern United States (EPA 1978c). Information is available regarding Chlordecone levels in blood of occupationally exposed workers and their families during 1974-1975 employed at the Hopewell, Virginia site. (Cannon *et. al.*, 1978; Epstein 1978; Knishkowy & Baker 1986; Taylor *et. al.*, 1978). (Quoted from US ATSDR, 1995) Further data on human exposure is quoted in section 2.4.1.

Information regarding human exposure resulting from direct use (application) of Chlordecone in the Caribbean Islands is not available. However, monitoring data in agricultural soils, crops, freshwater fish, littoral fish and shellfish indicates that human exposure more than 10 years after the use of chlordecone has ceased in Martinique and Guadeloupe, is still possible In soils having received Chlordecone, residues in crop are proportional to soil contamination and may exceed the recommended national residues limits (50 µg/kg to 200 µg/kg). This concerns mainly root vegetables such as radish (max. measured concentration: 0.055 µg/kg), sweet potatoes (max. measured concentration: 0.300 µg/kg), taro root (max. measured concentration: 0.230 µg/kg), but also aerial part of plants, such as sugar cane (max. measured concentration: 0.690 µg/kg), or pineapple (max. measured concentration: 0.160 µg/kg). In addition, workers are directly exposed to contaminated soils. Concentrations in fisheries products (freshwater and estuarine water) have also been found to exceed in some occasions national residues limits up by a factor of 100 (max. measured concentration: 20 mg/kg). National provisions have been taken in order to prohibit fisheries activities in contaminated area (Cabidoche *et. al*., 2006).

2.4 Hazard assessment for endpoints of concern

2.4.1 Toxicity

Toxicokinetics in experimental animals and in man

The US ATSDR (1995) and EHS 43 (IPCS, 1984) both record that Chlordecone is well absorbed following oral, dermal and inhalation exposure. Toxicokinetic data are mainly available from studies in experimental animals (*e. g.* Blanke *et. al.*, 1978; Boylan *et. al.*, 1979; Cohn *et. al.*, 1978; Egle *et. al.*, 1978; Fujimori *et. al.* 1982a; Guzelian *et. al.*, 1981; Hall *et. al.* 1988; Hewitt *et. al.*, 1986b; Kavlock *et. al.*,1980; Plaa *et. al.*, 1987; Richter *et. al.*, 1979; Shah *et. al.*, 1987; Skalsky *et. al.*, 1980; as reported in IPCS, 1984). Following absorption, it is widely distributed in the body, with accumulation in the liver and to a lesser extent in fat, brain and kidneys, both in experimental animal studies and in humans (as reported in US ATSDR (1995) and EHS 43 (IPCS, 1984). Following administration of a single oral dose to rats at 40 mg/kg body weight, the highest concentrations were found in the adrenal glands and liver, followed by the fat and lung (Egle *et. al.*, 1978, quoted from IPCS, 1984). Chlordecone has been reported to be slowly metabolised *via* reductive biotransformation to Chlordecone alcohol in the rat (Blanke *et. al.*, 1978, as reported in EHS 43). Elimination from the body is slow, with a half-life of the order of several months and Chlordecone disappears more slowly from the liver than from other tissues (Egle *et. al.*, 1978, quoted from IPCS, 1984). Elimination is mainly *via* the faeces, a total of 66% of the dose in the Egle study being removed in the faeces and 2% in the urine in the 84 days following administration (Egle *et. al.*, 1978, quoted from IPCS, 1984).

EHC 43 reports that Chlordecone was detected in high concentrations in the liver (range 13.3-173 mg/kg), whole blood (range 0.6-32 mg/litre), and subcutaneous fat (range 2.2-62 mg/kg) of 32 male workers (Cohn *et. al.*, 1976, adapted from IPCS (1984). In occupationally-exposed workers, serum Chlordecone concentrations ranged from 120 to 2109 µg/litre, and dropped to 37 - 486 µg/litre 6-7 months after exposure had ceased (Adir *et. al.*, 1978, reported in IPCS (1984). The half-life of Chlordecone in these workers was estimated to be 63-148 days. Reductive biotransformation to Chlordecone alcohol has also been reported in humans (Blanke *et. al.*, 1978, as reported in EHS 43). Chlordecone was eliminated, primarily in the faeces, at a mean daily rate of 0.075% of the estimated total store in the body (Cohn *et. al.*, 1976, quoted from IPCS, 1984).

