

6. POTENTIAL FOR HUMAN EXPOSURE

6.1 OVERVIEW

Heptachlor and heptachlor epoxide have been identified in at least 210 and 200 of the 1,684 hazardous waste sites, respectively, that have been proposed for inclusion on the EPA National Priorities List (NPL) (HazDat 2006). However, the number of sites evaluated for heptachlor is not known. The frequency of these sites can be seen in Figure 6-1 and 6-2, respectively. Of these sites for heptachlor, 207 are located within the United States, 2 are located in the Commonwealth of Puerto Rico (not shown), and 1 is located in the Virgin Islands. For heptachlor epoxide, 195 of these sites are located within the United States, 2 are located in Guam, 2 are located in the Commonwealth of Puerto Rico, and 1 is located in the Virgin Islands.

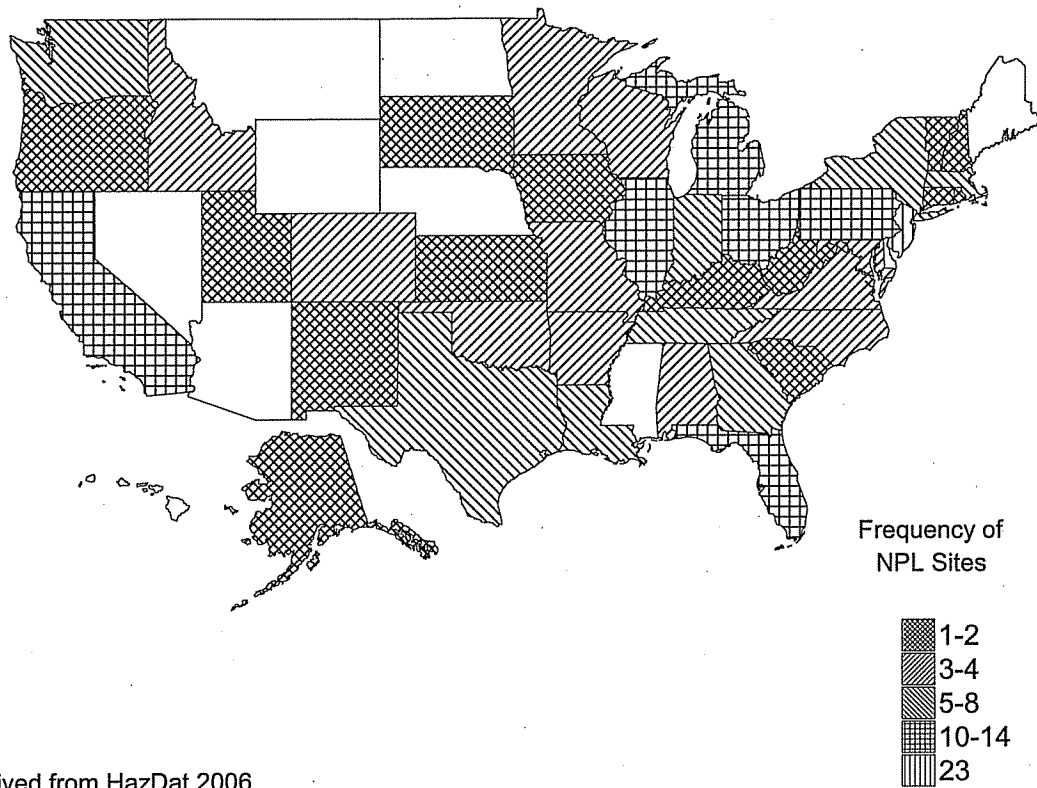
Heptachlor was used extensively until the 1970s as a broad-spectrum insecticide on a wide variety of agricultural crops, with the major use on corn. It also had nonagricultural uses including seed treatment, home and garden uses, and termite control. In 1974, EPA proposed cancellation of nearly all registered uses of heptachlor except termite and fire ant control and dipping of roots or tops of nonfood plants, a use that was subsequently voluntarily canceled by the registrant in 1983 (EPA 1986a). In 1988, the sale, distribution, and shipment of existing stocks of all heptachlor products were prohibited in the United States with an exemption for the use of fire ant control. As of April 1988, heptachlor could no longer be used for the underground control of termites. Currently, the only commercial use of heptachlor still permitted in the United States is fire ant control in underground power transformers (EPA 1990a); however, in 1999, the sole manufacturer of heptachlor chose not to renew its registration with the EPA (EPA 1999a). As of April 2007, there were no active pesticide labels containing heptachlor (NPIRS 2007). Therefore, it is unclear whether heptachlor is still available in the United States.

Heptachlor is converted to heptachlor epoxide and other degradation products in the environment.

Heptachlor epoxide degrades more slowly and, as a result, is more persistent than heptachlor. Heptachlor epoxide has been found in food crops grown in soils treated with heptachlor many years before. Both heptachlor and heptachlor epoxide adsorb strongly to sediments, and both are bioconcentrated in aquatic and terrestrial organisms. Biomagnification of heptachlor and heptachlor epoxide in aquatic food chains is significant. Because heptachlor is readily metabolized to heptachlor epoxide by higher trophic level organisms, biomagnification of heptachlor itself is not significant. Because of the more persistent nature of heptachlor epoxide and its lipophilicity, biomagnification of heptachlor epoxide in terrestrial food chains is significant.

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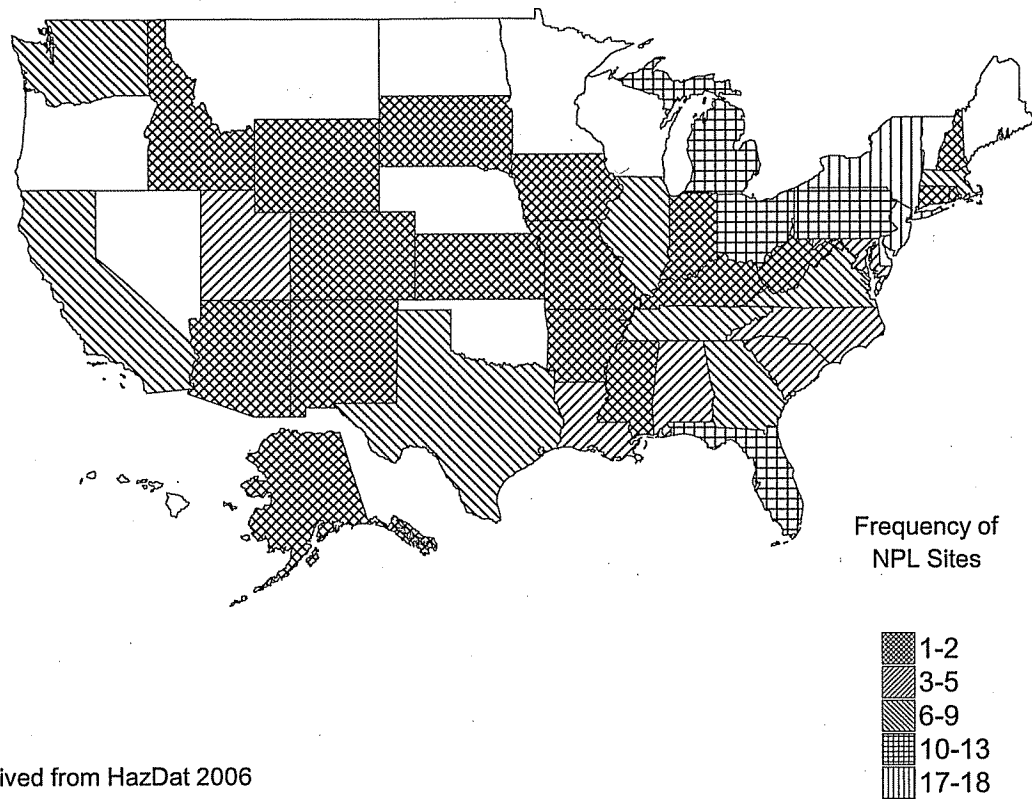
Figure 6-1. Frequency of NPL Sites with Heptachlor Contamination



Derived from HazDat 2006

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Figure 6-2. Frequency of NPL Sites with Heptachlor Epoxide Contamination



Derived from HazDat 2006

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In the past (prior to 1974), exposure of humans to heptachlor and heptachlor epoxide was directly related to the application of heptachlor as an insecticide. However, because of the persistence and bioaccumulation of heptachlor and heptachlor epoxide, exposure of the general population can occur through ingestion of contaminated food (especially cow or human milk), inhalation of vapors from contaminated soil and water, or direct contact with residual heptachlor from pesticide application. People whose homes have been treated may continue to be exposed to these chemicals in the air over long periods. Occupational exposure can occur in the manufacture of the chemical or from use of heptachlor to control fire ants. The most likely routes of exposure at hazardous waste sites are unknown. Heptachlor has been found infrequently in soil and groundwater at hazardous waste sites. Children who eat contaminated soil or people who obtain tap water from wells located near hazardous waste sites might be exposed to heptachlor. Further, since both compounds can volatilize from soil, people living near hazardous waste sites may be exposed to the compounds in the air. People whose homes have been professionally treated for termites, either by spraying or subsurface injection, may continue to be exposed to heptachlor and possibly to its transformation product, heptachlor epoxide, in the indoor air over long periods. Releases can also occur from the use of existing stocks in the possession of homeowners (EPA 1990a).

