AMBIENT WATER QUALITY CRITERIA FOR

CHLORINATED NAPTHALENE

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FOREWORD

Section 304 (a)(1) of the Clean Water Act of 1977 (P.L. 95-217), requires the Administrator of the Environmental Protection Agency to publish criteria for water quality accurately reflecting the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare which may be expected from the presence of pollutants in any body of water, including ground water. Proposed water quality criteria for the 65 toxic pollutants listed under section 307 (a)(1) of the Clean Water Act were developed and a notice of their availability was published for public comment on March 15, 1979 (44 FR 15926), July 25, 1979 (44 FR 43660), and October 1, 1979 (44 FR 56628). This document is a revision of those proposed criteria based upon a consideration of comments received from other Federal Agencies, State agencies, special interest groups, and individual scientists. The criteria contained in this document replace any previously published EPA criteria for the 65 pollutants. This criterion document is also published in satisifaction of paragraph 11 of the Settlement Agreement in Natural Resources Defense Council, et. al. vs. Train, 8 ERC 2120 (D.D.C. 1976), modified, 12 ERC 1833 (D.D.C. 1979).

The term "water quality criteria" is used in two sections of the Clean Water Act, section 304 (a)(1) and section 303 (c)(2). The term has a different program impact in each section. In section 304, the term represents a non-regulatory, scientific assessment of ecological effects. The criteria presented in this publication are such scientific assessments. Such water quality criteria associated with specific stream uses when adopted as State water quality standards under section 303 become enforceable maximum acceptable levels of a pollutant in ambient waters. The water quality criteria adopted in the State water quality standards could have the same numerical limits as the criteria developed under section 304. However, in many situations States may want to adjust water quality criteria developed under section 304 to reflect local environmental conditions and human exposure patterns before incorporation into water quality standards. It is not until their adoption as part of the State water quality standards that the criteria become regulatory.

Guidelines to assist the States in the modification of criteria presented in this document, in the development of water quality standards, and in other water-related programs of this Agency, are being developed by EPA.

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CRITERIA DOCUMENT

CHLORINATED NAPHTHALENES

CRITERIA

Aquatic Life

The available data for chlorinated naphthalenes indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 1,600 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of chlorinated naphthalenes to sensitive freshwater aquatic life.

The available data for chlorinated naphthalenes indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 7.5 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of chlorinated naphthalenes to sensitive saltwater aquatic life.

Human Health

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficiency in the available data for chlorinated naphthalenes.

INTRODUCTION

Chlorinated naphthalenes consist of two fused six carbon-membered aromatic rings where any or all of the eight hydrogen atoms can be replaced with chlorine. Theoretically, 76 individual isomers are possible and may exist. The commercial products are usually mixtures with various degrees of chlorination, and are presently manufactured and marketed in the United States under the trade name, Halowaxes®.

Mixtures of tri- and tetrachloronaphthalenes (solids) comprise the bulk of market use as the paper impregnant in automobile capacitors. Less use is made of mixtures of the mono- and dichloronaphthalenes as oil additivies for engine cleaning, and in fabric dyeing. In 1956, the total United States production of chlorinated naphthalenes was approximately 3,175 metric tons (Hardie, 1964).

Possible impurities of these products are chlorinated derivatives, corresponding to the impurities in coal tar, or petroleum-derived naphthalene feedstocks which may include biphenyls, fluorenes, pyrenes, anthracenes, and dibenzofurans.

The potential for environmental exposure may be significant when these compounds are used as oil additives, in the electroplating industry, and in the fabric dyeing industry. The extent of leaching of chlorinated naphthalenes from discarded capacitors and old cable insulation (manufactured prior to curtailment of using the chemical in such products) has not been determined.

Chlorinated naphthalenes have been detected as a contaminant in foreign commercial polychlorinated biphenyl (PCB) formulations

(Phenoclor, Clophen, and Kanechlor) along with chlorinated dibenzofurans, and are present in domestic PCBs (Aroclors) but at lower levels than in foreign formulations (Vos, et al. 1970; Bowes, et al. 1975; Roach and Pomerantz, 1974).

The synthesis of chlorinated naphthalenes generally involves the chlorination of naphthalene by chlorine in the presence of catalytic amounts of ferric or antimony chloride. This production process yields mixtures of highly chlorinated naphthalenes in varying quantities by further chlorination of the lesser substituted products. Only 1-chloronaphthalene and octachloronaphthalene are readily isolated from the products of direct chlorination (Hardie, 1964). All of the possible two monochloro-, 10 dichloro-, and 14 trichloronaphthalenes have been isolated and identified. However, not all of the tetra- and higher chloro-isomers have been characterized.

Table 1 presents physical property data for all chlorinated naphthalenes which have been isolated and identified. The physical properties of the chlorinated naphthalenes are generally dependent on the degree of chlorination. Melting points (MP) of the pure compounds range from 17°C for 1-chloronaphthalene to 198°C for 1,2,3,4-tetrachloronaphthalene (Hardie, 1964). Also, as the degree of chlorination increases, the specific gravity, boiling point (BP), fire and flash points all increase, while the vapor pressure and water solubility decrease (Hardie, 1964). Mixtures of the mono- and dichloronaphthalenes are generally liquid at room temperature, whereas mixtures of the more highly chlorinated naphthalenes tend to be waxy solids (U.S. EPA, 1973).

TABLE 1

Physical Properties of Chloronaphthalenes*

Isomer	MP(°C)	BP°C	density temp. (°C)
1-chloronaphthalene	ca.17	259.3	1.1938^{20}
2-chloronaphthalene	61	265	1.2656^{16}
1,2-dichloronaphthalene	35		$1.3147^{48.5}$
1,3-dichloronaphthalene	61.5	291 (755 mm Hg)	
1,4-dichloronaphthalene	67.5	287	$1.2997^{75.9}$
1,5-dichloronaphthalene	106.5		
1,6-dichloronaphthalene	48.5		
1,7-dichloronaphthalene	63.5	285.5	$1.2611^{99.5}$
1,8-dichloronaphthalene	88.5		$1.2924^{99.8}$
2,3-dichloronaphthalene	135	285	
2,6-dichloronaphthalene	120		
2,7-dichloronaphthalene	114		
1,2,3-trichloronaphthalene	81		
1,2,4-trichloronaphthalene	92		
1,2,5-trichloronaphthalene	78		
1,2,6-trichloronaphthalene	92.5		
1,2,7-trichloronaphthalene	88		
1,2,8-trichloronaphthalene	83		
1,3,5-trichloronaphthalene	94		
1,3,6-trichloronaphthalene	80.5		
1,3,7-trichloronaphthalene	113		
1,3,8-trichloronaphthalene	89.5		
1,4,5-trichloronaphthalene	133		
1,4,6-trichloronaphthalene	65		
2,3,5-trichloronaphthalene	109.5		
2,3,6-trichloronaphthalene	90.5		
1,2,3,4-tetrachloronaphthalene	198		
1,3,5,8-tetrachloronaphthalene	131		
1,4,6,7-tetrachloronaphthalene	139		
1,2,3,4,5-pentachloronaphthalene	168.5		
1,2,3,4,5,6,8-heptachloronaphthalene	194		
1,2,3,4,5,6,7,8-octachloronaphthalene	192		

*Source: Hardie, 1964
MP = Melting point; BP = Boiling point

Chlorinated naphthalenes, like PCBs, exhibit a high degree of chemical and thermal stability as indicated by their resistance to most acids and alkalies and to dehydrochlorination (U.S. EPA, 1975).

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Aquatic Life Toxicology*

INTRODUCTION

The only chlorinated naphthalenes for which data are available for freshwater organisms are 1-chloronaphthalene and octachloronaphthalene. The available LC_{50} and EC_{50} values for the bluegill, *Daphnia magna*, and an alga indicate similar sensitivity of these species.

Most of the data concerning the effects of chlorinated naphthalenes on saltwater organisms are for commercial mixtures of mono- through hexachloronaphthalene in different proportions. Most of the remaining data are for 1-chloronaphthalene. These results are very similar to those freshwater data for a fish, an invertebrate, and an algal species using comparable test procedures (U.S. EPA, 1978).

EFFECTS

Acute Toxicity

A single test with *Daphnia magna* and 1-chloronaphthalene (U.S. EPA, 1978) provides a 48-hour EC_{50} of 1,600 µg/l (Table 1). The 96-hour LC_{50} for the bluegill and 1-chloronaphthalene is 2,270 µg/l (Table 1).

Of the saltwater invertebrate species, only the mysid shrimp has been tested with 1-chloronaphthalene. The 96-hour LC_{50} is 370 µg/l (Table 1), which indicates a greater sensitivity than the sheepshead minnow. The sheepshead minnow has been exposed to 1-chloronaphthalene (U.S. EPA, 1978) and the 96-hour LC_{50} is 2,360 µg/l (Table 1). The remaining data are for the commercial mixtures.

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*The reader is referred to the Guidelines for Deriving Water Quality Criteria for the Protection of Aquatic Life and Its Uses in order to better understand the following discussion and recommendation. The following tables contain the appropriate data that were found in the literature, and at the bottom of each table are calculations for deriving various measures of toxicity as described in the Guidelines.