Toxicity of Chlordecone in animal studies

Chlordecone is of high acute toxicity in experimental animal studies, with an LD_{50} of approximately 100 mg/kg in the rat and ranging from 65 mg/kg in the rabbit to 250 mg/kg in the dog (taken from IPCS, 1984, Table 2). Acute toxicity effects include tremors indicative of a neurotoxic effect on the nervous and/or musculoskeletal systems, investigated by many authors as reported in US ATSDR (1995). The neurotoxic effects of Chlordecone have been reported in chickens (Naber & Ware, 1965), quail (McFarland & Lacy, 1969), fish (Couch *et. al.*, 1977), hamsters (Martinez *et. al.*, 1976), mice (End *et. al.*, 1979), rats (Epstein, 1978), and man (Martinez *et. al.*, 1978). Acute oral administration of Chlordecone is also associated with reproductive effects (Khera *et. al.*, 1976; Uzodinma *et. al.*, 1984a; Yarbrough *et. al.*, 1981) and hepatotoxicity in some studies (Fujimori *et. al.*, 1983; Mehendale 1977b, 1981b; Teo & Vore 1991) (quoted from US ATSDR (1995).

Repeated exposure to Chlordecone also causes reproductive, neurological, musculoskeletal and liver toxicity at doses as low as 10 mg/kg bw/day, although effects in other organs including kidney, thyroid, adrenals, and testes have also been reported (US ATSDR, 1995, IPCS, 1984). A Lowest-Observed-Adverse-Effect-Level (LOAEL) of 1.17 mg/kg bw/day was recorded in a 3 month feeding study in rats and signs of toxicity included focal necrosis in liver, enlargement of the adrenal gland, tremor, hyperactivity and exaggerated startle response (Cannon and Kimbrough, 1979, as quoted in US ATSDR, 1995). Histopathological changes in the liver, reduction in thyroid follicular size and colloid content and increase in epithelial cell height were reported in a 21-month gavage study in the rat, with a LOAEL of 0.07 mg/kg bw/day in males (Chu *et al*, 1981, as quoted in US ATSDR, 1995). Renal effects (proteinuria and increased severity of glomerulosclerosis) were seen in a 2-year feeding study in rats, with a NOAEL of 0.05 mg/kg/day (Larson *et. al.*, 1979b, as quoted in US ATSDR, 1995). Oral Chlordecone treatment caused decreased spleen and thymus weights, leukocyte counts, natural killer cell activity, and mitogenic responsiveness (EPA 1986c; Smialowicz *et. al.*, 1985; Swanson and Wooley, 1982); decreased natural killer cell activity (Smialowicz *et. al.*, 1985); and significant increase in plaque-forming cells (Chetty *et. al.*, 1993c) (as reported in ATSDR, 1995). The NOAEL was 5 mg/kg bw/day and the LOAEL was 10 mg/kg bw/day.

Hepatocarcinogenicity (hepatocellular carcinoma) of Chlordecone has been demonstrated in rats and mice (males and females) (NCI 1976, Reuber, 1978, 1979, as quoted in IPCS, 1984 and US ATSDR, 1995). Tumours have been observed at doses as low as 1 mg/kg bw/day in the rat and in mice at a dose of 2.6 mg/kg bw/day (NCI, 1976, as quoted in US ATSDR (1995). The International Agency for Research on Cancer (IARC) concluded in 1987 that there was sufficient evidence that Chlordecone is carcinogenic in mice and rats and possibly carcinogenic to humans (Group 2B). Chlordecone is not genotoxic in *in vitro* microbial and mammalian cell gene mutation assays, in a clastogenicity test and in the dominant lethal assay (Mortelmans *et. al.*, 1986; Probst *et. al.*, 1981; Schoeny *et. al.*, 1979, Tong *et. al.* 1981; Williams 1980, Khera *et. al.*, 1976; Simon *et. al.*, 1986, as reported in ATSDR (1995), although it has been reported to interfere with cell-to-cell communication (Tsushimoto *et. al.*, 1982, Caldwell and Loch-Caruso, 1992, as reported in US ATSDR (1995), suggests that it produces liver tumours by an epigenetic, tumour-promoting mechanism involving both hepatic toxicity and hypertrophy, including cytochrome P-450 induction.

