

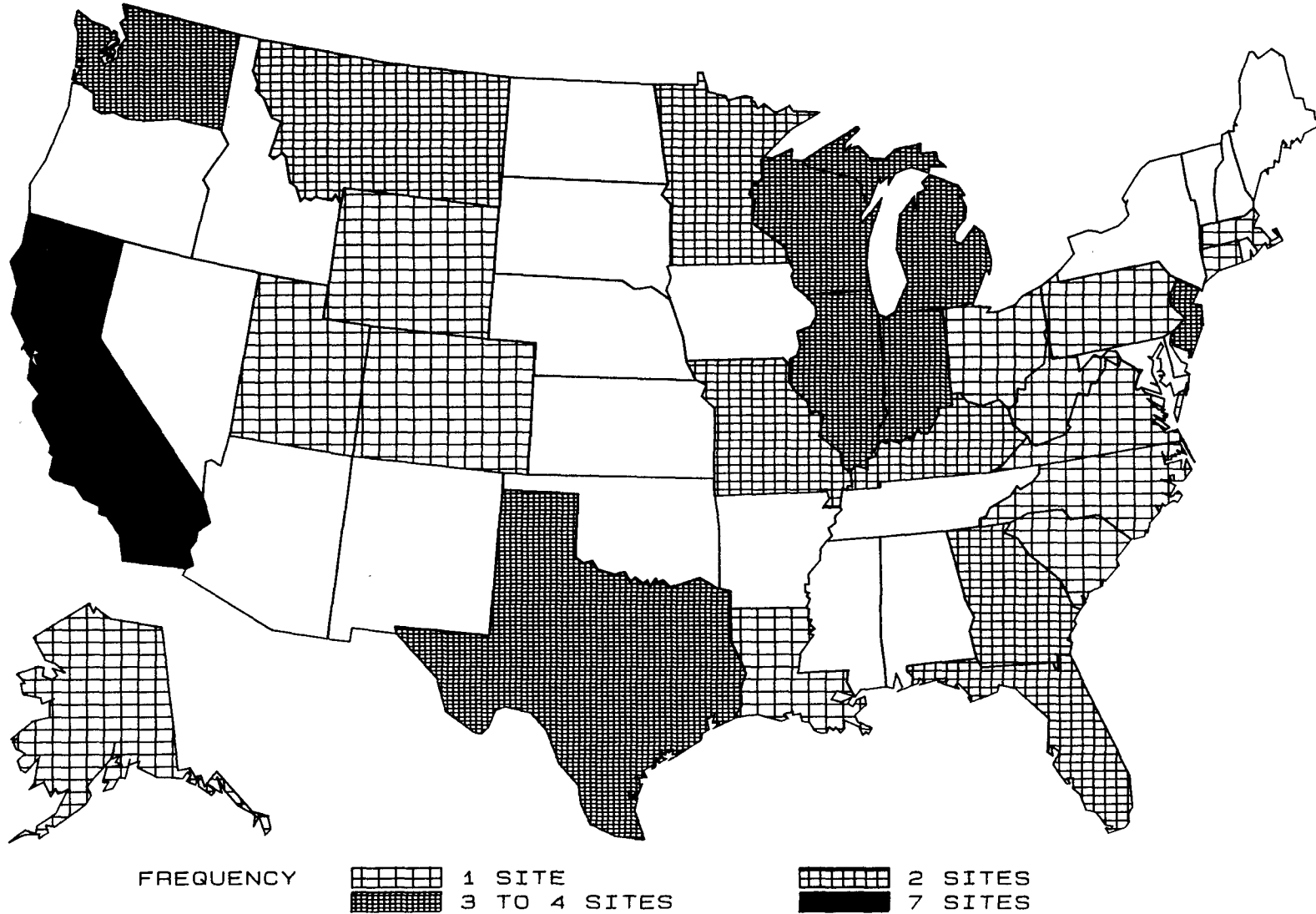
## 5. POTENTIAL FOR HUMAN EXPOSURE

### 5.1 OVERVIEW

Low levels of CDFs occur as contaminants in certain chemical products and during combustion of certain precursors of CDFs. The processes that are responsible for the production of CDFs in the environment form a mixture of congeners. In addition, many of the combustion processes that produce CDFs also produce structurally similar compounds, such as CDDs and chlorinated dibenzothiophenes (CDTs). Due to the similarity in their physicochemical properties, including low water solubility, high lipid solubility, low vapor pressure, and multiple chlorine substitution, these compounds are generally found together in environmental samples. Therefore, environmental exposures to CDFs occur not only from a mixture of CDFs, but also from CDDs, CDTs, and other structurally similar compounds and other structurally similar compounds present as cocontaminants. To simplify the assessment of human health risk of a mixture of CDDs and CDFs, EPA has recommended the TEF approach (see Section 2.4).

The sources of CDFs in the environment are combustion processes mainly involving municipal and industrial incineration; combustion of fossil fuels by power plants, home heating and fireplaces; automobile exhaust; medical waste incineration; yard waste composting; accidental fires or malfunction of PCB-filled transformers and capacitors; improper disposal of chlorinated chemical wastes; use of certain chemical products (e.g., chlorinated phenols); certain high temperature industrial processes, such as copper smelting, electrical arc furnaces in steel mills, and production of metallic magnesium and refined nickel; chlorine bleaching of pulp and paper; and photochemical processes involving certain products, such as chlorinated diphenyl ethers. Some of these sources emit CDFs in the air, while others discharge CDFs as effluents in surface water. The source of these compounds in soil is disposal of chemical wastes containing CDFs as contaminants. The deposition of atmospheric CDFs is also an important source of these compounds in surface water and soil. EPA has identified 1,300 NPL sites. CDFs have been found in at least 57 of the sites evaluated for their presence (HAZDAT 1991). However, the number of sites evaluated for the presence of CDFs is not known. The frequency of these sites within the United States can be seen in Figure 5-1.