Chronic Toxicity

No early life stage or life-cycle tests have been conducted with freshwater fish or invertebrate species and any chlorinated napthalene.

An early life stage test has been conducted with the sheepshead minnow and 1-chloronaphthalene (U.S. EPA, 1978). The chronic value is 660 µg/l (Table 2). This value with the 96-hour LC_{50} results in an acute-chronic ratio of 3.6 for the sheepshead minnow.

Plant Effects

The freshwater alga, Selenastrum capricornutum, has been exposed to 1-chloronaphthalene and the 96-hour EC_{50} values for chlorophyll a and cell numbers are 1,030 and 1,000 µg/l, respectively (Table 3). The corresponding values for chlorophyll a and cell numbers for the saltwater alga, Skeletonema costatum, are 1,130 and 1,300 µg/l, respectively, for 1-chloronaphthalene (Table 3).

Residues

There are no equilibrium residue data available for chlorinated naphthalenes with any freshwater or saltwater species.

Miscellaneous

A variety of acute tests of the effects of octachloronaphthalene have been conducted with the bluegill, and Daphnia magna. (U.S. EPA, 1978). No adverse effects were observed at concentrations as high as 500,000 to 600,000 µg/l (Table 4).

As with the freshwater species, the acute toxicity results for the sheepshead minnow, mysid shrimp, and an alga were all greater than 500,000 µg/l for octachloronaphthalene (Table 4). A great variety of other data is available for various mixtures of chlorinated naphthalenes, including bioconcentration, inhibition of algal growth, intermolt time for crabs, and other effects (Table 4).

Summary

Only 1-chloronaphthalene and octachloronaphthalene have been tested with freshwater aquatic organisms. The LC_{50} and EC_{50} values for 1-chloronaphthalene and the bluegill, Daphnia magna, and an alga, Selenastrum capricornutum, range from 1,000 to 2,270 µg/l. Comparable results with octachloronaphthalene and the same species were 500,000 µg/l.

The data base for saltwater aquatic life is comparable to that for freshwater species except for the large number and variety of data on commercial mixtures of chlorinated naphthalenes (Halowax® compounds). For 1-chloronaphthalene, the LC_{50} and EC_{50} values for the sheepshead minnow, mysid shrimp, and an alga, Skeletonema costastum, range from 370 to 2,360 µg/l. Comparable results with octachloronaphthalene and the same species were 500,000 µg/l. An acute-chronic ratio of 3.6 is calculated for the sheepshead minnow with a chronic value of 660 µg/l. Lethal and sublethal effects of the commercial mixtures occur at concentrations ranging from as high as 1,000 µg/l to as low as 7.5 µg/l.

CRITERIA

The available data for chlorinated naphthalenes indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 1,600 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of chlorinated naphthalenes to sensitive freshwater aquatic life.

The available data for chlorinated naphthalenes indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 7.5 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of chlorinated naphthalenes to sensitive saltwater aquatic life.

Table 1. Acute values for chlorinated naphthalenes

Species	Method*	Chemical	LC50/EC50 (µg/l)	Species Acute Value (µg/l)	Reference
		FRESHWATER SPECIES			
Cladoceran, *Daphnia magna*	S, U	1-chloro-naphthalene	1,600	1,600	U.S. EPA, 1978
Bluegill, *Lepomis macrochirus*	S, U	1-chloro-naphthalene	2,270	2,270	U.S. EPA, 1978
		SALTWATER SPECIES			
Mysid shrimp, *Mysidopsis bahia*	S, U	1-chloro-naphthalene	370	370	U.S. EPA, 1978
Brown shrimp, *Penaeus aztecus*	FT, M	Halowax 1014**	7.5	7.5	U.S. EPA, 1976
Grass shrimp, *Palaemonetes pugio*	FT, M	Halowax 1014**	248	248	U.S. EPA, 1976
Grass shrimp (post-larva), *Palaemonetes pugio*	R, M	Halowax 1000***	440	-	Green & Neff, 1977
Grass shrimp (adult), *Palaemonetes pugio*	R, M	Halowax 1000***	325	378	Green & Neff, 1977
Grass shrimp (post-larva), *Palaemonetes pugio*	R, M	Halowax 1013****	74	74	Green & Neff, 1977
Grass shrimp (post-larva), *Palaemonetes pugio*	R, M	Halowax 1099*****	69	-	Green & Neff, 1977
Grass shrimp (adult), *Palaemonetes pugio*	R, M	Halowax 1099*****	90	79	Green & Neff, 1977
Sheepshead minnow, *Cyprinodon variegatus*	S, U	1-chloro-naphthalene	2,360	2,360	U.S. EPA, 1978

* S = static, FT = flow-through, R = renewal, M = measured, U = unmeasured

** Halowax® 1014: 20% tetrachloronaphthalene, 40% pentachloronaphthalene, 40% hexachloronaphthalene

*** Halowax® 1000: 60% monochloronaphthalene, 40% dichloronaphthalene

**** Halowax® 1013: 10% trichloronaphthalene, 50% tetrachloronaphthalene, 40% pentachloronaphthalene

***** Halowax® 1099: 10% dichloronaphthalene, 40% trichloronaphthalene, 40% tetrachloronaphthalene, 10% pentachloronaphthalene

Table 2. Chronic values for chlorinated naphthalenes (U.S. EPA, 1978)

Species	Method*	Chemical	Limits (µg/l)	Chronic Value (µg/l)
	SALTWATER SPECIES			
Sheepshead minnow, *Cyprinodon variegatus*	ELS	1-chloro-naphthalene	460-940	660

* ELS = early life stage

Acute-Chronic Ratio

Species	Chemical	Chronic Value (µg/l)	Acute Value (µg/l)	Ratio
Sheepshead minnow, *Cyprinodon variegatus*	1-chloro-naphthalene	660	2,360	3.6

Table 3. Plant effects for chlorinated naphthalenes (U.S. EPA, 1978)

Species	Chemical	Effect	Result (µg/l)
	FRESHWATER SPECIES		
Alga, *Selenastrum capricornutum*	1-chloro-naphthalene	96-hr EC50 chlorophyll *a*	1,030
Alga, *Selenastrum capricornutum*	1-chloro-naphthalene	96-hr EC50 cell numbers	1,000
	SALTWATER SPECIES		
Alga, *Skeletonema costatum*	1-chloro-naphthalene	96-hr EC50 chlorophyll *a*	1,130
Alga, *Skeletonema costatum*	1-chloro-naphthalene	96-hr EC50 cell numbers	1,300

Table 4. Other data for chlorinated naphthalenes

Species	Chemical	Duration	Effect	Result (µg/l)	Reference
		FRESHWATER SPECIES			
Alga, *Selenastrum capricornutum*	Octachloro-naphthalene	96 hrs	EC50 chlorophyll *a*	>500,000	U.S. EPA, 1978
Alga, *Selenastrum capricornutum*	Octachloro-naphthalene	96 hrs	EC50 cell numbers	>500,000	U.S. EPA, 1978
Cladoceran, *Daphnia magna*	Octachloro-naphthalene	48 hrs	LC50	>530,000	U.S. EPA, 1978
Bluegill, *Lepomis macrochirus*	Octachloro-naphthalene	96 hrs	LC50	>600,000	U.S. EPA, 1978
		SALTWATER SPECIES			
Alga, *Chlorococcum* sp.	Halowax 1000	24 hrs	Bioconcentration factor = 25-32	-	Walsh, et al. 1977
Alga, *Chlorococcum* sp.	Halowax 1013	24 hrs	Bioconcentration factor = 60-120	-	Walsh, et al. 1977
Alga, *Chlorococcum* sp.	Halowax 1014	24 hrs	Bioconcentration factor = 110-140	-	Walsh, et al. 1977
Alga, *Chlorococcum* sp.	Halowax 1000	7 days	11.7% inhibition of growth	500	Walsh, et al. 1977
Alga, *Chlorococcum* sp.	Halowax 1000	7 days	45.8% inhibition of growth	1,000	Walsh, et al. 1977
Alga, *Dunaliella tertiolecta*	Halowax 1000	7 days	11% inhibition of growth	100	Walsh, et al. 1977
Alga, *Dunaliella tertiolecta*	Halowax 1000	7 days	18.6% inhibition of growth	500	Walsh, et al. 1977
Alga, *Dunaliella tertiolecta*	Halowax 1000	7 days	43% inhibition of growth	1,000	Walsh, et al. 1977
Alga, *Nitzschia* sp.	Halowax 1000	7 days	17.1% inhibition of growth	500	Walsh, et al. 1977

Table 4. (Continued)