Oral administration of Chlordecone to animals causes decreased fertility or fecundity and litter size, reduced sperm count and testicular atrophy (Khera *et. al.*, 1976; Linder *et. al.* 1983; Uzodinma *et. al.*, 1984a; Yarbrough *et. al.* 1981, as reported in US ATSDR (1995). A LOAEL of 0.83 mg/kg/day was recorded for sperm effects in a 90 day feeding study in rats, while effects on seminal vesicles and prostate were apparent at 1.67 mg/kg bw/day (Linder *et. al.*, 1983) (Quoted from US ATSDR (1995).

Chlordecone is also a developmental toxicant. As reported in US ATSDR (1995) and EHC 43 (IPCS, 1984), gestational exposure of rats and mice to low doses of Chlordecone resulted in increased stillbirths and decreased postnatal viability, reduced fetal or neonatal weight and/or skeletal ossification and a low incidence of malformations such as renal pelvis dilatation, undescended testes, enlarged cerebral ventricles, clubfoot, fused vertebrae or ribs, and encephalocele. Chlordecone administered at levels of 2, 6, and 10 mg/kg bw/day to rats and 2, 4, 8, and 12 mg/kg body weight per day to mice on days 7 - 16 of gestation caused 19% maternal mortality in rats at the highest dose and fetuses exhibited reduced weight, reduced degree of ossification, oedema, undescended testes, enlarged renal pelvis, and enlarged cerebral ventricles. (Chernoff & Rogers, 1976, as reported in IPCS, 1984). Lower dose levels induced reductions in fetal weight and degree of ossification. Male rats born to treated dams did not show any reproductive impairment. The reproductive performance of mice fed 0, 10, 30, or 37.5 mg Chlordecone/kg diet was impaired in terms of offspring and litter size (Huber, 1965, as reported in IPCS, 1984). No litters were produced by females fed 40 mg/kg, but litter production did resume within 7 weeks following withdrawal of the Chlordecone, although litters were still smaller than those of untreated controls (quoted from IPCS (1984)). Anovulation and persistent vaginal estrus were observed in female mice given Chlordecone at a dose level of 2 mg/kg bw/day) (Swartz *et. al.*, 1988, as quoted in US ATSDR, 1995), and similar changes were observed in female offspring of maternal rats given 15 mg/kg/day of Chlordecone on gestation days 14-20 (Gellert and Wilson, 1979, as

quoted in US ATSDR, 1995), although no effects on vaginal patency or fertility were observed in female offspring of maternal mice given 20 mg/kg/day during gestation days 8-12 or 14-18 (Gray and Kavlock 1984, as quoted in US ATSDR, 1995).

Toxicity of Chlordecone in humans

Available human data support the conclusion that Chlordecone has a similar toxicity profile in humans to that seen in experimental animal studies. As reported in US ATSDR (1995), a high incidence of nervous system toxicity was seen in a single group of workers exposed to Chlordecone during its manufacture (Cannon *et. al.*, 1978; Martinez *et. al.*, 1978; Sanbom *et. al.*, 1979; Taylor 1982, 1985; Taylor *et. al.*, 1978, taken from US ATSDR (1995)). Exposure of this population occurred by a combination of inhalation, oral, and dermal exposures, although the dermal route was suggested to be the predominant route. The toxicity was manifested as tremors, visual difficulties, muscle weakness, gait ataxia, in coordination, headache, and increased cerebrospinal fluid pressure (US ATSDR (1995). Prolonged exposure to high concentrations of Chlordecone in the workplace has been suggested to cause oligospermia and decreased sperm motility among male workers, although fertility was not impaired (Guzelian 1982a; Taylor 1982, 1985; Taylor *et. al.,* 1978, taken from US ATSDR (1995). A correlation between blood levels, atmospheric levels and sperm effects has however been difficult to prove conclusively (US ATSDR (1995). Epidemiological evidence for carcinogenicity of Chlordecone in exposed humans following inhalation exposure to Chlordecone is extremely limited (US ATSDR, 1995, IPCS, 1984). Liver biopsy samples taken from 12 workers with hepatomegaly resulting from intermediate- or chronic-duration exposures to high concentrations of Chlordecone showed no evidence of cancer (Guzelian *et. al.,* 1980, taken from US ATSDR (1995). However, conclusions from this study are limited by the very small number of workers sampled (US ATSDR, 1995)

Effects on endocrine systems

The effects of Chlordecone on reproduction indicate that this pesticide has effects on endocrine systems. It has been evaluated under the EU-Strategy for Endocrine Disrupters[9] and has been placed in category 1 (evidence of endocrine-disrupting activity in at least one species using intact animals), in the priority list of chemicals established under the EU-Strategy. This categorisation is based on evidence of ED activity in a number of experimental systems including the mouse uterotropic assay, increased uterine weight in rats given multiple injections of Chlordecone postnatally and receptor binding assays, indicative of an oestrogenic effect (as reported in BKH report, 2000, US ATSDR, 1995).