6.2 RELEASES TO THE ENVIRONMENT

The Toxics Release Inventory (TRI) data should be used with caution because only certain types of facilities are required to report (EPA 2005f). This is not an exhaustive list. Manufacturing and processing facilities are required to report information to the TRI only if they employ 10 or more full-time employees; if their facility is included in Standard Industrial Classification (SIC) Codes 10 (except 1011, 1081, and 1094), 12 (except 1241), 20–39, 4911 (limited to facilities that combust coal and/or oil for the purpose of generating electricity for distribution in commerce), 4931 (limited to facilities that combust coal and/or oil for the purpose of generating electricity for distribution in commerce), 4939 (limited to facilities that combust coal and/or oil for the purpose of generating electricity for distribution in commerce), 4953 (limited to facilities regulated under RCRA Subtitle C, 42 U.S.C. section 6921 et seq.), 5169, 5171, and 7389 (limited S.C. section 6921 et seq.), 5169, 5171, and 7389 (limited to facilities primarily engaged in solvents recovery services on a contract or fee basis); and if their facility produces, imports, or processes $\geq 25,000$ pounds of any TRI chemical or otherwise uses $>10,000$ pounds of a TRI chemical in a calendar year (EPA 2005f).

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6.2.1 Air

Estimated releases of 2 pounds of heptachlor and heptachlor epoxide to the atmosphere from 14 domestic manufacturing and processing facilities in 2004, accounted for <0.1% of the estimated total environmental releases from facilities required to report to the TRI (TRI04 2006). These releases are summarized in Table 6-1.

6.2.2 Water

Estimated releases of 9 pounds of heptachlor and heptachlor epoxide to surface water from 14 domestic manufacturing and processing facilities in 2004, accounted for about 0.3% of the estimated total environmental releases from facilities required to report to the TRI (TRI04 2006). These releases are summarized in Table 6-1. These releases were predominantly from hazardous waste disposal agencies (TRI04 2006).

Heptachlor and heptachlor epoxide may enter surface water and groundwater in runoff from contaminated soils or in discharges of waste water from production facilities.

6.2.3 Soil

Estimated releases of 3,140 pounds of heptachlor and heptachlor epoxide to soils from 14 domestic manufacturing and processing facilities in 2004, accounted for >99% of the estimated total environmental releases from facilities required to report to the TRI (TRI04 2006). These releases are summarized in Table 6-1. These releases were predominantly from hazardous waste disposal agencies (TRI04 2006).

6.3 ENVIRONMENTAL FATE**6.3.1 Transport and Partitioning**

Heptachlor has a low vapor pressure (3.0×10^{-4} mmHg at 25 °C) and low water solubility (0.056 mg/L) (EPA 1987; Jury et al. 1987). The experimental value for the Henry's law constant is 1.48×10^{-3} suggesting that heptachlor partitions somewhat rapidly to the atmosphere from surface water and that volatilization is significant (EPA 1987; Lyman et al. 1982). Heptachlor is also subject to long-range transport and wet deposition.

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Table 6-1. Releases to the Environment from Facilities that Produce, Process, or Use Heptachlor^a

State ^c	RF ^d	Reported amounts released in pounds per year ^b							Total release		
		Air ^e	Water ^f	UI ^g	Land ^h	Other ⁱ	On-site ^j	Off-site ^k	On- and off-site		
AR	2	0	No data	No data	0	0	0	0	0		
LA	1	0	No data	No data	7	0	7	0	7		
NE	1	0	No data	No data	0	0	0	0	0		
NJ	1	0	9	No data	7	0	16	0	16		
NV	1	0	No data	No data	162	0	162	0	162		
OH	2	1	0	No data	1	0	1	1	2		
OR	1	0	No data	No data	2,962	0	2,962	0	2,962		
PA	1	0	No data	No data	0	0	0	0	0		
TX	3	0	0	No data	0	0	0	0	0		
UT	1	0	No data	No data	0	0	0	0	0		
Total	14	2	9	No data	3,140	0	3,149	1	3,150		

^aThe TRI data should be used with caution since only certain types of facilities are required to report. This is not an exhaustive list. Data are rounded to nearest whole number.

^bData in TRI are maximum amounts released by each facility.

^cPost office state abbreviations are used.

^dNumber of reporting facilities.

^eThe sum of fugitive and point source releases are included in releases to air by a given facility.

^fSurface water discharges, waste water treatment-(metals only), and publicly owned treatment works (POTWs) (metal and metal compounds).

^gClass I wells, Class II-V wells, and underground injection.

^hResource Conservation and Recovery Act (RCRA) subtitle C landfills; other on-site landfills, land treatment, surface impoundments, other land disposal, other landfills.

ⁱStorage only, solidification/stabilization (metals only), other off-site management, transfers to waste broker for disposal, unknown

^jThe sum of all releases of the chemical to air, land, water, and underground injection wells.

^kTotal amount of chemical transferred off-site, including to POTWs.

RF = reporting facilities; UI = underground injection

Source: TRI04 2006 (Data are from 2004)

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The log soil organic carbon adsorption coefficient ($\log K_{oc}$) for heptachlor was estimated to be 4.34 (Chapman 1989). The $\log K_{oc}$ value indicates a very high sorption tendency, suggesting that it will adsorb strongly to soil and is not likely to leach into groundwater in most cases (Chapman 1989). The leaching potential at 15 cm (concentration in soil water/concentration in soil) for heptachlor is 0.06, and the volatilization potential at 15 cm (concentration in soil air/concentration in soil) determined in laboratory studies is 5.5×10^{-3} , again suggesting that heptachlor is unlikely to leach appreciably in soil but has some volatilization potential (McLean et al. 1988). These are important properties since heptachlor can remain deep in soil for years. The organic matter content of the soil is another factor affecting mobility. Heptachlor is less likely to leach from soil with a high organic matter content. When released into water, it adsorbs strongly to suspended and bottom sediment.

Volatilization from soil particles to the atmosphere is possible (McLean et al. 1988). Volatilization is an important mechanism of transport of heptachlor from land surfaces (Jury et al. 1987). When heptachlor was applied to orchard grass, approximately 90% was lost in 7 days. When it was applied to moist soil surfaces, 50% was lost in 6 days. When it was applied to dry soil surface, 14–40% was lost in approximately 2 days (50 hours). Volatilization was much less—only 7% in 167 days—when incorporated to a shallow depth of 7.5 cm (Jury et al. 1987). Temperature and humidity affect the persistence of heptachlor and total heptachlor (heptachlor plus heptachlor epoxide) in soil (Shivankar and Kavadia 1989). An increase in temperature resulted in a decrease in the volatilization half-lives of heptachlor and total heptachlor. For example, at 18 ± 1 °C ($90 \pm 5\%$ relative humidity [RH]) and 35 ± 1 °C ($90 \pm 5\%$ RH), the half-lives of heptachlor (6 ppm) were 44.8 days and 38 days, respectively. Persistence of heptachlor and total heptachlor was found to be greater at higher humidity, irrespective of temperature. At the combination of higher temperature (25 ± 1 °C) and low humidity ($55 \pm 5\%$ RH), faster dissipation of heptachlor occurred (half-life=24.67 days). At lower temperatures (18 ± 1 °C) and low humidity ($55 \pm 5\%$ RH), greater persistence of heptachlor was found (40.67 days). Half-lives of total heptachlor (6 ppm) were longer because of the more persistent nature of heptachlor epoxide (Shivankar and Kavadia 1989).