Species	Chemical	Duration	Effect	Result (µg/l)	Reference
Alga, *Nitzschia* sp.	Halowax 1000	7 days	42.3% inhibition of growth	1,000	Walsh, et al. 1977
Alga, *Nitzschia* sp.	Halowax 1013	7 days	13.2% inhibition of growth	500	Walsh, et al. 1977
Alga, *Nitzschia* sp.	Halowax 1013	7 days	16.6% inhibition of growth	1,000	Walsh, et al. 1977
Alga, *Skeletonema costatum*	Octachloro-naphthalene	96 hrs	Chlorophyll *a* EC50	>500,000	U.S. EPA, 1978
Alga, *Skeletonema costatum*	Octachloro-naphthalene	96 hrs	Cell numbers EC50	>500,000	U.S. EPA, 1978
Alga, *Thalassiosira pseudonana*	Halowax 1000	7 days	21.3% inhibition of growth	500	Walsh, et al. 1977
Alga, *Thalassiosira pseudonana*	Halowax 1000	7 days	48.4% inhibition of growth	1,000	Walsh, et al. 1977
Alga, *Thalassiosira pseudonana*	Halowax 1013	7 days	7.1% inhibition of growth	1,000	Walsh, et al. 1977
Horseshoe crab, *Limulus polyphemus*	Halowax 1099	27 days	Time required for 50% mortality (LT50) of T_1 stage larvae	80	Neff & Giam, 1977
Horseshoe crab, *Limulus polyphemus*	Halowax 1099	-	Average length of time of intermolt between T_2 and T_3 stages reduced by 3.4 days	40	Neff & Giam, 1977
Horseshoe crab, *Limulus polyphemus*	Halowax 1099	-	Average length of time of intermolt between T_3 and T_4 stages reduced by 14.8 days	20	Neff & Giam, 1977

Table 4. (Continued)

Species	Chemical	Duration	Effect	Result (µg/l)	Reference
Horseshoe crab, *Limulus polyphemus*	Halowax 1099	-	Average length of time of intermolt between T_3 and T_4 stages reduced by 16.8 days	20	Neff & Glam, 1977
Horseshoe crab, *Limulus polyphemus*	Halowax 1099	-	Average length of time of intermolt between T_3 and T_4 stages reduced by 18.4 days	80	Neff & Glam, 1977
Horseshoe crab, *Limulus polyphemus*	Halowax 1099	-	Increased rates of respiration of T_1 and T_2 stages	20 and 40	Neff & Glam, 1977
Brown shrimp, *Penaeus aztecus*	Halowax 1014	4 days	Bioconcentration factor = 2,300	-	U.S. EPA, 1976
Grass shrimp, *Palaemonetes pugio*	Halowax 1000	15 days	Bioconcentration factor = 63	-	Green & Neff, 1977
Grass shrimp, *Palaemonetes pugio*	Halowax 1013	12 days	Bioconcentration factor = 187	-	Green & Neff, 1977
Grass shrimp, *Palaemonetes pugio*	Halowax 1099	5 days	Bioconcentration factor = 257	-	Green & Neff, 1977
Mysid shrimp, *Mysidopsis bahia*	Octachloro-naphthalene	96 hrs	LC50	>500,000	U.S. EPA, 1978
Mud crab, *Rhithropanopeus harrisi*	Halowax 1000	13 days	Slightly lowered survival of larvae to megalopa	300	Neff, et al. 1977
Mud crab, *Rhithropanopeus harrisi*	Halowax 1099	27 days	15% survival of larvae to megalopa	100	Neff, et al. 1977
Mud crab, *Rhithropanopeus harrisi*	Halowax 1000	-	Length of intermolt time from 4th zoeal molt to megalopa stage extended to 2.9 days	300	Neff, et al. 1977

Table 4. (Continued)

Species	Chemical	Duration	Effect	Result (µg/l)	Reference
Mud crab, *Rhithropanopeus harrisi*	Halowax 1099	-	Length of intermolt time from 4th zoeal molt to megalopa stage extended to 4.9 days	100	Neff, et al. 1977
Mud crab, *Rhithropanopeus harrisi*	Halowax 1099	-	Supernumerary zoeae (a fifth zoeal stage)	100	Neff, et al. 1977
Mud crab, *Rhithropanopeus harrisi*	Halowax 1000	-	Deformed megalopa (eyestalks and appendages malformed)	300	Neff, et al. 1977
Mud crab, *Rhithropanopeus harrisi*	Halowax 1099	-	Deformed megalopa (eyestalks and appendages malformed)	100	Neff, et al. 1977
Sheepshead minnow, *Cyprinodon variegatus*	Halowax 1014	96 hrs	LC50	>343	U.S. EPA, 1976
Sheepshead minnow, *Cyprinodon variegatus*	Octachloro-naphthalene	96 hrs	LC50	>560,000	U.S. EPA, 1976
Striped mullet (juvenile), *Mugil cephalus*	Halowax 1014	96 hrs	LC50	>263	U.S. EPA, 1976

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Mammalian Toxicology and Human Health Effects

INTRODUCTION

Chlorinated naphthalenes consist of two fused six carbon-membered aromatic rings where any or all of the eight hydrogen atoms can be replaced with chlorine. Theoretically, 76 individual isomers are possible and may exist. The commercial products are usually mixtures with various degrees of chlorination, and are presently manufactured and marketed in the United States under the trade name, Halowaxes®.

Mixtures of tri- and tetrachloronaphthalenes (solids) comprise the bulk of market use as the paper impregnant in automobile capacitors. Less use is made of mixtures of the mono- and dichloronaphthalenes as oil additivies for engine cleaning, and in fabric dyeing. In 1956, the total United States production of chlorinated naphthalenes was approximately 3,175 metric tons (Hardie, 1964).

Possible impurities of these products are chlorinated derivatives, corresponding to the impurities in coal tar, or petroleum-derived naphthalene feedstocks which may include biphenyls, fluorenes, pyrenes, anthracenes, and dibenzofurans.

The potential for environmental exposure may be significant when these compounds are used as oil additives, in the electroplating industry, and in the fabric dyeing industry. The extent of leaching of chlorinated naphthalenes from discarded capacitors and old cable insulation (manufactured prior to curtailment of using the chemical in such products) has not been determined.

Chlorinated naphthalenes have been detected as a contaminant in foreign commercial polychlorinated biphenyl (PCB) formulations (Phenoclor, Clophen, and Kanechlor) along with chlorinated dibenzofurans, and are present in domestic PCBs (Aroclors) but at lower levels than in foreign formulations (Vos, et al. 1970; Bowes, et al. 1975; Roach and Pomerantz, 1974).

The synthesis of chlorinated naphthalenes generally involves the chlorination of naphthalene by chlorine in the presence of catalytic amounts of ferric or antimony chloride. This production process yields mixtures of highly chlorinated naphthalenes in varying quantities by further chlorination of the lesser substituted products. Only 1-chloronaphthalene and octachloronaphthalene are readily isolated from the products of direct chlorination (Hardie, 1964). All of the possible two monochloro-, 10 dichloro-, and 14 trichloronaphthalenes have been isolated and identified. However, not all of the tetra- and higher chloro-isomers have been characterized.

Table 1 presents physical property data for all chlorinated naphthalenes which have been isolated and identified. The physical properties of the chlorinated naphthalenes are generally dependent on the degree of chlorination. Melting points (MP) of the pure compounds range from 17°C for 1-chloronaphthalene to 198°C for 1,2,3,4-tetrachloronaphthalene (Hardie, 1964). Also, as the degree of chlorination increases, the specific gravity, boiling point (BP), fire and flash points all increase, while the vapor pressure and water solubility decrease (Hardie, 1964). Mixtures of the mono- and dichloronaphthalenes are generally liquid at room

TABLE 1

Physical Properties of Chloronaphthalenes*

Isomer	MP(°C)	BP°C	density temp. (°C)
1-chloronaphthalene	ca.17	259.3	1.1938^{20}
2-chloronaphthalene	61	265	1.2656^{16}
1,2-dichloronaphthalene	35		$1.3147^{48.5}$
1,3-dichloronaphthalene	61.5	291 (755 mm Hg)	
1,4-dichloronaphthalene	67.5	287	$1.2997^{75.9}$
1,5-dichloronaphthalene	106.5		
1,6-dichloronaphthalene	48.5		
1,7-dichloronaphthalene	63.5	285.5	$1.2611^{99.5}$
1,8-dichloronaphthalene	88.5		$1.2924^{99.8}$
2,3-dichloronaphthalene	135	285	
2,6-dichloronaphthalene	120		
2,7-dichloronaphthalene	114		
1,2,3-trichloronaphthalene	81		
1,2,4-trichloronaphthalene	92		
1,2,5-trichloronaphthalene	78		
1,2,6-trichloronaphthalene	92.5		
1,2,7-trichloronaphthalene	88		
1,2,8-trichloronaphthalene	83		
1,3,5-trichloronaphthalene	94		
1,3,6-trichloronaphthalene	80.5		
1,3,7-trichloronaphthalene	113		
1,3,8-trichloronaphthalene	89.5		
1,4,5-trichloronaphthalene	133		
1,4,6-trichloronaphthalene	65		
2,3,5-trichloronaphthalene	109.5		
2,3,6-trichloronaphthalene	90.5		
1,2,3,4-tetrachloronaphthalene	198		
1,3,5,8-tetrachloronaphthalene	131		
1,4,6,7-tetrachloronaphthalene	139		
1,2,3,4,5-pentachloronaphthalene	168.5		
1,2,3,4,5,6,8-heptachloronaphthalene	194		
1,2,3,4,5,6,7,8-octachloronaphthalene	192		

*Source: Hardie, 1964

MP = Melting point; BP = Boiling point

temperature, whereas mixtures of the more highly chlorinated naphthalenes tend to be waxy solids (U.S. EPA, 1973).