Conclusion on effects assessment and toxicity of Chlordecone

Chlordecone is readily absorbed into the body and accumulates following prolonged exposure. The pesticide is both acutely and chronically toxic, producing neurotoxicity, immunotoxicity, reproductive, musculoskeletal and liver toxicity at doses between 1 - 10 mg/kg bw/day in experimental animal studies. Liver cancer was induced in rats at a dose of 1 mg/kg body weight per day and in mice at a dose of 2.6 mg/kg bw/day, and reproductive effects are seen at similar dose levels. The International Agency for Research on Cancer has classified Chlordecone as a possible human carcinogen (IARC group 2B).

Table 2.3 summarises the outcomes of key toxicological studies on Chlordecone, including the NOAEL/LOAEL derived in each study. The studies included in this Table have been selected from the very large database on toxicological studies on Chlordecone, on the basis of the importance of the endpoint investigated (*e. g.* reproductive toxicity, carcinogenicity, other key target organ toxicity), robustness of the reported studies and the dose level (NOAEL/LOAEL) at which effects were reported. These studies were considered to be particularly relevant for characterisation of the toxicological risks of these compounds, and some of these studies have been used by US ATSDR to define Minimal Risk Levels (MRLs) for Chlordecone (US ATSDR, 1995).

Table 2.3 Summary of key toxicological studies on Chlordecone.

Species	Study type	Effect	LOAEL/NOAEL (mg/kg bw/day)	Reference
Rat Fischer 344	Short-term/acute toxicity 10 day repeat dose gavage study	65% loss in body weight, changes in clinical chemistry parameters	10 mg/kg bw/day (LOAEL) 5 mg/kg bw/day (NOAEL)	EPA, 1986 (as quoted in US ATSDR, 1995).
Rat Fischer 344	Short-term/acute toxicity 10 day repeat dose	Reductions in spleen and thymus weights, numbers of neutrophils, and natural killer cell activity, secondary to generalized toxicity	10 mg/kg bw/day (LOAEL) 5 mg/kg bw/day	EPA, 1986; Smialowicz *et. al.*, 1985, (as quoted in US ATSDR, 1995).