The logarithm of the *n*-octanol/water partition coefficient ($\log K_{ow}$) is a useful preliminary indicator of bioconcentration potential of a compound. The $\log K_{ow}$ for heptachlor is 5.44 (Chapman 1989; MacKay 1982), suggesting a high potential for bioaccumulation and biomagnification in the aquatic food chain. The bioconcentration factors (BCFs) for heptachlor were 10,630 in Asiatic clam fat (*Corbicula*

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manilensis), 2,570 in soft clams (*Mya arenaria*), and 8,511 in oysters (*Crassostrea virginica*) (Hawker and Connell 1986).

Heptachlor epoxide is soluble in water at a concentration of 0.275 mg/L (EPA 1987). The experimental value for Henry's law constant is 3.2×10^{-5} (EPA 1987), suggesting that heptachlor epoxide partitions slowly to the atmosphere from surface water (Lyman et al. 1982). Based on regression equations, the log K_{oc} for heptachlor epoxide was estimated to range between 3.34 and 4.37 (Lyman et al. 1982). These log K_{oc} values suggest a high sorption tendency, meaning that this compound is not mobile in soil and has a low potential to leach. The organic matter content of soil affects the mobility of heptachlor epoxide. Heptachlor epoxide is less likely to leach from soil with a high organic matter content. If released into water, it adsorbs strongly to suspended and bottom sediments.

The log K_{ow} for heptachlor epoxide is 5.40 (MacKay 1982), indicating a high potential for bioconcentration and biomagnification in the aquatic food chain. Estimated BCFs for heptachlor epoxide are 1,698 in mussels (*Mytilus edulis*), 851 in oysters (*C. virginica*) (Hawker and Connell 1986; Geyer et al. 1982), and 2,330 in Asiatic clam fat (*C. manilensis*) (Hartley and Johnston 1983). The bioconcentration potentials of heptachlor and heptachlor epoxide differ, with the more polar epoxide being concentrated to a lesser degree than the parent compound (Hartley and Johnston 1983). Biomagnification of heptachlor and heptachlor epoxide in aquatic food chains is significant. Because heptachlor is readily metabolized to heptachlor epoxide by higher trophic level organisms, biomagnification of heptachlor itself is not significant. Because of the more persistent nature of heptachlor epoxide and its lipophilicity, biomagnification of heptachlor epoxide in terrestrial food chains is significant.

Heptachlor and heptachlor epoxide are subject to long-range transport and removal from the atmosphere by wet deposition. Snowpack samples were collected at 12 sites in the Northwest Territories, Canada, in the winter of 1985–1986. Heptachlor epoxide was present in 20 of 21 samples at a mean concentration of 0.18 ng/L (1.8×10^{-4} ppb) with reported concentrations ranging from 0.02 to 0.41 ng/L (from 2×10^{-5} to 4.1×10^{-4} ppb). Heptachlor epoxide was present in both the Bering and Chukchi Seas in 1993 at mean concentrations of 2.4 and 2.8 ng/m³, respectively (Macdonald et al. 2000).

Heptachlor and heptachlor epoxide are also taken up by plants (translocated into plants by absorption through the roots). Loamy soils were treated with heptachlor at a total of 25 pounds per 5-inch acre over a 5-year period (1958–1962) (Lichtenstein et al. 1970). The commercial formulation of heptachlor used also contained γ -chlordane and nonachlor. Insecticide residues were absorbed by crops grown in these

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soils, with carrots absorbing the largest amounts. Although residue levels in soils increased up to 1962, the residue concentrations in both carrots and potatoes peaked during the 1960 growing season. During that year, the concentration of total heptachlor in carrots was 1,900 ppb. Residue levels of total heptachlor on potatoes never exceeded 540–510 ppb (1960–1962). Apparently, a threshold had been reached beyond which the content of insecticidal residues remained constant in these two crops. When insecticide residue levels in soil started to decline (1963), both carrots and potatoes also contained proportionally smaller amounts of residue. In the fall of 1968, residues of total heptachlor were found in the following crops: carrots, 413 ppb (92% heptachlor epoxide); potatoes, 70 ppb (98% heptachlor epoxide); beets, 60 ppb (100% heptachlor epoxide); radishes, 140 ppb (100% heptachlor epoxide); and cucumbers, 90 ppb (95% heptachlor epoxide) (Lichtenstein et al. 1970). Despite being banned in Argentina, trace amounts of heptachlor and heptachlor epoxide (<10 ng/g dry weight) were found in organically grown tomato plants that had never been sprayed with any pesticide outside of Buenos Aires (Gonzalez et al. 2003). Heptachlor epoxide was detected in spruce and pine trees of western Canada and the concentration of heptachlor in these trees seemed to increase as the altitude increased (Davidson et al. 2003).

6.3.2 Transformation and Degradation

6.3.2.1 Air

Heptachlor may undergo direct photolysis in sunlight and is also susceptible to photosensitized reactions (Graham et al. 1973; Ivie et al. 1972). Heptachlor epoxide is converted to intermediate and final photoproducts when exposed to sunlight or ultraviolet light on the surface of plants (Podowski et al. 1979). About 40–50% conversion occurred in 4 hours on bean leaves treated with rotenone, an insecticide, acting as a photosensitizer. No detectable photoproducts (photoheptachlor epoxide) were formed in the absence of rotenone. The photolysis products were ketones. The intermediate photoproduct possesses a reduced toxicity in mice as compared to heptachlor epoxide, and it is completely nontoxic to houseflies. The final photoproduct is more toxic to flies and mice than the parent heptachlor epoxide (Ivie et al. 1972). The photoisomers of heptachlor epoxide are not expected to form in appreciable amounts in the environment unless a potent photosensitizer is present (Ivie et al. 1972). The photolysis of heptachlor epoxide as a solid (pressed) disk, as a powder, and as 0.5% heptachlor epoxide in a potassium bromide (a photosensitizer) disk was studied. The physical nature of the sample and the intensity of illumination affected the rate of photolysis. After 121 hours of exposure to sunlight in July, 93, 98, and 0% heptachlor epoxide remained in the solid disk, powder, and potassium bromide disk, respectively. When a powdered sample of heptachlor epoxide was irradiated on a rooftop of an

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unspecified location from January through mid-September, degradation was almost negligible until May, then increased through July, reaching a maximum decomposition rate of 1% per day at the end of July. By the end of the experiment (8.5 months), 39% of the original sample had decomposed (Graham et al. 1973).

6.3.2.2 Water

Heptachlor is hydrolyzed in surface water and distilled water to 1-hydroxychlordehene and heptachlor epoxide. When heptachlor was added to a sample of river water maintained at room temperature and exposed to sunlight, only 25% remained after 1 week, and no heptachlor remained after the second week. The 75% loss of heptachlor after 1 week corresponds to a half-life of 3.5 days. It was observed that an equilibrium exists at the end of 4 weeks between 1-hydroxychlordehene and heptachlor epoxide, so that approximately 60% of the converted heptachlor remained as 1-hydroxychlordehene and 40% was converted to the epoxide. When heptachlor epoxide was added to a sample of river water (pH 7.3–8) and to distilled water, it remained unchanged for 8 weeks. A half-life of at least 4 years was calculated for heptachlor epoxide (Eichelberger and Lichtenberg 1971).

When a ^{14}C -heptachlor-treated model aquatic ecosystem was examined for transformation of heptachlor in water, the relative amounts of various transformation products in water were determined as the percentage of the total ^{14}C label in the water sample. Heptachlor was found to decrease from 100% to approximately 10% of total ^{14}C material in 1 day (Lu et al. 1975). After 1 day, 1-hydroxychlordehene epoxide was present as 50% of the total ^{14}C , rose to 70% on day 3, and then remained constant until day 13 of the experiment. The heptachlor hydrolysis product, 1-hydroxychlordehene, reached a maximum of 10% of the total ^{14}C at day 1 and decreased thereafter. A relatively small proportion of heptachlor epoxide was formed. Heptachlor epoxide was never found to be >10% of the total ^{14}C in the water sample. The authors concluded that the major pathway of heptachlor in aquatic systems is rapid abiotic hydrolysis of heptachlor to 1-hydroxychlordehene followed by metabolism to 1-hydroxychlordehene epoxide (Lu et al. 1975).

