

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
<p>【生分解性・加水分解性】 水生環境中であるいは土壤中で、生分解又は加水分解するとは予測されない。</p> <p>【光分解性】 大気中で直接的な光分解を受けることは考えられないと結論している。</p> <p>・利用可能な全てのデータに基づき、クロルデコンは環境中で高い残留性を示すと考えられる。</p>	<p>【オクターノール/水分配係数】 logKow=4.50-5.41</p> <p>【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</p> <p>【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、エビからアミ、アミからスポ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。</p>	<p>【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)</p> <p>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</p> <p>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</p> <p>【生殖毒性】 ラット(3ヶ月): NOAEL 0.25mg/kg/day 精巣萎縮 ラット(90日): LOAEL 0.83mg/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、膻発情持続、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</p>	<p>【慢性毒性】 ミジンコ <i>Daphnia magna</i> : 21dNOEC=0.0283 mg/L(繁殖), 21dNOEC=0.025 mg/L(成長) ミシッドシュリンプ <i>Americamysis bahia</i> : 28dMATC=0.000026-0.00034 mg/L(成長) ユスリカ <i>Chironomus tentans</i> : 14dNOEC=17.9 mg/kg sediment(発達)</p>

		<p>【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</p> <p>【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)</p> <p>【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</p>	
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**United Nations
Environment
Programme**

Distr.: General
4 December 2007

English only



Stockholm Convention on Persistent Organic Pollutants
Persistent Organic Pollutants Review Committee
Third meeting
Geneva, 19–23 November 2007

**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.

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

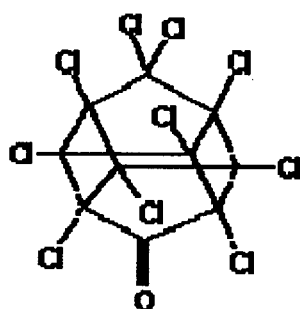
Trade names:

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, I <i>et. al.</i> , 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, I <i>et. al.</i> , 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 <i>et. al.</i> , 1995 ²
Log K _{aw}		-6.69	Scheringer <i>et. al.</i> , 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 2005¹ 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 Programme² and the UNEP Regionally based assessment of Persistent Toxic Substances Global Report³ 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 concern⁴.

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 ($3.0-4.0 \times 10^{-5}$ Pa) of Chlordecone, results in a relatively low potential for volatilisation as the Henry's Law Constant is between 2.0×10^{-2} and 5.45×10^{-3} Pa m³/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 reached⁶. Two additional studies from EHC 43 (IPCS, 1984) are also included.

Table 2.1 BCF values for Chlordecone.

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

1: All quoted from the Ecotox database (US EPA, 2006), except for two² 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; Naqui 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 (Naqui 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/m³, depending on weather conditions and date of collection. At more distant sites in May 1975, levels ranged from 1.4-21 ng/m³. Specifically, in South Richmond, 15.6 miles north west from Hopewell, the level was 1.41 ng/m³. At Byrd airport, 14.12 miles north of Hopewell, the level was 1.93 ng/m³. In Petersburg, 8.19 miles south west from Hopewell, the level was 20.7 ng/m³. (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.