[9] http://europa.eu.int/comm/environment/endocrine/strategy/substances_en.htm

Species	Study type	Effect	LOAEL/NOAEL (mg/kg bw/day)	Reference
	gavage study		(NOAEL)	
Rat Fischer 344	Short-term/acute toxicity 10 day repeat dose gavage study	Increased startle response	2.5 mg/kg bw/day (LOAEL) 1.25 mg/kg bw/day (NOAEL)	EPA, 1986c (as quoted in US ATSDR, 1995).
Rat (Sherman)	3 month feeding study	Focal necrosis in liver, enlargement of the adrenal gland, hyperplasia and hypertrophy of cortical cells, tremor, hyperactivity, exaggerated startle response	1.17 mg/kg bw/day (LOAEL)	Cannon and Kimbrough 1979 (as quoted in IPCS, 1984 and US ATSDR, 1995).
Rat, Wistar	2 year feeding study	Renal effects (proteinuria and increased severity of glomerulosclerosis)	0.25 mg/kg bw/day. (LOAEL) 0.05 mg/kg bw/day (NOAEL)	Larson *et. al.*, 1979b (as quoted in IPCS, 1984 and US ATSDR, 1995).
Rat Sprague-Dawley	21 month gavage study	Histopathological changes in liver, reduction in follicular size and colloid content and increase in epithelial cell height in thyroid	0.07 mg/kg bw/day (LOAEL), in males	Chu *et. al.*, 1981(as quoted in IPCS, 1984 and US ATSDR, 1995).
Rat, Wistar	3 month feeding study	Testicular atrophy	0.5 mg/kg bw/day. (LOAEL) 0.25 mg/kg bw/day (NOAEL)	Larson *et. al.* , 1979b (as quoted in IPCS, 1984 and US ATSDR, 1995).
Rat (Osborne-Mendel) and mouse (B3C6F1)	80 week feeding study	Hepatocellular adenoma and carcinoma	1.2 mg/kg bw/day. (LOAEL, rat) and 2.6 mg/kg bw/day (LOAEL, mouse)	NCI, 1976, Reuber, 1978, 1979(as quoted in IPCS, 1984 and US ATSDR, 1995).
Rat	Multiple injections of Chlordecone to neonatal rats	Uterotrophic response - uterine weights increased in a dose-related manner	10 mg/kg bw/day (LOAEL, Gellert, 1978) $\leq$ 6 mg/kg bw/day (LOAEL, Hammond *et. al.*, 1979)	Gellert 1978; Hammond *et. al.*, 1979 (as quoted in IPCS, 1984 and US ATSDR, 1995).
Rat, Hotzman strain, ovarectomized immature females	Rats injected x 3 with 0 - 45 mg/kg bw/day Chlordecone $\pm$ 0.01, 0.1, 1 or 10 mg/kg bw/day estradiol benzoate	Uterotrophic response. Effect was additive to that of estradiol benzoate over the dose range studied	Dose of 20 mg/kg bw/day Chlordecone appeared to be threshold for embryo implantation functions	Johnson, 1996
Rat	90-day feeding study	Decrease in sperm motility and viability, decreased sperm, decrease in the weight of seminal vesicles and prostate	0.83 mg/kg bw/day LOAEL for sperm effects 1.67 mg/kg bw/day LOAEL for effects on seminal vesicles and prostate	Linder *et. al.*, 1983 (as quoted in IPCS, 1984 and US ATSDR, 1995).
Mouse, Balbc	130 day feeding study	8% decrease in litter size and 19% increase in pair-days to litter (constant oestrus)	1.3 mg/kg bw/day. (LOAEL)	Huber, 1965 (as quoted in IPCS, 1984 and US ATSDR, 1995).
Rats and mice	2, 6, and 10 mg/kg bw/day by gavage to rats and 2, 4, 8, and 12 mg/kg bw/day to mice on days 7 - 16 of gestation.	Reduced foetal weight, reduced degree of ossification, oedema, undescended testes, enlarged renal pelvis, and enlarged cerebral ventricles. Reductions in fetal weight and degree of ossification at lower dose levels. Maternal mortality at top dose. In the mouse, fetotoxicity was observed only at the highest dose level and consisted of increased fetal mortality and clubfoot.	2 mg/kg bw/day. (LOAEL, rat)	Chernoff & Rogers, 1976). (as quoted in IPCS, 1984 and US ATSDR, 1995).
Balbc mice	160 day feeding study	Increased ovulation, persistent oestrus	2 mg/kg bw/day. (LOAEL)	Swartz *et. al.*, 1988 (as quoted in IPCS, 1984 and US ATSDR, 1995).
Rat	Reproductive toxicity	Increased ovulation, persistent oestrus in female offspring of maternal rats given Chlordecone on gestation days 14-20	15 mg/kg/day (LOAEL)	Gellert and Wilson, 1979, as quoted in US ATSDR, 1995)

Species	Study type	Effect	LOAEL/NOAEL (mg/kg bw/day)	Reference
Humans	Occupational exposure	Histories of tremors, unfounded nervousness or anxiety, and visual difficulties. Also skin rashes	Mean blood levels of Chlordecone in workers reporting adverse effects were 2.53 ppm Skin rashes reported in workers with blood Chlordecone levels in excess of 2 µg/L	Cannon *et. al.*, 1978 (as quoted in IPCS, 1984 and US ATSDR, 1995).

2.4.2 Ecotoxicity

A summary of results of aquatic ecotoxicity tests with Chlordecone from the Ecotox database (US EPA, 2006) is given in Table 2.4.