Heptachlor is metabolized by the freshwater microcrustacean, *Daphnia magna*, to heptachlor epoxide or 1-hydroxychlordehene. 1-Hydroxychlordehene is then converted to 1-ketochlordehene, 1-hydroxy2,3-epoxychlordehene, and their glucosides, sulfates, and other conjugates (Feroz et al. 1990).

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6.3.2.3 Sediment and Soil

Incubations of heptachlor with a mixed culture of soil microorganisms for 12 weeks showed slow conversion of heptachlor to chlordene, 1-exohydroxychlordene, heptachlor epoxide, and chlordene epoxide. A mixed culture of soil microorganisms, obtained from a sandy loamy soil, degraded heptachlor epoxide to the less toxic 1-exohydroxychlordene at a rate of 1% per week during the 12-week test period (Miles et al. 1971).

Soil samples that contained heptachlor were taken from five locations selected to represent typical soil types and rainfall patterns in portions of the United States. The samples were taken from places where subterranean termites were a major problem and where heptachlor was applied for treatment (Carter and Stringer 1970). Residues were found in the soil 1, 2, and 3 years after application of heptachlor. Relatively high values for 1-hydroxychlordene, representing approximately 60% of the insecticide in the soil, were obtained from extracts of a Quincy loamy fine sand from Oregon 2 years after application. Significant amounts of 1-hydroxychlordene were also found in extracts of Lakeland sand from Florida. Generally, heptachlor epoxide represented only a small fraction of the insecticide present in the soils (Carter and Stringer 1970). Because the distribution and penetration of heptachlor were uneven, there were large variations in concentration in the soils and therefore, no general trends were recognized (Carter and Stringer 1970).

Loamy soils treated with heptachlor at 25 pounds per 5-inch acre, over a 5-year period from 1958 through 1962, contained about 5% of the applied dosages in the fall of 1968, primarily in the form of heptachlor epoxide. In addition to γ -chlordane and nonachlor, which were present in the original heptachlor formulation, two toxic metabolites (heptachlor epoxide and α -chlordane) as well as three unidentified compounds were detected, thus indicating the breakdown in soils of heptachlor and related compounds (Lichtenstein et al. 1970).

Experiments with thick anaerobically digested waste water sludge at 35°C showed that heptachlor was converted to an extractable degradation product that was more persistent than the initial heptachlor. About a 50% loss of heptachlor epoxide was found in anaerobic thick sludge after approximately 60 days. No information was given as to the identity of the product. No heptachlor epoxide loss occurred in aerobic dilute sludge, and only slight heptachlor epoxide loss occurred in anaerobic dilute sludge (Hill and McCarty 1967).

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6.3.2.4 Other Media

Heptachlor was reported to degrade up to 45% after 3 weeks of composting. Heptachlor and heptachlor epoxide were found in concentrations of 8.5–26 and <3.8 µg/kg of municipal solid waste, respectively. Concentrations of biosolid and municipal solid waste compost were recorded at levels <0.23 and <0.63 µg/kg for heptachlor and heptachlor epoxide, respectively (Buyuksonmez et al. 2000).

6.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

Reliable evaluation of the potential for human exposure to heptachlor and heptachlor epoxide depends in part on the reliability of supporting analytical data from environmental samples and biological specimens. Concentrations of heptachlor and heptachlor epoxide in unpolluted atmospheres and in pristine surface waters are often so low as to be near the limits of current analytical methods. In reviewing data on heptachlor and heptachlor epoxide levels monitored or estimated in the environment, it should also be noted that the amount of chemical identified analytically is not necessarily equivalent to the amount that is bioavailable. The analytical methods available for monitoring heptachlor and heptachlor epoxide in a variety of environmental media are detailed in Chapter 7.

6.4.1 Air

Indoor air levels of heptachlor were measured in various homes in Bloomington, Indiana, that had been professionally treated with a termiticide either by spraying or subsurface injection. Heptachlor was detected at concentrations ranging from 1.1 to 110 ng/m³ (0.0001–0.007 ppb) (Anderson and Hites 1989). Three houses in North Carolina were treated with a termiticide containing both chlordane (0.5%) and heptachlor (0.25%). Immediately after treatment, the average ambient air level of heptachlor was 1.41±0.64 µg/m³ (0.092 ppb). At 12 months post-treatment, the heptachlor level in the air was 1.00±0.70 µg/m³ (0.065 ppb) (Wright and Leidy 1982). Heptachlor was detected at levels ranging from 1.64 to 13.2 ppb in workplace air in 1977 at the Velsicol Chemical Corporation plant in Tennessee that manufactured heptachlor (Netzel 1981). No heptachlor epoxide levels in air were detected (Netzel 1981). A study of nine households selected on the basis of high pesticide usage in an urban-suburban area in the southeastern United States found outdoor air levels of heptachlor ranging from not detectable (0.0006 ppb) to 0.003 ppb, with a mean of 0.001 ppb (Lewis et al. 1986). Heptachlor was found in seven of nine households at levels in indoor air ranging from not detectable to 0.02 ppb, with a mean of 0.006 ppb (Lewis et al. 1986). Air samples taken from Corpus Christi, Texas in 1998 had a mean heptachlor concentration of 0.04 ng/m³ (Park et al. 2002). Heptachlor was measured in Alabama air from

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January to October 1996. Heptachlor was found in concentrations ranging from 20 to 50 $\mu\text{g}/\text{m}^3$ with the highest concentrations in the summer months and the lowest concentrations in April and May. No heptachlor was detected in October (Jantunen et al. 2000). Heptachlor and heptachlor epoxide were also detected in air in Galveston, Texas in concentrations ranging from 6.1 to 77.2 and from not detected to 30.4 $\mu\text{g}/\text{m}^3$, respectively (Park et al. 2001).

Since heptachlor was used for termite control, monitoring the levels of heptachlor when applied in a home is of interest. In a study of 19 homes where heptachlor was used in the treatment of subterranean termite control, a mean concentration of 5 $\mu\text{g}/\text{m}^3$ was observed during treatment. After 24 hours, the concentration of heptachlor decreased to about 2 $\mu\text{g}/\text{m}^3$. However, even after 180 days, heptachlor levels remained around 2 $\mu\text{g}/\text{m}^3$, which was much higher than the 0.5 $\mu\text{g}/\text{m}^3$ mean from before treatment. Concentrations of heptachlor were highest in the basement of these homes with mean concentrations of 9 and 2 $\mu\text{g}/\text{m}^3$ during treatment and after 180 days, respectively (Kamble et al. 1992).

6.4.2 Water

A statewide survey (December 1985–February 1986) was conducted in Kansas to determine the degree and extent of pesticide contamination of drinking water from approximately 100 private farmstead wells. Heptachlor was detected in 1% of the wells tested at a concentration range of 0.023–0.026 ppb with an average concentration of 0.025 ppb (detection limit=0.02 ppb) (Steichen et al. 1988).

Heptachlor was included in EPA's Pesticides in Groundwater Database for 17 states and was found in 6 states: Illinois, Indiana, Missouri, New Jersey, South Carolina, and Virginia. Concentrations of heptachlor in groundwater from these six states ranged from 6.6×10^{-5} to 0.052 ppb (EPA 1992).

Heptachlor epoxide was included in EPA's Pesticides in Groundwater Database for 16 states and was found in 7 states: Alabama, Illinois, Indiana, Kansas, Massachusetts, South Carolina, and Virginia. Concentrations of heptachlor in groundwater from these seven states ranged from a trace to 0.014 ppb (EPA 1992).

Heptachlor and heptachlor epoxide were detected in water column samples at different depths in Lake Pontchartrain in New Orleans, Louisiana. Heptachlor was detected in the 1.5-m ebb- and flood-tide samples and in the 10-m flood-tide samples at concentrations of 0.6, 9.1, and 9.3 ppt, respectively. Heptachlor epoxide was detected in the 1.5-m ebb- and flood-tide samples and in the 10-m flood-tide sample at concentrations of 2, 3.9, or 2.5 ppt, respectively (McFall et al. 1985).