Chlorinated naphthalenes, like PCBs, exhibit a high degree of chemical and thermal stability as indicated by their resistance to most acids and alkalies and to dehydrochlorination (U.S. EPA, 1975).

Polychlorinated naphthalenes have been used in various industrial processes since the turn of the century. Peak use of these compounds occurred during World War I in Germany, where they were used in place of rubber, and in the United States during World War II, where they were used to a large extent in heat-resistant electrical insulation. Since then many uses of polychlorinated naphthalenes have been replaced by a growing variety of plastics. In 1956 production and utilization of polychlorinated naphthalenes in the United States had decreased to approximately 3,200 metric tons per year. By 1972 production had decreased further to approximately 2,300 metric tons per year. At the present time, Halochem, Inc. in Boonton, N.J. is the only known manufacturer of polychlorinated naphthalenes in the United States. Amounts of chlorinated naphthalenes processed in 1978 were less than 22 metric tons for monochloronaphthalene, less than 45 metric tons total for di-, tri-, and tetrachloronaphthalene, less than 1 metric ton for pentachloronaphthalene, and virtually zero for the more highly chlorinated naphthalenes (Cuozzo, 1978). Projected production for 1979 totaled less than 270 metric tons, with 20 percent of this total expected to be monochloronaphthalene, less than 5 percent pentachloronaphthalene, and none of the more highly chlorinated naphthalenes.

Although several foreign companies manufacture polychlorinated naphthalenes, there are no known imports of these compounds. Because of their chemical and thermal stability, dielectric properties, and low viscosity in a liquid state, polychlorinated naphthalenes are still used as engine oil additives, cutting oil additives, capacitor dielectrics, and electroplating stopoff compounds. They are also used to some extent in the production of fabric dyes. In the past, polychlorinated naphthalenes have been used as pesticides, waterproofing and flame retardant compounds, and cable-covering materials (Minagawa, 1976).

During World Wars I and II, the industrial use of polychlorinated naphthalenes was implicated in many cases of chloracne and, to a lesser extent, liver disease. The purpose of this report is to summarize available information on the occurrence, pharmacokinetic properties, and health effects of polychlorinated naphthalenes (PCNs) in an effort to set a criterion for acceptable levels of polychlorinated naphthalenes in water.

EXPOSURE

Polychlorinated naphthalenes do not occur naturally in the environment. Potential environmental accumulation can occur around points of manufacture of polychlorinated naphthalenes or products containing them, near sites of disposal of polychlorinated naphthalene-containing wastes, and, since polychlorinated biphenyls (PCBs) are to some extent contaminated by polychlorinated naphthalenes (Vos, et al. 1970; Bowes, et al. 1975), near sites of heavy polychlorinated biphenyl contamination.

Currently available industrially-produced polychlorinated naphthalenes occur as mixtures of various isomers as noted in Table 2 (Brinkman and Reymer, 1976). These mixtures are marketed by Koppers, Inc. under the trade name Halowax. ®

Ingestion from Water and Food

To date, polychlorinated naphthalenes have not been identified in either drinking water or market basket foods. Polychlorinated naphthalenes have been found in waters or sediments adjacent to point sources or areas of heavy polychlorinated biphenyl contamination (Table 3).

Polychlorinated naphthalene-contaminated sediments occur less frequently than polychlorinated biphenyl-contaminated sediments. Law and Goerlitz (1974) found polychlorinated naphthalenes in only 1 of 39 sediment samples from streams emptying into San Francisco Bay. In contrast, 97 percent of the samples contained measurable levels of polychlorinated biphenyls.

Polychlorinated naphthalenes do appear to be magnified in the aquatic ecosystem. As noted in Table 3, Crump-Wiesner, et al. (1973) found that concentrations of polychlorinated naphthalenes in sediments were 220- to 877-fold greater than in the water overlying these sediments. Erickson, et al. (1978) found a polychlorinated naphthalene level in contaminated sediments near a capacitor factory that was only sixfold greater than the level in the overlying water. Algae definitely accumulate polychlorinated naphthalenes. Walsh, et al. (1977) have found polychlorinated naphthalene levels in algae that were 24- to 140-fold higher than in the surrounding water. The degree of biomagnification was greater for the more

TABLE 2

Approximate Compositions (WT.%) of Halowaxes (PCNs)*

Halowax Number	Types of Polychlorinated Naphthalene							
	Mono-	Di-	Tri-	Tetra-	Penta-	Hexa-	Hepta-	Octa-
1031	95	5						
1000	60	40						
1001		10	40	40	10			
1099		10	40	40	10			
1013			10	50	40			
1014				20	40	40		
1051							10	90

*Source: Brinkman and Reymer, 1976

TABLE 3

Water and Sediment Polychlorinated Naphthalene Levels

Industry	Type of Sample	Level (µg/kg or µg/l)	Reference
Airplane engine overhaul	Sediment	1250-5000	Crump-Wiesner, et al. 1973
Airplane engine overhaul	Water	5-7	Crump-Wiesner, et al. 1973
None identified	Sediment	55	Law and Goerlitz, 1974
Reprocessing oil	Sediment	trace	Minagawa, 1976
Polychlorinated Naphthalene manufacturer	Water	n.d.[a]-1.4	Erickson, et al. 1978
Capacitor manufacturer A	Water	n.d.[a]	Erickson, et al. 1978
Capacitor manufacturer B	Water	n.d.[a]-0.6	Erickson, et al. 1978
Capacitor manufacturer B	Sediment	1.8-2.6	Erickson, et al. 1978
Capacitor dumps (2)	Water	n.d.[a]	Erickson, et al. 1978

[a]n.d. means not detectable with a sensitivity threshold of 0.2 µg/l for water and 0.5 µg/kg for soil and sediment.

highly chlorinated polychlorinated naphthalene mixtures. Biomagnification of polychlorinated naphthalenes also occurs in shrimp. Grass shrimp concentrate various mixtures of polychlorinated naphthalenes by a factor ranging from 63 to 257 compared to the surrounding water (Green and Neff, 1977). As with algae, there is also greater biomagnification in grass shrimp with the more highly chlorinated naphthalenes.

A bioconcentration factor (BCF) relates the concentration of a chemical in aquatic animals to the concentration in the water in which they live. The steady-state BCFs for a lipid-soluble compound in the tissues of various aquatic animals seem to proportional to the percent lipid in the tissue. Thus, the per capita ingestion of a lipid-soluble chemical can be estimated from the per capita consumption of fish and shellfish, the weighted average percent lipids of consumed fish and shellfish, and a steady-state BCF for the chemical.

Data from a recent survey on fish and shellfish consumption in the United States were analyzed by SRI International (U.S. EPA, 1980). These data were used to estimate that the per capita consumption of freshwater and estuarine fish and shellfish in the United States is 6.5 g/day (Stephan, 1980). In addition, these data were used with data on the fat content of the edible portion of the same species to estimate that that the weighted average percent lipids for consumed freshwater and estuarine fish and shellfish is 3.0 percent.

No measured steady-state bioconcentration factor is available for any of the following compounds, but the equation

"Log BCF - (0.85 Log P) - 0.70" can be used (Veith, et al. 1979) to estimate the steady-state BCF for aquatic organisms that contain about 7.6 percent lipids (Veith, 1980) from the octanol/water partition coefficient (P). Calculated log P values for monochloronaphthalenes and octachloronaphthalenes were obtained using the method described in Hansch and Leo (1979). The other values were obtained by linear interpolation between these two values. The adjustment factor of 3.0/7.6 = 0.395 is used to adjust the estimated BCF from the 7.6 percent lipids on which the equation is based to the 3.0 percent lipids that is the weighted average for consumed fish and shellfish in order to obtain the weighted average bioconcentration factor for the edible portion of all freshwater and estuarine aquatic organisms consumed by Americans.

Chemical	Calc. Log P	Estimated steady state BCF	Weighted Average BCF
Monochloronaphthalenes	4.01	511	202
Dichloronaphthalenes	4.72	2,050	810
Trichloronaphthalenes	5.43	8,230	3,250
Tetrachloronaphthalenes	6.14	33,000	13,000
Pentachloronaphthalenes	6.85	133,000	52,500
Hexachloronaphthalenes	7.56	532,000	210,000
Heptachloronaphthalenes	8.27	2,140,000	845,000
Octachloronaphthalenes	8.98	8,570,000	3,385,000

Erickson, et al. (1978) noted a higher level of polychlorinated naphthalenes in a dead fish (39 µg/kg) than in the surrounding water (0.2 µg/l).