In addition to this, the EHC 43 (IPCS, 1984), summarised a series of experiments investigating the bioavailability of Chlordecone, noting that it is strongly adsorbed on sediment. Exposure of aquatic organisms is therefore partly *via* the water phase and partly *via* sediment. D'Asaro & Wilkes (1982) examined the effects of sediments previously exposed to Chlordecone at a known concentration, and of James River sediments contaminated with Chlordecone, on an estuarine community established in aquaria supplied with non-filtered sea water. Mysid shrimps showed a dose-related mortality rate, when exposed to sediments previously equilibrated at 0.1, 1.0, or 10 µg Chlordecone/L. Mysids were not affected by James River sediment. Put concentration in sediments, if available Oysters showed dose-dependent reduced shell growth when exposed to Chlordecone-equilibrated sediments, and also responded adversely to river sediment. Lugworms *Arenicola cristata* died after 28 days of treatment with sediment exposed to 10 µg Chlordecone/L, though numbers were not affected by lower doses. Both lugworms and oysters concentrated Chlordecone from the sediment. (Quoted from EHC 43, (IPCS, 1984)).

Table 2.4 Summary of key ecotoxicological studies on Chlordecone.

Taxonomic group and species	End point	Duration	Result mg/L	Reference [1]
Algae *Chlorococcum sp., Dunaliella tertiolecta, Nitzschia sp., Thalassiosira pseudonana*	EC_{50} growth inhibition	7 days	0.35 - 0.60 (formulation)	Walsh *et. al.*, 1977
Algae *Chlorococcum sp., Dunaliella tertiolecta, Nitzschia sp., Thalassiosira pseudonana*	EC_{50} growth inhibition	7 days	350 – 600 (formulation)	Hansen *et. al.*, 1977
Crustaceans *Daphnia magna*	EC_{50} immobility	48 hours	0.120 - 0.690	Barera & Adams, 1983; Adams & Heidolph, 1985; Ziegenfuss *et. al.*, 1986
Crustaceans *Americamysis bahia, Callinectes sapidus, Palaemonetes pugio*	LC_{50}	96 hours	0.01 - 0.210	Nimmo *et. al.*, 1977, 1981; Hansen *et. al.*, 1977; Schimmel, 1977; US EPA, 1976
Crustacean *Daphnia magna*	NOEC reproduction	21 days	0.0283	McKee & Knowles, 1986
Crustacean *Daphnia magna*	NOEC growth	21 days	0.025	Adams & Heidolph, 1985
Crustacean *Americamysis bahia*	MATC growth	28 days	0.000026 - 0.00034	Nimmo *et. al.*, 1981
Insect *Chironomus tentans*	LC_{50}	48 hours	0.17 - 2.3	Adams *et. al.*, 1985; Ziegenfuss *et. al.,* 1986
Fish 9 species	LC_{50}	96 hours, flow through	0.0066 - 0.512	Roberts & Bendl, 1982; Roberts & Fisher, 1985; Schimmel, 1977; Hansen *et. al.*, 1977; Mallat & Barron, 1988; Buckler *et. al.*, 1981
Insect *Chironomus tentans*	NOEC development	14 days	17.9 mg/kg sediment	Adams *et. al.*, 1985

1: All are as quoted in Ecotox, US EPA 2006

In a publication from SETAC a collation of critical tissue residues (CTR) was presented and evaluated (Jarvinen *et. al.*, 1999). The database contains 32 entries for Chlordecone, with data originating from different studies (see Table 2.5). Some of the tissue residues were from studies where no effects were observed, so they may not represent the real CTR. Critical tissue residue values obtained in studies where effects were identified represent 15 CTR values for three fish species. For fathead minnow two studies are available with values of 1.7 and of 3.8-5.4 mg/kg ww. For sheepshead minnow 12 CTRs are available, ranging from 0.13 to 17 mg/kg ww with an average of 5.9 mg/kg ww. Furthermore, one CTR of 2.7 mg/kg ww for spot is available.

Conclusion

In summary, Chlordecone is very toxic to aquatic organisms. The most sensitive group is the invertebrates, which is not surprising for a substance with insecticidal properties. Even if the lowest effect concentration (0.000026 mg/L) was considered to be an outlier, the lowest effect concentrations would be well below 1 mg/L with the results of short term tests (mortality) in the range of 0.01 to 0.69 mg/L and those of long term tests (reproduction and growth) at 0.0025 and 0.0028 mg/L.