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Findings from the Nationwide Urban Runoff Program priority pollutant samples collected in 1982 showed that heptachlor and heptachlor epoxide were detected at a concentration of 0.1 ppb for both compounds (Cole et al. 1984). Heptachlor and heptachlor epoxide were detected in 5 and 1%, respectively, of the 86 urban storm water runoff samples taken from 15 cities.

Despite being banned in 1988, heptachlor and heptachlor epoxide are still found in the water. Heptachlor was found in concentrations ranging from 180 to 22 ng/sample of lower Missouri River water (Petty et al. 1995). Heptachlor epoxide was found in samples taken from the Mississippi Delta in May and July of 1997 at concentrations of about 10 ng/g (Zimmerman et al. 2000). Heptachlor was found in 7% of the influent and 10% of the effluent of 84 New York City municipal waste water samples. Concentrations were 0.021–0.35 and 0.02–0.447 ng/L, respectively, for the years 1989–1993. Heptachlor epoxide was found in 1% the influent and 2% of the effluent out of 84 New York City municipal waste water samples in concentrations of 0.012 and 0.018–0.03 µg/L, respectively, for the years 1989–1993 (Stubin et al. 1996). Heptachlor epoxide was found in 11 out of 242 groundwater samples taken from areas near golf courses in concentrations lower than the maximum contaminant level (MCL), 0.16 µg/L (Cohen et al. 1999).

Analysis of rain samples demonstrates how heptachlor can be deposited at sites where it was not applied. Heptachlor epoxide was detected in rain samples at concentrations ranging from 0.03 to 1 ppt at four widely separated sites in Canada from May to October in 1984. The sites are representative of overlake and shoreline locations (Strachan 1988). Snowpack samples representing snow accumulation for the winter of 1985–1986 were collected at a total of 12 widely distributed sites throughout the Northwest Territories, Canada, during the spring of 1986. Heptachlor epoxide was detected at 11 of the 12 sites at concentrations ranging from 0.2 to 0.41 ng/L (2×10^{-4} – 4×10^{-4} ppb). The only reasonable source for these compounds is long-range atmospheric transport and deposition (Gregor and Gummer 1989). Heptachlor was detected in wet precipitation samples (rain/snow) from Lake Erie at a volume-weighted mean concentration (based on the total volume collected over the 12-month period) of 0.1 ng/L (1×10^{-5} ppb) (Chan and Perkins 1989). Heptachlor epoxide was detected at volume-weighted mean concentrations of 0.05 ng/L (5×10^{-5} ppb), 0.24 ng/L (2.4×10^{-4} ppb), and 0.02 ng/L (2×10^{-5} ppb) in wet precipitation samples from Lake Superior, Lake Erie, and Lake Ontario, respectively (Chan and Perkins 1989). Heptachlor and Heptachlor epoxide were detected in rain water near Galveston Bay, Texas in concentrations ranging as high as 139.7 and 155.7 pg/L, respectively (Park et al. 2001). Heptachlor epoxide was found in two of eight samples of rain water from horticultural areas in Denmark and in two of eight background areas in

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Denmark at concentrations of above the detection limit (0.011), 0.002, 0.005, and 0.002 $\mu\text{g/L}$, respectively (Hamers et al. 2001). In January 1997, heptachlor was found in rain water in farm, urban, and Oakdale samples in Iowa at concentrations of 0.016, 0.011, and 0.0073 $\mu\text{g/L}$, respectively (Hochstedler et al. 2000).

Data maintained in the STORET database for 2003–2005 included heptachlor and heptachlor epoxide concentrations in industrial. Heptachlor was reported in 53% of the 804 water samples taken around the country in concentrations ranging from 1 $\mu\text{g/L}$ to below quantification limits. Heptachlor epoxide was reported in 49% of the 809 water samples taken around the country in concentrations ranging from 1 $\mu\text{g/L}$ to below quantification limits (EPA 2007).

6.4.3 Sediment and Soil

Data from the 1971 National Soils Monitoring Program at 1,486 sampling sites in 37 states showed that heptachlor was detected in 4.9% of the samples from cropland soils at concentrations ranging from 10 to 1,370 ppb. Heptachlor epoxide was detected in 6.9% of the samples at concentrations ranging from 100 to 430 ppb (Carey et al. 1978). A survey of agricultural soils (pasture soils) in the New South Wales North Coast region in Australia (1983–1984) showed soils contaminated with organochlorine residues. Heptachlor levels in the pasture soils generally averaged <100 ppb. Heptachlor epoxide residues were quantitatively higher. Heptachlor and heptachlor epoxide were generally highest in the top 22.5 cm of soil (McDougall et al. 1987). Heptachlor epoxide was detected in 17 out of 822 soil samples at 10 out of 49 agricultural sites in Illinois with a mean concentration of 17 $\mu\text{g/kg}$. In the same study, heptachlor was detected in 26 soil samples from 14 different sites with a mean concentration of 50 $\mu\text{g/kg}$ (Krapac et al. 1995). Heptachlor was found in 3 out of 39 samples of Alabama soil with a geometric mean concentration of 0.037 ng/g . In the same study, heptachlor epoxide was found in 12 of the 26 soil samples with a geometric mean concentration of 0.099 ng/g (Harner et al. 1999).

Heptachlor epoxide was detected in grab and core samples of southern Lake Michigan sediments (period of sampling, 1969–1970) at trace levels up to 0.7 ppb (Leland et al. 1973). The U.S. Geological Survey investigated the sediment quality of the upper Rockaway River in New Jersey. Sediment samples were collected from seven stations along the upper Rockaway River. Stations 1 and 2 drain primarily forested areas of the upper Rockaway basin. Stations 3–7 drain an area consisting primarily of residential, commercial, and industrial land usage, including six NPL sites. Concentrations of heptachlor epoxide

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were <0.1 ppb for stations 1 and 2. Heptachlor epoxide concentrations ranged from <0.1 to 10 ppb for stations 3–7 (Smith et al. 1987).

Heptachlor and heptachlor epoxide were monitored at six different sites in the sediment of San Pablo Bay, California. Heptachlor was not detected in four of the samples, while the other two samples contained 2.14 and 1.63 µg/kg of heptachlor. Heptachlor epoxide concentrations were below detection levels for all six samples (Baum et al. 2001). Heptachlor was found in the sediment of Casco Bay, Washington in concentrations ranging from 0.04 to 0.13 ppb (Kennicutt et al. 1994).

Heptachlor, which may have been applied to the World Trade Center for termite control, was detected in concentrations too low to quantify in the dust that settled across lower Manhattan after September 11, 2001 (Offenberg et al. 2003).

Heptachlor and heptachlor epoxide have been monitored in all 50 states and parts of Canada by the United States Geological Society (USGS). Heptachlor was detected in sediment at 9 out of 1,148 sites in 49 major hydrological basins at a maximum concentration of 8.3 µg/kg (USGS 2003); these data were collected from 1992 to 2001. In the same monitoring study, heptachlor epoxide was detected at 20 of the 1,148 sites, at a maximum concentration of 19.7 µg/kg. Data maintained in the STORET database for 2003–2005 included heptachlor and heptachlor epoxide concentrations in industrial effluent and ambient water. Heptachlor epoxide was reported in 4 of the 176 sediment samples taken with a maximum concentration of 0.621 µg/kg. Heptachlor was not reported in any of the 186 sites reporting data from 2003 to 2005 (EPA 2007).

6.4.4 Other Environmental Media

Heptachlor and heptachlor epoxide have been detected in several aquatic species. Heptachlor was measured in shrimp collected from the Calcasieu River/Lake Complex in Louisiana at concentrations ranging from 10 to 750 ppb (Murray and Beck 1990). A survey of organic compound concentrations in whole body tissues of the Asiatic clam, *C. manilensis*, was conducted on the Apalachicola River in northwest Florida in 1979–1980 as part of the Apalachicola River Quality Assessment. Heptachlor epoxide was detected in the whole body tissue of the clam at concentrations ranging from <0.1 to 0.6 ppb, with a median concentration of 0.3 ppb (Elder and Matraw 1984).