Erickson, et al. (1978) also noted a higher relative biomagnification of the least chlorinated naphthalene by the fruit of apple trees grown on contaminated soil. The soil was found to have a polychlorinated naphthalene level of 190 µg/kg, of which 1.6 µg/kg was monochloronaphthalenes. While the apples grown on this soil had only 90 µg/kg of polychlorinated naphthalenes, the level of monochloronaphthalenes was 62 µg/kg.

Inhalation

The two major effects of chlorinated naphthalenes in man are chloracne arising primarily by the direct contact route, but also shown in animals to result from ingestion, and liver damage arising primarily as a result of inhalation in the industrial setting.

Drinker, et al. (1937) first reported the potential problem of systemic effects arising from inhalation citing 3 fatalities among individuals exposed to chlorinated naphthalenes. Acute "yellow atrophy of the liver" was the cause of death in each instance. Mayers and Smith (1942) recorded toxic hepatitis in a worker exposed to 3,000 $\mu g/m^3$ of trichloronaphthalene (tetrachloronaphthalene probably present). Strauss (1944) presented an additional fatal case and reviewed the literature of reported exposures, including 6 fatal cases. One severe but non-fatal case was reported where air concentrations of Halowax® 1014 was reported to be 3.4 mg/m^3.

Elkins (1959) noted air concentrations of 1,000 to 2,000 $\mu g/m^3$ of a penta- and hexachloronaphthalene mixture in a factory where two fatal cases of toxic hepatitis occurred. Erickson, et al. (1978) found ambient air concentrations of polychlorinated

naphthalenes ranging from 0.25 to 2.90 $\mu g/m^3$ near a polychlorinated naphthalene production plant. Concentrations of trichloronaphthalene were as high as 0.95 $\mu g/m^3$, while hexachloronaphthalene concentrations never exceeded 0.007 $\mu g/m^3$. Near one capacitor factory, ambient air concentrations of polychlorinated naphthalenes ranged from non-detectable to 0.005 $\mu g/m^3$, while at a second factory they ranged from 0.0098 to 0.033 $\mu g/m^3$.

Dermal

The likelihood of significant dermal absorption of polychlorinated naphthalenes from a water source appears negligible. Water solubility is low thus skin exposure levels would be minimal. Link, et al. (1958) found no evidence of systemic disease after spraying pigs with 6,710 to 8,250 mg/kg of hexachloronaphthalene over a period of 28 days, while a total dose of 198 mg/kg of hexachloronaphthalene given orally over a period of nine days was uniformly fatal.

However, Sikes, et al (1952) applied 250 mg (weekly) of used crankcase oil containing polychlorinated naphthalenes to the vertebral column of a Jersey cow with a 4-month-old calf. Both cow and calf developed hyperkeratosis and systemic toxicity suggesting skin absorption and secretion in milk. No restraint of either cow or calf was attempted, thus it is not possible to completely rule out oral ingestion by licking of the material from the skin.

PHARMACOKINETICS

Absorption, Distribution, and Excretion

There is currently no information on the pharmacokinetic mechanisms of absorption, distribution, and excretion of polychlorinated naphthalenes in man. Chu, et al. (1977a) noted that in rats

fed ^{14}C-1,2-dichloronaphthalene, the half-life of this compound in the blood after the first day was 24 hours. Blood samples were collected every hour for 8 hours, then at 24 and 48 hours. Total radiactivity was highest in the one hour sample indicating rapid absorption from the gastrointestinal tract. Tissue distribution in rats at 24 hours, 48 hours, and 7 days is shown in Table 4. At 24 and 48 hours, the highest levels of radioactivity (DPM/mg), in descending order, were found in intestine, kidney, bladder, liver, lung and adipose tissue. Thus adipose tissue showed no great tendency to accumulate 1,2-dichloronaphthalene although traces were still present in adipose tissue, in contrast to other soft tissues, after one week. Twenty-six percent of the total dose was excreted in the urine in 24 hours, 33 percent by 48 hours, and a total of 35 percent at 7 days. Nineteen percent of the total dose was excreted in the feces in 24 hours, 31 percent in 48 hours, and 42 percent by day 7. Thus urinary and fecal excretion accounted for 77 percent of the original dose by day 7. Twenty-three percent of the dose remains unaccounted for, since tissue levels were essentially zero at 7 days. Serial sample collection of bile from a series of bile-duct cannulated rats demonstrated that 62 percent of the total dose was excreted via the bile within 24 hours. In intact animals only 42 percent of the dose was excreted via the feces over a 7-day period, thus considerable reabsorption of the compound or its metabolites from the gut must occur. This indicates a rather active enterohepatic circulation of these compounds with much of the reabsorbed material being eventually excreted in the urine. Thin layer chromatography in this study showed the labeled fecal compound to

TABLE 4

Tissue Distribution[a] of radioactivity (DPM) in rats after a single oral dose of ^{14}C-1,2-dichloronaphthalene, 20 µCi/kg (400 mg/kg) in corn oil*

	24 hours post dose		48 hours post dose		7 days post dose	
	DPM/mg	%	DPM/mg	%	DPM/mg	%
Adipose	8.1	0.10	11.7	0.15	3.26	0.04
Lung	14.1	0.04	14.3	0.03	-	-
Liver	21.3	0.70	34.3	0.07	-	-
Bladder	30.6	0.01	42.4	0.01	-	-
Kidney	39.6	0.18	46.5	0.15	-	-
Intestine	87.0	0.45	251.0	3.60	-	-
Skin	4.7	0.07	5.7	0.08	0.73	0.01
GI-content	1124.0	18.30	1963.0	17.90	7.60	0.04
Fecal excretion		18.90		30.80		42.00
Urine		26.40		32.60		35.20

*Source: Chu, et al. 1977a

[a]The average value of four or more animals. The S.D. are within 40% of the means.

DPM/mg = radioactivity per mg of dried tissue

% = percent of total administered dose

be unchanged dichloronaphthalene. No unchanged compound of free chloronaphthol was found in the urine. The urinary metabolite was identified as the glucuronide of a dihydrodiol.

Ruzo, et al. (1976) studied the tissue uptake and distribution of 1- and 2-chloronaphthalene in pigs. The chloronaphthalenes were injected into the carotid artery and blood samples were collected over a 6-hour period at which time the pigs were sacrificed. The blood concentrations of 1- and 2-chloronaphthalenes were 5 to 6 μg/g at 10 minutes and essentially zero 4 to 5 hours after the injection. 4-Chloronaphthol, a metabolite of 1-chloronaphthalene, was first detectable in the blood at 160 minutes and was at its highest level at 300 minutes when the parent compound was not detectable. Similarly 3-chloro-2-naphthol, a metabolite of 2-chloronaphthalene, was first detectable in blood 200 minutes after injection of the compound, and was at its highest level at 300 minutes when the animals were sacrificed. Tissue distribution studies indicated that kidney and brain contained the highest levels of the injected 1- or 2-chloronaphthalene at the time of sacrifice. Metabolite levels were highest in liver, kidney, urine, and bile.

These two studies utilized chloronaphthalenes of low levels of chlorination. Both found little evidence of accumulation in fat, rather rapid metabolism, and considerable biliary excretion.

No comparable studies are available with more highly chlorinated samples which may be more slowly metabolized and more lipophilic, thus enhancing fat storage capabilities.

In seagulls with environmental exposures to chlorinated naphthalenes, analyses of fat, liver, and plumage resulted in the

detection of polychlorinated naphthalenes only in liver samples, the highest value being 62,500 µg/kg calculated as octachloronaphthalene (Vannucchi, et al. 1978).

Metabolism

In mammals there appears to be appreciable metabolism of polychlorinated naphthalenes containing four chlorine atoms or less. Cornish and Block (1958) investigated the excretion of polychlorinated naphthalenes in rabbits. They found that 79 percent of 1-chloronaphthalene, 93 percent of dichloronaphthalene, and 45 percent of tetrachloronaphthalene were excreted in the urine as metabolites of the parent compounds. There was no measurable urinary excretion (either as metabolites or the unchanged compound) of penta-, hepta-, or octachloronaphthalene. The authors suggested that high degrees of chlorination may prevent the formation of dihydrodiol intermediates.

There have been detailed studies of the urinary metabolites of several polychlorinated naphthalenes as noted in Table 5. Metabolism may involve direct hydroxylation or hydroxylation and dehalogenation.