Table 2.5 Collation of critical tissue residues (CTR)

Species	Life Stage	Exprte	Expo of Concentration	Results □g/g (wet) _)	effect
Cladoceran, Daphnia magna (Fw)	1st instar	Water	175 ng/L	0.133	Survival, Reproduction - No effect
Grass shrimp, Palaemonetes pugio (Sw)	0.09g	Water; Diet	0.04 µg/L; 0.118 µg/g (wet wt)	0.147	Growth - No effect
Blue crab, Callinectes sapidus (Sw)	Juvenile	Diet	2.26 - 2.50 µg/g (wet wt)	2.54 - 4.61	Survival, Growth - No effect
Fathead minnow, Pimephales promelas (Fw)	Larvae-Adult	Water	3.1 µg/L	3.8 - 5.4	Survival, Growth - Reduced
Fathead minnow, Pimephales promelas (Fw)	Larvae-Adult	Water	1.2 µg/L	2.6	Survival, Growth - No effect
Fathead minnow, Pimephales promelas (Fw)	Embryo, 2nd generation	Water; Adult fish	0.31 µg/L; 0.21-0.38 µg/g	1.7	Survival (hatchability) - Reduced
Fathead minnow, Pimephales promelas (Fw)	Embryo, 2nd generation	Water; Adult fish	0.17 µg/L; 0.17-0.46 µg/g	0.26	Survival - No effect
Fathead minnow, Pimephales promelas (Fw)	Larvae, 2nd generation	Water; Adult fish	0.31 µg/L; 0.21- 0.38 µg/g	0.50	Survival, Growth - No effect
Sheepshead minnow, Cyprinodon variegatus (Sw)	Adult	Water	0.8 µg/L	2.5 - 3.6	Survival - Reduced 22%
Sheepshead minnow, Cyprinodon variegatus (Sw)	Adult	Water	1.9 µg/L	11 - 12	Survival - Reduced 80%
Sheepshead minnow, Cyprinodon variegatus (Sw)	Adult	Water	7.8 µg/L	17	Survival - Reduced 100%
Sheepshead minnow, Cyprinodon variegatus (Sw)	Adult	Water	0.16 µg/L	0.65 - 0.90	Survival - No effect
Sheepshead minnow, Cyprinodon variegatus (Sw)	Embryo	Adult fish	11-12 µg/g	11	Survival - Reduced 25%
Sheepshead minnow, Cyprinodon variegatus (Sw)	Embryo	Adult fish	2.5 - 3.6 µg/g	4.7	Survival - No effect
Sheepshead minnow, Cyprinodon variegatus (Sw)	Larvae-Juvenile	Water; Adult fish	1.9 µg/L; 11-12 µg/g	8.4	Survival - Reduced 63%
Sheepshead minnow, Cyprinodon variegatus (Sw)	Larvae-Juvenile	Water	2.0 µg/L	7.8	Survival - Reduced 40%

Species	Life Stage	Exprte	Expo of Concentration	Results □g/g (wet)_)	effect
Sheepshead minnow, Cyprinodon variegatus (Sw)	Larvae-Juvenile	Water	0.8 µg/L	2.0	Survival - No effect
Sheepshead minnow, Cyprinodon variegatus (Sw)	Larvae-Juvenile	Adult fish	11-12 µg/g	0.13	Growth - Reduced
Sheepshead minnow, Cyprinodon variegatus (Sw)	Larvae-Juvenile	Water	0.08 µg/L	1.1	Growth – Reduced
Sheepshead minnow, Cyprinodon variegatus (Sw)	Embryo-Adult	Water	0.78 µg/L	5, 6.8*	Survival - No effect
Sheepshead minnow, Cyprinodon variegatus (Sw)	Embryo-Adult	Water	0.39 µg/L	2.2, 3*	Growth – Reduced
Sheepshead minnow, Cyprinodon variegatus (Sw)	Embryo-Adult	Water	0.12 µg/L	0.86, 1.2*	Growth - No effect
Sheepshead minnow, Cyprinodon variegatus (Sw)	Embryo-Adult	Water	0.78 µg/L	5, 6.8*	Reproduction – Reduced
Sheepshead minnow, Cyprinodon variegatus (Sw)	Embryo-Adult	Water	0.39 µg/L	2.2, 3*	Reproduction - No effect
Sheepshead minnow, Cyprinodon variegatus (Sw)	Embryo, 2nd generation	Adult Fish + Water	0.78 µg/L	2.3	Survival – Reduced
Sheepshead minnow, Cyprinodon variegatus (Sw)	Embryo, 2nd generation	Adult Fish + Water	0.39 µg/L	1.3	Survival - No effect
Sheepshead minnow, Cyprinodon variegatus (Sw)	Fry, 2nd generation	Adult Fish + Water	0.78 µg/L	2.3	Survival - No effect
Sheepshead minnow, Cyprinodon variegatus (Sw)	Fry, 2nd generation	Adult Fish + Water	0.12 µg/L	0.41	Growth – Reduced
Sheepshead minnow, Cyprinodon variegatus (Sw)	Fry, 2nd generation	Adult Fish + Water	0.074 µg/L	0.30	Growth - No effect
Spot, Leiostomus xanthurus (Sw)	Juvenile	Diet	3.3 µg/g (wet wt)	2.7	Survival – Reduced
Spot, Leiostomus xanthurus (Sw)	Juvenile	Diet	3.3 µg/g (wet wt)	0.7	Survival - No effect
Spot, Leiostomus xanthurus (Sw)	Juvenile	Water; Diet	0.04 µg/L; 0.101 µg/g (wet wt)	0.144	Growth, No effect