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Composite whole fish samples taken from tributary rivers around the Great Lakes in 1980–1981 had heptachlor levels of <0.002 mg/kg (<2 ppb) at all sites except the Ashtabula River where a maximum concentration of 0.30 mg/kg (300 ppb) occurred. Heptachlor epoxide was detected at concentrations ranging from 0.003 to 0.48 mg/kg (3–480 ppb) (DeVault 1985). Freshwater fish collected in 1984 for the National Contaminant Biomonitoring Program run by the U.S. Fish and Wildlife Service contained a geometric mean residue concentration of total heptachlor (heptachlor epoxide plus traces of heptachlor) of 0.01 ppm (wet weight). Heptachlor residues in fish were present in 49.1% of the collection stations (n=112) located at major rivers throughout the United States, including Alaska and Hawaii.

Concentrations of heptachlor epoxide in whole fish samples remained highest in Hawaii and in the Midwest, especially in Lake Michigan and in the Mississippi, Missouri, Ohio, and Illinois Rivers (Schmitt et al. 1990).

Average residue levels of total heptachlor detected in Illinois soybeans in 1980 (6.6 ppb) showed an increase from 1974 levels (5.3 ppb), even though the usage of heptachlor declined during that period (MacMonegle et al. 1984). Heptachlor residues above maximum residue limits were reported in Australian beef in 1987. Upon removing the animals from contaminated pastures, the proportion of samples of beef with residue levels above the permitted limits decreased from 0.42% in 1986–1987 to 0.22% in 1987–1988 (Corrigan and Seneviratna 1989). In an earlier study, heptachlor epoxide levels in cow's milk reached a maximum of 0.22 ppm within 3–7 days after the animals had grazed on pastures immediately following treatment of the grasses with heptachlor (Gannon and Decker 1960).

Heptachlor concentrations in pork and beef have decreased from 1974 to 1996. In 1974–1984, heptachlor was detected in beef and pork in concentrations of 0.1–54 and 11.2–970 ppb, respectively. By 1988, heptachlor was not detected in beef and was detected in 33% of the pork samples studied in concentrations ranging from 1 to 8 ppb with no other detections in pork after 1988. Heptachlor epoxide was detected in concentrations of 1.9–2.9 and 0.5–5.9 ppb in pork and beef, respectively, during studies from 1974 to 1984. During the years 1985–1988, heptachlor epoxide was not detected in pork, but was detected in 35% of beef samples at concentrations ranging from 19 to 27 ppb. Heptachlor epoxide was still found in 3% of pork samples and 12% of beef samples taken from 1993 to 1996 (Cantoni and Comi 1997).

Monitoring data collected by the USGS from 1992 to 2001 at 1,148 sites in 49 U.S. major hydrological basins indicated that heptachlor and heptachlor epoxide were infrequently detected in fish (USGS 2003).

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Heptachlor was detected in fish at 3 sites at a maximum concentration of 12 µg/kg and heptachlor epoxide was detected in fish at 88 sites at a maximum concentration of 270 µg/kg (USGS 2003).

6.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

The general population is primarily exposed to heptachlor and heptachlor epoxide through diet. The food classes most likely to contain residues are milk and other dairy products, vegetables, meat, fish, and poultry. In the FDA Total Diet Study conducted between 1981 and 1982, levels of chemicals in the diet were determined by analyzing samples from retail markets in 13 cities throughout the continental United States. These samples represent the typical 14-day diet. Approximately 120 individual food items, including drinking water, were collected for each market basket sample; the infant diet consisted of about 50 of these foods, and the toddler diet included 110. The average daily intake of heptachlor epoxide for infants was estimated to be 0.01 µg/kg/day. The 1981–1982 average daily intake of heptachlor epoxide for toddlers was reported to be 0.009 µg/kg/day. Whole milk, with an average concentration of 0.1 ppb, contributed the highest daily intake of heptachlor epoxide for both toddlers and infants (Gartrell et al. 1986b). In the FDA Total Diet Study conducted between 1982 and 1984, analyses were performed of 234 items depicting the diets of eight population groups with members ranging in age from infants to elderly adults. The data represent eight food collections in regional metropolitan areas during the 2-year period. Toddlers (2 years old) had the highest daily intake of heptachlor epoxide (6.1 ng/kg/day). Infants had a daily intake of heptachlor epoxide of 2.7 ng/kg/day. Daily intake from whole milk was not included in this study. Adults had heptachlor epoxide intakes that ranged from 1.5 ng/kg/day (60–65-year-old females) to 2.8 ng/kg/day (14–16-year-old males). Heptachlor epoxide was found in 8% of the food samples analyzed between 1982 and 1984. Heptachlor intake was <0.1 ng/kg/day for all age/gender groups. Between 1980 and 1982–1984, daily intakes of heptachlor epoxide decreased from 19 to 3 ng/kg/day for infants, from 20 to 6 ng/kg/day for toddlers, and from 7 to 2–3 ng/kg/day for adults (Gunderson 1988). Heptachlor epoxide was found in 45 different food items from a total diet study. From this information and from questionnaires, it was estimated that heptachlor epoxide was found at a mean concentration of 0.3 µg/day in people surveyed in 1990 (MacIntosh et al. 1996).

The 1988 Acceptable Daily Intake (ADI) established by the United Nation's Food and Agriculture Organization and the World Health Organization (FAO/WHO) for total heptachlor was 0.5 µg/kg/day (FDA 1989). Total heptachlor intakes found in the Total Diet Analysis (1988) were 0.004 µg/kg/day for 6–11-month-old infants, 0.017 µg/kg/day for 14–16-year-old males, and 0.0007 µg/kg/day for 60–63-year-old females (FDA 1989).

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Adipose tissue samples from various body parts of people living in northeast Louisiana, an area of heavy agriculture, were taken during pathological examination. Heptachlor epoxide levels in the individual tissue samples ranged from 20 to 790 ppb (average=239 ppb) for the 1980 study and from 60 to 220 ppb (average=159 ppb) from adipose tissue samples taken from other donors for the 1984 study (Holt et al. 1986).

Heptachlor and heptachlor epoxide have been found in human milk samples (Al-Omar et al. 1986; Fytianos et al. 1985; Larsen et al. 1971; Mes et al. 1986; Ritcey et al. 1972; Savage et al. 1981). Breast milk samples (n=210) taken from Canadian women from five different regions who had resided in Canada for at least 5 years were analyzed for chlorinated hydrocarbon contaminants as part of a monitoring program. Trends from 1967 to 1982 showed heptachlor epoxide levels decreased from a mean of 3 ppb in 1967 to a mean of <1 ppb in 1982 (maximum, 7 ppb) (Mes et al. 1986). Heptachlor epoxide was found in 62% of all samples taken in 1982 (Mes et al. 1986). Human milk samples obtained from 1,436 women residing in the United States were analyzed for chlorinated hydrocarbon insecticides. While heptachlor was recovered in <2% of the samples, heptachlor epoxide was found in 63% of the samples. The proportion of breast milk samples containing heptachlor epoxide varied significantly among the five geographic regions (66.1–128 ppb) with the southeastern states having the highest mean residual level. The reasons for higher levels of these chemicals in samples from women in the southeastern United States are not clear, but there may be several contributing factors. For example, more people in the southeast use pesticides in the home, lawn, and garden, and a larger proportion of southeastern U.S. homes have been treated with heptachlor for termite control. The mean residual level of heptachlor epoxide in breast milk for the whole United States was 91.4 ppb (Savage et al. 1981). A 5-month follow-up study of four pregnant Iraqi women without occupational exposure to organochlorine pesticides found total heptachlor levels in the placenta immediately after delivery ranging from not detectable to 28 ppb total tissue weight. Milk samples were then taken for 20 consecutive weeks. Average total heptachlor levels in the mothers' milk ranged from 15 to 68 parts per billion parts of whole milk (Al-Omar et al. 1986). There was considerable fluctuation in the residue concentrations over the 20 weeks. The authors suggest that the fluctuations could be attributed to changes in daily diet intake of residues and daily variations in milk production and fat content of the milk.