Because of the difficulty of synthesis and purification of specific isomers of the more highly chlorinated naphthalenes, most of the metabolic studies have been carried out with mono- and disubstituted compounds (Table 5). Ruzo, et al. (1976) found 2,4-dichloro-1-naphthol is a metabolite of 1,4-dichloronaphthalene which is consistent with an arene oxide intermediate accompanied by a susequent 1,2-Cl shift. In this study no dehalogenated metabolites were found. Chu, et al. (1977b) reported on the metabolism

TABLE 5

Polychlorinated Naphthalene Metabolites Found in Urine

Parent	Metabolite	Animal	Reference
1-chloro-naphthalene	4-chloro-1-naphthol	frog	Sundstrom, et al. 1975
		pig	Ruzo, et al. 1976
2-chloro-naphthalene	3-chloro-2-naphthol	pig	Ruzo, et al. 1976
1,2-dichloro-naphthalene	3,4,-dichloro-1-naphthol	pig	Ruzo, et al. 1976
1,4-dichloro-naphthalene	2,4,-dichloro-1-naphthol	pig	Ruzo, et al. 1976
		frog	Sundstrom, et al. 1975
2,6-dichloro-naphthalene	6-chloro-2-naphthol 2,6-dichloronaphthol (free and conjugated)	rat	Chu, et al. 1977b
2,7-dichloro-naphthalene	7-chloro-2-naphthol (free and conjugated)	rat	Chu, et al. 1977b
1,2-dichloro-naphthalene	5,6-dichloro-1,2-dihy-droxy-1,2-dihydronaph-thalene (glucuronide)	rat	Chu, et al. 1977b
1,2,3,4-tetra-chloronaphthalene	5,6,7,8-tetrachloro-1- and -2-naphthols	pig	Ruzo, et al. 1976
1,2,3,4,5,6-hexa-chloronaphthalene	none	pig	Ruzo, et al. 1976

of a series of dichloronaphthalene isomers. Ring hydroxylation and/or hydroxylation-dechlorination was reported in several instances (Table 5), thus also establishing a metabolic dehalogenation pathway for these compounds.

Ruzo, et al. (1976) also studied the metabolism of 1,2,3,4-tetrachloro- and 1,2,3,4,5,6-hexachloronaphthalene in pigs. The tetrachloronaphthalene was hydroxylated on the adjacent ring while no metabolites of the hexachloronaphthalene were found. These findings are consistent with the early report of Cornish and Block (1958) who found considerable metabolism of mono-, di- and tetrachloronaphthalenes in the rabbit, primarily as the gluronide. They, also, were unable to detect metabolism of the more highly chlorinated naphthalene.

Ruzo, et al. (1976) also investigated the 1,2 shift during the metabolism of 1-chloro-4-(^{2}H) naphthalene. Eighteen percent of the deuterium was retained in the metabolite after hydroxylation at the 4-position to yield 4-chloronaphthol. Thus the deuterium must have shifted to another position on the metabolite (Figure 1). The formation of an arene oxide intermediate is one mechanism which could account for this finding.

EFFECTS

In man the first disease that was recognized as being associated with exposure to polychlorinated naphthalenes was halowax acne (a form of chloracne), also known as "cable itch" or "cable rash." Occurrence of this disease was associated with the manufacture or use of polychlorinated naphthalene-treated electrical cables. During World War II chloracne was commonly found among shipyard

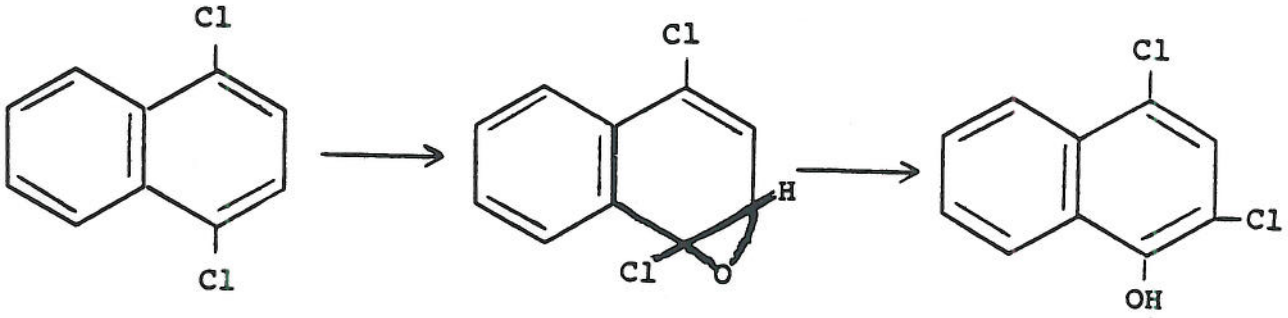

FIGURE 1

Conversion of 1,4-dichloronaphthalene to 2,4-dichloro-1-naphthol Via a Proposed Arene Oxide Intermediate

Source: Brinkman and Reymer, 1976; Ruzo, et al. 1976

electricians. Individuals who stripped the polychlorinated naphthalene-treated covering from cables would often contaminate their clothes with dust or flakes from the covering. If they wore their dirty work clothes home, their wives or children could get a milder form of chloracne (Schwartz, 1943). Chloracne has resulted from both skin contact and inhalation of polychlorinated naphthalene fumes. Polychlorinated naphthalenes dissolve readily and concentrate in the sebum material found in hair follicles (Jones, 1941). Initial symptoms are loss of the sebaceous glands emptying into the follicle, derangement of keratin formation, and plugging of the follicle with resultant comedo. If exposure stops at this point, the sebaceous glands can empty into the follicle with resultant comedo; the sebaceous glands can regenerate and the rash can clear after several months. Continued exposure injures the follicle walls, causing an inflammatory reaction and formation of a pustule. Later, the walls deteriorate and rupture with loss of follicular material to the surrounding tissues. This results in the formation of a cyst or sterile abcess.

Not all polychlorinated naphthalenes are acneigenic. Shelley and Kligman (1957) applied various polychlorinated naphthalenes to human subjects. They found chloracne only after treating their subjects with a suspension containing a mixture of penta- and hexachlorinated naphthalenes. Similarly, Hambrick (1957) noted chloracne only after treating his subjects with a 3 percent solution of hexachloronaphthalene or a mixture of penta- and hexachlorinated naphthalenes. In addition, these were the only two mixtures that produced hyperkeratosis when applied to the ears of rabbits.

Epidemiologic studies confirm these clinical and experimental impressions. Crow (1970) noted a continuing incidence of chloracne in a capacitor plant that utilized both tri-/tetrachlorinated and penta-/hexachlorinated naphthalene mixtures. As soon as the use of the latter mixture was stopped, chloracne ceased to be found at this factory. Kleinfeld, et al. (1972) noted that an electric coil manufacturing plant had no problems with chloracne while using a mono- and dichloronaphthalene mixture. When a tetra-/pentachlorinated naphthalene mixture was unwittingly substituted for the original mixture, 56 of the 59 potentially exposed workers developed chloracne within a short time. They also complained of puritis, eye irritation, headaches, fatigue, vertigo, nausea, loss of appetite, and weight loss. Liver function studies in five of the affected individuals were normal. Kimbrough and Chamblee (1972) provided a general review of the toxic response of industrial populations exposed to chlorinated naphthalenes as paraphrased below.

Individuals with high-level exposures to the fumes of polychlorinated naphthalenes can develop acute or subacute liver disease with or without an associated chloracne. With a rapidly progressive course there are jaundice, abdominal pain, edema, ascites, and decrease in liver size. At autopsy the liver is small and necrotic with evidence of fatty metamorphosis, a condition called acute yellow atrophy. With less exposure the course can be long enough for the development of a postnecrotic-type of cirrhosis or liver scarring. At the time of death, common findings include evidence of damage to the heart, pancreas, gall bladder, lungs, adrenal glands, and kidney tubules in addition to severe liver damage

(Greenburg, et al. 1939; Strauss, 1944). With even less exposure, there may be few or no clinical findings and only mild-to-moderate laboratory evidence of liver dysfunction that resolves with time (Cotter, 1944).

Acute, Subacute, and Chronic Toxicity

Almost invariably, clinical evidence of damage from polychlorinated naphthalene exposure has occurred only after repeated exposures. Consequently, there have been few tests of acute toxicity. Cornish and Block (1958), in investigating metabolites of polychlorinated naphthalenes, gave groups of three rabbits single oral doses of various compounds at a level of 500 mg/kg and followed their course for 7 days. No mortality or illness occurred in the rabbits given mono-, di-, or tetrachloronaphthalenes. One of the three rabbits given pentachloronaphthalene died. All of the rabbits given a solution of hepta- or octachloronaphthalene died.

During 1930-1940 a number of herds of cattle were afflicted with hyperkeratosis of cattle. This unusual disease is also known as "X-disease" of cattle. Severely afflicted animals developed coarse, wrinkled skin, a chronic cough and shortness of breath, weight loss with associated inflammation of the upper portion of the gastrointestinal tract, pancreatitis and pancreatic scarring, kidney damage, gall bladder disease, severe liver damage, hair loss, and reversible suppression of spermatogenesis (Vlahos, et al. 1955). In addition cattle were found to be more susceptible to a viral infection, proliferative stomatitis, which caused warty growths of the mucosal lining of the nose, mouth, and intestinal tract (Olson, 1969). This disease was eventually traced to the

ingestion (either by licking farm equipment or by eating contaminated food pellets) of oil or grease containing polychlorinated naphthalenes. The investigation of the origins of this illness stimulated studies on the subacute and chronic toxicity of orally ingested polychlorinated naphthalenes. Although many studies were performed using several species, including rats (Bennett, et al. 1938), sheep (Brock, et al. 1957), pigs (Link, et al. 1958), and hamsters (Schoettle, et al. 1955) (Table 6), the most comprehensive studies involved cattle and calves (Bell, 1953; Sikes and Bridges, 1952; Sikes, et al. 1952; Vlahos, et al. 1955) (Table 7).