3 Synthesis of the information

Chlordecone is a synthetic chlorinated organic compound, which has mainly been used as an agricultural pesticide. It is closely related chemically to Mirex, a pesticide which is already listed in Annex A of the Stockholm Convention. Chlordecone is already listed in Annex I of the UNECE Protocol on POPs.

According to available data, Chlordecone can be considered to be highly persistent in the environment. Chlordecone is not expected to hydrolyse or biodegrade in aquatic environments, nor in soil. Direct photodegradation is not significant. Chlordecone does not volatilise to any significant extent.

With BCF-values in algae up to 6,000, in invertebrates up to 21,600 and in fish up to 60,200 and documented examples of biomagnification, Chlordecone is considered to have a high potential for bioaccumulation and biomagnification.

Concerning the potential for causing adverse effects, there is a convincing set of data. Chlordecone is readily absorbed into the body and accumulates following prolonged exposure. It is both acutely and chronically toxic, producing neurotoxicity, immunotoxicity, reproductive, musculoskeletal and liver toxicity at doses between 1 - 10 mg/kg bw/day in experimental animal studies. Liver cancer was induced in rats at a dose of 1 mg/kg body weight per day, and reproductive effects are seen at similar dose levels. The International Agency for Research on Cancer has classified Chlordecone as a possible human carcinogen (IARC group 2B). Moreover, Chlordecone is very toxic to aquatic organisms, most sensitive group being the invertebrates.

The available data on Chlordecone are not fully conclusive when it comes to long-range atmospheric transport in gaseous form. It should be noted that atmospheric transport of particle-bound substances and transport of sediment particles in ocean currents as well as biotic transport could also contribute to long-range environmental transport of Chlordecone.

Due to lack of monitoring data on Chlordecone, the assessment of the potential for long-range transport of Chlordecone is based on physico-chemical properties and especially, on modelling data. While the first of these two approaches may seem somehow insufficient, the modelling data state clearly Chlordecone's LRET potential.

Based on the available data, Chlordecone should be considered as a POP warranting global action.

Production and use of Chlordecone has ceased over the last decades in developed countries, but it is assumed that it can still be produced or used as an agricultural pesticide in some developing countries. If it is still used as pesticide, it will be directly released to the environment. Moreover, the high persistency of the substance has caused high contamination of soil and waters in the areas where it has been used and these contaminated sites can serve as a source of pollution for long times.

4 Concluding statement

It has been demonstrated that Chlordecone meets all the criteria laid down in Annex D of the Stockholm Convention. Moreover, it is chemically very similar to Mirex, an organochlorine pesticide which is already listed in the Stockholm Convention. It is very persistent in the environment and has a great potential for bioaccumulation and in addition there is clear evidence of its biomagnification. While there is no monitoring data from areas remote from sources, the physical and chemical properties, as well as the modelling results, suggest that Chlordecone can be transported long distances bound to particles in air and water, and possibly through coupled transport between these two compartments. Chlordecone is associated with a wide range of harmful effects on both mammals and aquatic organisms.

As Chlordecone can travel in the atmosphere far from its sources, neither a single country nor group of countries alone can abate the pollution caused by this substance. Regional action has already been considered necessary and Chlordecone is totally banned under the UNECE Convention on Long-range Transboundary Air Pollution Protocol on Persistent Organic Pollutants. Although the production and use of Chlordecone seems to be ceased in most countries, its reintroduction remains possible. This could lead to increased releases and levels in the environment.

Based on the available evidence, Chlordecone 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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