A pilot study for EPA's Non-Occupational Exposure Study was conducted in August 1985 in order to assess nonoccupational exposures to pesticides, including heptachlor, in indoor air and personal respiratory air. The study was conducted in nine households selected on the basis of high pesticide usage

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in an urban-suburban area in the southeastern United States. The residents of these households were generally retired or semi-retired persons, who spent the majority of their time indoors (average=18 hours) and, consequently, do not represent the general adult population. The results showed that heptachlor was found in seven of nine households at levels in indoor air ranging from not detectable (at 0.0001 ppb) to $0.31 \mu\text{g}/\text{m}^3$ (0.02 ppb), with a mean of $0.088 \mu\text{g}/\text{m}^3$ (0.006 ppb). When residents wore personal monitors, operated only during periods of activity, heptachlor was detected in six of nine households at personal exposure levels of not detectable to $0.18 \mu\text{g}/\text{m}^3$ (0.01 ppb), with a mean of $0.06 \mu\text{g}/\text{m}^3$ (0.004 ppb). Outdoor air levels of heptachlor were lower, ranging from not detectable to $0.048 \mu\text{g}/\text{m}^3$ (0.003 ppb), with a mean of $0.016 \mu\text{g}/\text{m}^3$ (0.001 ppb), and were detected in five of nine households (Lewis et al. 1986).

Heptachlor has been routinely found in human breast milk as well as in animal and commercial milk products and has been studied extensively. A 25-year study of contaminants in human breast milk found that heptachlor in breast milk of Canadian mothers decreased from 3 ng/g in 1965 to 0.11 ng/g in 1992 (Craan and Haines 1998). Heptachlor has been detected in milk and umbilical cord fluid of 13.5% of the 385 mothers tested in the Arctic region of Canada with a mean concentration of 0.6 $\mu\text{g}/\text{L}$ (Butler Walker et al. 2003). Termite control was associated with high heptachlor body burden as analyzed through breast milk in Australia where heptachlor epoxide was found in the breast milk of 575 of the 797 women tested in Victoria, Australia with concentration median of 0.007 mg/kg in 1997 (Sim et al. 1998). Average heptachlor epoxide levels in whole blood samples from non-occupationally exposed mothers and their newborns in Argentina were 0.23 ± 0.29 ppb in 13 mothers and 0.06 ± 0.01 ppb in 13 newborn infants (Radomski et al. 1971a). Heptachlor and heptachlor epoxide were found in 50 samples (51.5%) of pasteurized milk samples tested in Spain. Of the samples with heptachlor and heptachlor epoxide, eight of them contained levels that exceeded the limits stated by the European Union (Martinez et al. 1997). Heptachlor and heptachlor epoxide were found in cows' milk at concentrations of 6.5–28.5 and 8.5–34 ng/g, respectively (Armendariz et al. 2004).

In a study of non-occupationally exposed people in Jacksonville, Florida and Springfield/Chicopee, Massachusetts from 1986 to 1988, heptachlor was found in personal, outdoor, and indoor air samples. While Springfield/Chicopee did not have any samples that contained heptachlor, the concentration of heptachlor in samples from Jacksonville ranged from 0.1 to 0.8 ng/m^3 (Whitmore et al. 1994).

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6.6 EXPOSURES OF CHILDREN

This section focuses on exposures from conception to maturity at 18 years in humans. Differences from adults in susceptibility to hazardous substances are discussed in Section 3.7, Children's Susceptibility.

Children are not small adults. A child's exposure may differ from an adult's exposure in many ways. Children drink more fluids, eat more food, breathe more air per kilogram of body weight, and have a larger skin surface in proportion to their body volume. A child's diet often differs from that of adults. The developing human's source of nutrition changes with age: from placental nourishment to breast milk or formula to the diet of older children who eat more of certain types of foods than adults. A child's behavior and lifestyle also influence exposure. Children crawl on the floor, put things in their mouths, sometimes eat inappropriate things (such as dirt or paint chips), and spend more time outdoors. Children also are closer to the ground, and they do not use the judgment of adults to avoid hazards (NRC 1993).

Infants and toddlers are exposed to higher levels (based on their greater dose to surface area [or body weight] ratio) of heptachlor epoxide in the diet (particularly from milk) than are adults. Higher exposure rates in indoor air may occur for at least 1 year in homes that have been treated for termites with heptachlor in the past. Although the most likely routes of exposure at hazardous waste sites are unknown, exposure may result from ingestion of contaminated soil near these sites particularly by children. Since both heptachlor and heptachlor epoxide volatilize from soil, inhalation exposure may also be important for persons living near hazardous waste sites. Exposure via ingestion of contaminated drinking water obtained from wells near hazardous waste sites is unlikely. Heptachlor and heptachlor epoxide are considered too lipophilic to leach to groundwater. While some samples have been found in well water, this trend is not universal. Workers involved in the manufacture of heptachlor and in the application of heptachlor for fire ant control are at risk of exposure to heptachlor. People living in the southeastern United States may be exposed to higher than background levels of heptachlor or heptachlor epoxide because of the larger proportion of southeastern U.S. homes that have been treated with heptachlor for termite control and the greater usage of pesticides in the home, lawn, and garden. Infants living in this region may be more likely to ingest heptachlor or heptachlor epoxide from maternal breast milk, although this exposure pathway is not restricted to the southeastern United States.

The average daily intake of heptachlor epoxide for infants was estimated to be 0.01 $\mu\text{g}/\text{kg}/\text{day}$. The 1981–1982 average daily intake of heptachlor epoxide for toddlers was reported to be 0.009 $\mu\text{g}/\text{kg}/\text{day}$. Whole milk, with an average concentration of 0.1 ppb, contributed the highest daily intake of heptachlor

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epoxide for both toddlers and infants (Gartrell et al. 1986b). In the FDA Total Diet Study conducted between 1982 and 1984, analyses were performed of 234 items depicting the diets of eight population groups with members ranging in age from infants to elderly adults. The data represent eight food collections in regional metropolitan areas during the 2-year period. Toddlers (2 years old) had the highest daily intake of heptachlor epoxide (6.1 ng/kg/day). Infants had a daily intake of heptachlor epoxide of 2.7 ng/kg/day. The 1988 Acceptable Daily Intake (ADI) established by the United Nation's Food and Agriculture Organization and the World Health Organization (FAO/WHO) for total heptachlor was 0.5 µg/kg/day (FDA 1989). Total heptachlor intakes found in the Total Diet Analysis (1988) were 0.004 µg/kg/day for 6–11-month-old infants, 0.017 µg/kg/day for 14–16-year-old males, and 0.0007 µg/kg/day for 60–63-year-old females (FDA 1989).

Heptachlor epoxide was found in whole blood samples from nonoccupationally exposed mothers and their newborns in Argentina (Radomski et al. 1971a). The average level of heptachlor epoxide was 0.23 ± 0.29 ppb in 13 mothers and 0.06 ± 0.01 ppb in 13 newborn infants, although no blood samples were taken from the mothers during pregnancy (Radomski et al. 1971a).

In order to understand the exposure of children to pesticides, studies have been done to monitor pesticide levels in areas and food that are specific to children. Heptachlor was not detected in apple, pear, squash, or carrot baby food. Both organic and traditional manufacturers were studied (Moore et al. 2000). Studies of school areas along the Mexican-Texas border found heptachlor in 63% of all soil samples tested in concentrations ranging from a trace to 5 ppb (Miersma et al. 2003). Heptachlor was one of the most frequent chemicals found in a study of children's exposure to pesticides and was found in 8/9 home dust samples, 3/8 play areas, and 3/4 children's hand rinse samples (Lewis et al. 1994). In a study of pesticide exposure of children of farmworkers in Virginia and North Carolina, heptachlor was found in 10% of the floors at a mean concentration of 2 µg/m². Heptachlor, however, was not detected on any of the toys or hands of the children (Quandt et al. 2004).

6.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Data concerning occupational exposure levels of heptachlor are very limited. An industrial hygiene survey conducted in 1977 at the Velsicol Chemical Corporation, Memphis, Tennessee, a plant that manufactured heptachlor, detected heptachlor in workplace air at levels ranging from 0.025 to 0.202 mg/m³ (1.64–13.2 ppb) (Netzel 1981). Data from the National Occupational Exposure Survey

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(NOES) conducted by NIOSH from 1981 to 1983 were not available for heptachlor or heptachlor epoxide.