The early studies by Bennett, et al. (1938) were undertaken because of reports of fatal jaundice in several workers exposed to chlorinated naphthalenes. The various chlorinated naphthalenes were mixed in the diet and fed to rats housed 10 per cage. The animals fed trichloronaphthalene survived but developed slight liver damage (swelling of parenchymal cells) after about 90 days of treatment. Ingestion of the tetra-penta mixture or the penta-hexa mixture resulted in severe systemic disease with all animals either dying or sacrificed in a moribund condition. Histopathological studies showed marked swelling and vacuolization of liver cells. Scattered necrotic cells and occasional mitotic figures were also seen.

Unfortunately the feeding studies by Bennett, et al. (1938) were carried out at rather high doses in order to demonstrate effects which were often severe. Only a single dose level was used, thus there are generally no intermediate or no-effect levels available.

TABLE 6

Oral Toxicity of Polychlorinated Naphthalenes

No. of Chlorine Atoms	Dose	Duration (days)	Results	Species	Reference
3*	300 mg/rat/day	9-182	Slight liver damage	Rats	Bennett, et al. 1938
4,5	50 mg/rat/day	63	All moribund or dead	Rats	Bennett, et al. 1938
5,6	125 mg/rat/every other day	26	Moderate liver damage	Rats	Bennett, et al. 1938
5,6	100 mg/rat/day	55	All moribund or dead	Rats	Bennett, et al. 1938
5,6	300 mg/rat/day	33	All dead	Rats	Bennett, et al. 1938
4,5,6	1.1 mg/kg/day	90-135	Severe liver damage or death	Sheep	Brock, et al. 1957
4,5,6	11.0-27.6 mg/kg/day	7-35	All dead	Sheep	Brock, et al. 1957
6	11.0-16.5 mg/kg/day	8-10	No effect	Pigs	Link, et al. 1958
6	17.1-17.6 mg/kg/day	9-10	Depressed Vitamin A	Pigs	Link, et al. 1958
6	19.8-22.0 mg/kg/day	8-10	All moribund or dead	Pigs	Link, et al. 1958

*With traces of 4

TABLE 7

Oral Toxicity of Polychlorinated Naphthalenes in Cattle

No. of Chlorine Atoms	Dose (mg/kg/day)	Duration (days)	Results	Reference
2	4.4	7	No effect	Bell, 1953
3	2.4-2.6	7-10	No effect	Bell, 1953
4	1.6-2.7	10	Slight hyperkeratosis	Bell, 1953
4	3.4	13	No effect	Bell, 1953
5	1.7-3.3	5-10	Severe systemic disease	Bell, 1953
6	1.1-3.2	5-10	Severe systemic disease	Bell, 1953
6	4.6-13.9	20-30	Severe systemic disease	Sikes, et al. 1952
7	0.69-2.4	7-9	Severe systemic disease	Bell, 1953
8	1.0	11	Mild systemic disease	Bell, 1953
8	2.4	9	Severe systemic disease	Bell, 1953
8	4.9-12.3	13-18	Severe systemic disease	Sikes, et al. 1952

The sheep studies by Brock, et al. (1957) (Table 6) were at dose levels only a fraction of those used by Bennett, et al (1938) in the rat studies. Nevertheless the sheep also developed severe liver damage and died even when only 1.1 mg/kg/day of (4,5,6) chloronaphthalene was fed in the diet. Thus in this study also, even though 3 dose levels were used, no intermediate or no-effect level was determined.

Link, et al. (1958) fed hexachloronaphthalene to pigs for 8 to 10 days at dose levels ranging from 11 to 22 mg/kg/day (Table 6). At necropsy (36 to 64 days) pigs receiving 11 mg/kg for the 10 days had no visible effects and histological examination showed liver and kidney to be essentially normal. At higher dose levels (19-22 mg/kg/day) for 10 days animals became moribund and were sacrificed. These animals had hemorrhagic liver and mild gastritis. The pigs did not develop the typical signs and symptoms seen in cattle nor did they develop more than a minimal hyperkeratotic response. The authors suggest that the pig is considerably more resistant to the chlorinated naphthalenes than is the cow.

Data reported by Schoettle, et al. (1955) suggest that the hamster appears to be more resistant to chlorinated naphthalenes than the rat. This study also demonstrated decreased vitamin A levels in the treated animals. A subsequent study of vitamin A levels in rats treated with 90 percent octachloronaphthalene fed at levels as low as 0.002 percent of the diet resulted in rapid loss of vitamin A from the liver, but blood levels were essentially unchanged (Deadrick, et al. 1955). This is in contrast to the report of decreased vitamin A levels in plasma of calves treated with wood

preservative containing chlorinated naphthalenes (Hansel, et al. 1951).

Bell (1953) reported the effects of a series of chlorinated naphthalenes in cattle (Table 7). In some instances several dose levels were utilized. These were all short-term dosing studies (5-13 days) with period of subsequent observation ranging up to several months prior to sacrifice depending on the condition of the animal. These dosage levels are much lower than those used in Bennett's rat studies (Table 6) and are more comparable to those used in sheep and pigs (Table 6). No effects were noted in cattle fed di- or trichloronaphthalene at dosages approximately 2 to 4 mg/kg/day for 7 to 10 days. Minimal systemic effects and hyperkeratosis developed in cattle fed tetrachloronaphthalene. With all other more highly chlorinated naphthalenes severe systemic effects were noted in cattle receiving 1.1 to 3.3 mg/kg/day for 5 to 10 days.

Sikes and Bridges (1952) fed pentachloronaphthalene to two cows at increasing dose levels of 2, 4, 6, and 8 g/day. Each dose level was fed for a 10-day period then increased for the next 10 days. Animals were sacrificed at 40 days showing hyperkeratosis and severe systemic distress, diarrhea, salivation, cough, and weight loss. The livers showed severe central lobular degeneration. A subsequent study, Table 7 (Sikes, et al. 1952), at high dose levels of hexa- and octachloronaphthalene also produced similar toxic results. One nursing calf, kept separate from the mother except when nursing, also developed hyperkeratosis suggesting transfer of the octachloronaphthalene through the milk.

An additional study by Vlahos, et al. (1955) examined the effect of penta- and hexachloronaphthalene on a bull fed 2 to 8 mg/kg/day for 21 days. Five days after the first dose plasma vitamin A levels had dropped by 50 percent. Four months after the final dose vitamin A levels were approaching normal. An examination of semen indicated that the concentration of sperm dropped from 400,000 to 5,000 per mm^3 within 3 months after the administration of the chlorinated naphthalene. For the following 4 months the sperm count was 0 to 200 per mm^3. Recovery was gradual and the count was at 300,000 per mm^3 nine months after the initial dose. Ten days after the final dose the left epididymis and testis was surgically removed from the treated bull and a control bull. This treatment did not significantly alter sperm count or sperm motility of the control animal. The seminiferous epithelium of the treated bull had degenerated and there was pronounced squamous metaplasia in the head of the epididymis.

Bennett, et al. (1958) along with their oral feeding studies carried out a relatively long-term inhalation study with trichloronaphthalene and with a penta-hexachloronaphthalene mixture. The results are shown in Table 8. Rats exposed to trichloronaphthalene at 1.31 mg/m^3 or 10.97 mg/m^3 for approximately four months, 16 hours per day, developed slight to moderate liver damage. The lower dose level may be close to a no-effect level by the inhalation route. Three exposure levels were chosen for the penta-hexachloronaphthalene study. At an exposure level of 8.88 mg/m^3 for 16 hr/day all animals died or were sacrificed <u>in extremis</u>. At 1.16 mg/m^3 for 16 hr/day animals had developed in about 30 days a

moderate degree of liver damage described as swollen and granular liver cells with a moderate excess of small fat droplets. These abnormalities increased slightly during the next 30 days of exposure, but were then unchanged even though exposure continued for several additional months. Rats exposed for 105 days then removed from exposure for a period of two months still showed liver changes similar to those present when they were removed from the exposure. Thus recovery was extremely slow. Animals exposed to 1.44 mg/m^3 for 8 hr/day for 143 days had liver damage comparable to that of the animals exposed to 1.16 mg/m^3 for 16 hours daily. Thus, in this study also a no-effect level was not demonstrated.