People who worked with pesticides from 1954 to 1988, such as farmers and pest control workers, were at potentially higher risk of being exposed to heptachlor and heptachlor epoxide. People who worked in termite control before 1988 may have higher exposures to heptachlor since it was commonly used as a pesticide in the treatment of termites. High concentrations of heptachlor were found on applicators' hands and forearms with exposure rates calculated at 83 and 23 ng/cm²/hour (Kamble et al. 1992). Heptachlor was not found in the blood of Japanese termite control workers in 1987, 1 year after chlordane, which contained heptachlor, was banned in Japan. Heptachlor epoxide, however, was found in all of the Japanese termite workers monitored from 1987 to 1990. The highest level of heptachlor epoxide was in the blood of a worker who had been working in pest control for 20 years and almost all of the workers still had heptachlor epoxide in their blood in 1990 (Jitunari et al. 1995). A study showed that farmers and their spouses in Iowa and North Carolina were exposed to heptachlor epoxide at concentration ranges of 0.21–0.55 ng/mL. With the exception of two of the spouses, everyone in the study had exposure limits of 0.21 ng/mL or greater as analyzed from serum concentrations (Brock et al. 1998).

6.8 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of heptachlor and heptachlor epoxide is available. Where adequate information is not available, ATSDR, in conjunction with NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of heptachlor and heptachlor epoxide.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

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6.8.1 Identification of Data Needs

Physical and Chemical Properties. The physical and chemical properties of heptachlor and heptachlor epoxide are sufficiently well defined to allow assessments of the environmental fate of the compounds to be made (ACGIH 1986; Chapman 1989; HSDB 2007a; MacKay 1982). Some physical and chemical properties of heptachlor epoxide that are not relevant to environmental fate are lacking. Knowledge of these properties, such as odor, flashpoint, and flammability limits, would be useful for workers involved in the manufacture, use, or clean-up of heptachlor and heptachlor epoxide.

Production, Import/Export, Use, Release, and Disposal. According to the Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. Section 11023, industries are required to submit substance release and off-site transfer information to the EPA. The TRI, which contains this information for 2004, became available in May of 2006. This database is updated yearly and should provide a list of industrial production facilities and emissions.

The United States International Trade Commission (USITC) did not report separate import data for heptachlor for the years 1981, 1982, or 1983 (USITC 1982a, 1983a, 1984a). The sale, distribution, and shipment of existing stocks of all canceled heptachlor products were prohibited by EPA in 1988 (EPA 1990a). According to the USITC, no heptachlor has been imported into the United States from 1996 through 2007 (USITC 2007).

Currently, heptachlor use in the United States is limited to fire ant control in power transformers (EPA 1990a). However, because of former widespread use of heptachlor and the persistence of heptachlor epoxide, these compounds and their degradation products can still be found at low levels in indoor air, water, soil, and food. Disposal methods are well documented in the literature (EPA 1986b; Sittig 1985); however, more current information would be useful. Information on historical disposal practices would be helpful in evaluating the potential for environmental contamination. More information on the volume of heptachlor used in fire ant control would be useful in estimating potential occupational exposure.

Environmental Fate. Heptachlor and heptachlor epoxide are partitioned to the air, water, and soil (EPA 1987; Jury et al. 1987; Lichtenstein et al. 1970; Shivankar and Kavadia 1989). They are both transported in air and water and sorb to soils and sediment (Chapman 1989; MacKay 1982). They are biotransformed in soil and surface water, with biotransformation occurring faster for heptachlor than for heptachlor epoxide. Current data on the biotransformation (including half-life data) of both compounds

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in surface water, surface soil, and subsurface soil would be useful in assessing the environmental persistence of these substances. Data on the toxicity of the biotransformation products of both compounds would assist in better characterizing the potential public health threat. Both heptachlor and heptachlor epoxide undergo photolysis (Graham et al. 1973; Ivie et al. 1972; Podowski et al. 1979). Data regarding the half-lives for photolysis would be helpful in determining the persistence of both compounds.

Bioavailability from Environmental Media. The limited pharmacokinetic data indicate that both compounds are absorbed following inhalation, oral, and dermal exposure (Arthur et al. 1975; Gaines 1969; Harradine and McDougall 1986). Additional information on the absorption of these compounds following inhalation and following ingestion of contaminated drinking water and soil would be useful in evaluating the relative importance of various routes of exposure to populations living in the vicinity of hazardous waste sites and those whose homes have been treated for termites with heptachlor or chlordane.

Food Chain Bioaccumulation. Heptachlor and heptachlor epoxide accumulate in aquatic and terrestrial organisms (Elder and Matraw 1984; Murray and Beck 1990; Schmitt et al. 1990). Biomagnification of heptachlor and heptachlor epoxide in aquatic food chains is significant (Connell et al. 2002; Cullen and Connell 1994; Geyer et al. 1982; Hawker and Connell 1986). Because heptachlor is readily metabolized to heptachlor epoxide by higher trophic level organisms, biomagnification of heptachlor itself is not significant (Feroz et al. 1990). Because of the more persistent nature of heptachlor epoxide and its lipophilicity, biomagnification of heptachlor epoxide in terrestrial food chains is significant (Connell et al. 2002; Cullen and Connell 1994; Hartley and Johnston 1983). More current information regarding biomagnification of heptachlor epoxide in terrestrial food chains would be helpful in evaluating the extent of environmental contamination.

Exposure Levels in Environmental Media. Reliable monitoring data for the levels of heptachlor and heptachlor epoxide in contaminated media at hazardous waste sites are needed so that the information obtained on levels of heptachlor and heptachlor epoxide in the environment can be used in combination with the known body burden of heptachlor and heptachlor epoxide to assess the potential risk of adverse health effects in populations living in the vicinity of hazardous waste sites.

Heptachlor and heptachlor epoxide have been detected in indoor and outdoor air, surface water, groundwater, soil, sediment, food (Larsen et al. 1971; Lewis et al. 1986; MacIntosh et al. 1996; Park et al. 2002; USGS 2003), and fish (USGS 2003). Current monitoring data on levels of both compounds in

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outdoor and indoor air and soil would be useful. Dietary intake data for the general population were located (FDA 1989; Gartrell et al. 1986b; Gunderson 1988; MacIntosh et al. 1996). Intake data for other media (air and water) are needed to estimate the risk of exposure of the general population.

Exposure Levels in Humans. Heptachlor epoxide has been detected in human blood, tissues (including adipose tissue), and breast milk (Al-Omar et al. 1986; Butler Walker et al. 2003; Craan and Haines 1998; Holt et al. 1986; Larsen et al. 1971; Savage et al. 1981). The presence of heptachlor epoxide is used as an indicator of exposure to heptachlor. Current monitoring studies of heptachlor epoxide in these tissues and fluids would be helpful in assessing the extent to which populations, particularly in the vicinity of hazardous waste sites, have been exposed to heptachlor. Reliable data regarding heptachlor levels in the elderly were not found. The elderly who may have been exposed to heptachlor have reduced capability to eliminate toxicants.

This information is necessary for assessing the need to conduct health studies on these populations.

Exposures of Children. Heptachlor levels have been monitored in human breast milk as well as baby food (Moore et al. 2000). Heptachlor exposure of children at the Mexican-American border was studied as well as the exposure of children of farm workers and children whose homes were treated for termites (Lewis et al. 1994; Miersma et al. 2003; Quandt et al. 2004). Current monitoring studies of heptachlor and heptachlor epoxide in blood, fluids and tissues of children would be helpful in assessing the extent to which populations, particularly in the vicinity of hazardous waste sites, have been exposed to heptachlor.

Child health data needs relating to susceptibility are discussed in Section 3.12.2, Identification of Data Needs: Children's Susceptibility.

Exposure Registries. No exposure registries for heptachlor were located. This substance is not currently one of the compounds for which a sub-registry has been established in the National Exposure Registry. The substance will be considered in the future when chemical selection is made for sub-registries to be established. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to exposure to this substance.

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6.8.2 Ongoing Studies

The Federal Research in Progress (FEDRIP 2006) database provides additional information obtainable from a few ongoing studies that may fill in some of the data needs identified in Section 6.8.1. The only current study pertaining to heptachlor was of the direct and indirect photolytic fate of persistent organic pollutants in Arctic surface waters. The principal investigator of this study is Yu-Ping Chin of Ohio State University. This research is funded by the National Science Foundation (NSF).