Dichloronaphthalene was found to be non-toxic at a dose of 4.4 mg/kg/day in calves (Bell, 1953). Although ingestion of trichloronaphthalene did not result in any toxic effects in cattle, inhalation of this chemical by rats at a concentration producing an average daily dose of 0.78 mg/kg resulted in mild liver changes (Table 8). Tetrachloronaphthalene, when given in doses of 1.6 to 3.4 mg/kg/day to calves, caused no systemic effects but did produce a mild hyperkeratosis in some animals. Exposures to penta- and hexachloronaphthalene, either alone or as a mixture, did result in severe systemic disease except at very small doses. Rats inhaling a mixture of these two compounds equivalent to a dose of 0.48 mg/kg/day developed slight liver changes, while more severe changes or death were found at 5.97 mg/kg/day dose levels (Table 8). Although sheep and cattle also developed severe systemic disease when treated with low doses of penta- and/or hexachloronaphthalene, swine appeared to be more resistant to the effects of hexachloro-

TABLE 8

Inhalation Toxicity of Polychlorinated Naphthalenes in Rats*

No. of Chlorine Atoms	No. of Animals	Air Level (mg/m^3)	Exposure Days	Exposure Hr/day	Dose[a] (mg/kg/day)	Results
3[b]	80	1.31	134	16	0.78	Very slight liver damage
3[b]	50	10.97	102	16	7.37	Moderate liver damage
5,6	80	1.44	143	8	0.48	Slight to moderate liver damage
5,6	80	1.16	134	16	0.68	Slight to moderate liver damage
5,6	80	8.88	52	16	5.97	All moribund or dead

*Source: Bennett, et al. 1938

[a]Calculated using a respiratory rate for rats of 42 ml/hr/gm body weight (Altman and Ditmer, 1974) and assuming 100 percent absorption.

[b]With traces of 4

naphthalene. Bell (1953) found that a suspension of octachloronaphthalene was considerably less toxic than solutions of this compound when administered orally to calves.

Chloracne and liver disease similar to that found in individuals exposed to high levels of chlorinated naphthalenes are also seen in individuals exposed to polychlorinated biphenyls. Much of the toxicity of polychlorinated biphenyls has been attributed to contamination of the biphenyls by chlorinated dibenzofurans (Cordle, et al. 1978). Although chlorinated naphthalenes and chlorinated dibenzofurans have been found as co-contaminants of polychlorinated biphenyls (Vos, et al. 1970), chlorinated dibenzofurans have not been identified in samples of chlorinated naphthalenes or implicated in disease states associated with exposure to chlorinated naphthalenes.

Synergism and/or Antagonism

Drinker, et al. (1937) exposed rats to an average of 1.31 mg/m^3 of trichloronaphthalene or to 1.16 mg/m^3 of a penta-/hexachloronaphthalene mixture in air for 6 weeks with only minor liver effects. When a similarly exposed group of rats was challenged with a sublethal dose of an ethanol/carbon tetrachloride mixture, no effect was seen in the trichloronaphthalene-exposed rats, but 7 of the 10 penta-/hexachloronaphthalene-exposed rats died. No other data are available on potentially synergistic or antagonistic effects.

Teratogenicity, Mutagenicity, and Carcinogenicity

No animal or human studies have been completed on the carcinogenicity, mutagenicity, or teratogenicity of polychlorinated naphthalenes.

CRITERION FORMULATION

Existing Guidelines and Standards

The only standards that presently exist for polychlorinated naphthalenes are the Occupational Safety and Health Administration (OSHA) standards which were adopted from and are identical to the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs). These TLVs were developed to prevent the occurrence of chloracne or liver changes among workers with potential exposures to chlorinated naphthalenes (ACGIH, 1971). The rigor of these standards increases as the number of chlorine atoms present increases based on the assumption that vapor toxicity is proportional to the number of chlorine atoms present in each compound. The present Threshold Limit Values (ACGIH, 1979) are:

Trichloronaphthalene	5.0 mg/m^3
Tetrachloronaphthalene	2.0 mg/m^3
Pentachloronaphthalene	0.5 mg/m^3
Hexachloronaphthalene	0.2 mg/m^3
Octachloronaphthalene	0.1 mg/m^3

There are no state or federal water quality or ambient air quality standards for chlorinated naphthalenes.

Current Levels of Exposure

Polychlorinated naphthalenes have not been identified in drinking water samples, market basket food samples, or at standard ambient air stations. Near point sources, concentrations in water can range as high as 7.0 µg/l (Crump-Wiesner, et al. 1973) and concentrations in air as high as 2.9 $\mu g/m^3$ (Erickson, et al. 1978). Near a point source one fish sample had a level of 39 µg/kg for the whole fish, and a sample of apples contained 90 µg/kg of

polychlorinated naphthalenes (Erickson, et al. 1978). Polychlorinated naphthalenes have been detected in several samples of PCBs, compounds that are known to be widely distributed in the aquatic environment. Measurements of chlorinated naphthalenes in environmental samples have not been widely performed using current sensitive measurement techniques for these compounds.

Special Groups at Risk

Because of the possible potentiation of the toxicity of higher chlorinated naphthalenes by ethanol and carbon tetrachloride, individuals who ingest enough alcohol to result in liver disfunction would be a special group at risk. Individuals who are routinely exposed to carbon tetrachloride or other hepatotoxic chemicals (e.g., analytical and synthetic chemists, mechanics, and cleaners) would also be at a greater risk than a population without such an exposure. Individuals involved in the manufacture, utilization, or disposal of polychlorinated naphthalenes would be expected to have higher levels of exposure than the general population.

Basis and Derivation of Criteria

The chlorinated naphthalenes have not been tested for teratogenicity, mutagenicity, or carcinogenicity.

Although these compounds have been associated with the development of chloracne and, in some instances, fatal liver disease, little quantitative data is available. This is particularly true with respect to the oral route of exposure which is of major concern in the development of water criterion. Both animal and human studies provide evidence that the less highly chlorinated naphthalenes appear less toxic than the highly chlorinated ones.

With respect to trichloronaphlalene the oral studies by Bell, (1953), were of short duration (7-10 days) at a daily dose level of 2 to 3 mg/kg/day in cattle. No effects were noted. However, the treatment period is too brief to be useful in developing a criterion. The Bennett, et al. (1938) study in ten rats was a a high dose level (750 mg/kg/day) and exposure extended up to 182 days for some animals. Minimal liver damage was noted, thus even in this limited study, a no-effect level was not achieved. The inhalation study by Bennett, et al. (1938) summarized in Table 8 provided approximately a four-month exposure period for two groups of rats at 0.68 mg/kg/day and at 7.37 mg/kg/day. At the termination of the study, the rats (80) at the low-dose level had minimal liver damage while the high-dose level had more severe liver damage. Thus the low exposure level did not define a no-effect level. Additionally, the effects noted in rats at the low level inhalation study appear comparable to the effects seen in rats fed approximately 1,000 times that dose by the oral route. One might question the degree of absorption of the compound when incorporated into the diet. Bell (1953) fed three cows 2.4 to 2.6 mg/kg/day of trichloronaphthalene in solution also without effect. This and subsequent studies make the rat appear to be more resistant to the effects of chloronaphthalenes, but the rat studies involve ingestion of the solid material. Bell (1953) reported that in one study compounds suspended in mineral oil were not as toxic as when the material was fed in solution (Table 7). Overall, the lack of a no-effect level in any study, the short exposure time of the oral feeding studies, and the

apparent species differences in response preclude the use of these data for developing a criterion for trichloronaphthalene.

With respect to the more highly chlorinated naphthalene, the oral feeding data in animals provides evidence that these compounds are reasonably toxic, since, with two exceptions, no-effect levels were not achieved in the studies on cattle, rats, sheep, or pigs (Tables 6 and 7). In one exception Bell (1953) found no-effect in one cow fed 3.6 mg/kg/day of tetrachloronapthalene, however two other cows fed only 2.6 mg/kg/day for 10 days developed mild symptoms of hyperkeratosis. Link, et al. (1958) found no effect in pigs fed 11-16 mg/kg/day of hexachloronaphthalene for 8-10 days. However, no histopathological studies were done, thus liver damage may not have been detected.

One must keep in mind that none of the oral studies were designed to examine dose-response relationships with respect to establishing safe levels of exposure. Most were designed to study the nature of the response in the several species, because of the established potential for this compound to produce hyperkeratosis in cattle.

The inhalation study of a mixture of hexa- and pentachloronaphthalene by Bennett, et al. (1938) comprised three dose levels with exposures continuing for 52 to 143 days. At the high dose level, calculated to be a maximum of 5.97 mg/kg/day, all animals died or were sacrificed in a moribund condition. At the two lower dose levels animals survived approximately four months of exposure, but exhibited slight to moderate liver damage at autopsy. These dosage levels, calculated at 0.48 and 0.68 mg/kg/day with slight to

moderate liver damage, are not inconsistent with the level of 1.1 mg/kg/day that produced severe liver damage in sheep (Table 6). Again in the rat inhalation study, these animals appear much more susceptible to the inhaled penta-hexachloronaphthalene than do the orally fed rats that survived dosages of 250 to 750 mg/kg/day for 33 to 55 days.

Thus the inconsistencies in the data, the lack of a no-effect level, and what may be marked differences in the response by the oral versus the inhalation route make it extremely difficult to interpret these data. One is forced to the decision that insufficient data is available to develop a rational criteria for these compounds.

It must be emphasized that the failure to derive any criteria for the chlorinated naphthalenes is due solely to the lack of appropriate data. By comparison of their chemical and physical properties, one might predict that persistence in the environment could be comparable to that of the polychlorinated biphenyls.

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