FIGURE 5-1. FREQUENCY OF NPL SITES WITH CDFs CONTAMINATION \*



\*Derived from HAZDAT 1991

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In the atmosphere, the higher chlorinated CDFs are present predominantly in the particulate phase, but tetra- and pentaCDFs may be present in the vapor phase as well. Due to higher atmospheric temperatures, the concentrations of CDFs in the vapor phase increase during summer. The most important chemical process in determining the fate of CDFs in air is the reaction with hydroxyl radicals. The lifetime of CDFs due to this process is >10 days, and increases with higher chlorinated CDFs, which allows these compounds to be transported long distances in air. Wet and dry deposition of atmospheric CDFs may also be important for the removal of these compounds from air. CDFs will be present in water mainly in the particulate-sorbed phase. Significant loss of CDFs in water, either due to chemical reactions including photochemical reactions or biodegradation processes, has not been observed. CDFs in water partition into the particulate phase and settle into the sediment. Sediment is the ultimate sink of atmospheric and aquatic CDFs. CDFs bioconcentrate in aquatic organisms, but the bioconcentration factor is lower than the predicted value based on the  $K_{OW}$  value, due to the ability of fish to partially metabolize these compounds. CDFs are very persistent in soils. They also strongly adsorb to soil; consequently, very little vertical movement of these compounds has been observed in soil.

The concentrations of CDFs in air usually exist in the following order: rural < suburban < urban < industrial/ auto tunnel. The concentrations of total tetra-, penta-, hexa-, hepta-, and octaCDF in ambient urban/suburban air vary, ranging from 0.13 to 7.34, 0.09 to 5.10, <0.09 to 12.55, 0.08 to 12.71, and 0.13 to 3.78  $\text{pg}/\text{m}^3$ , respectively. CDFs were detected in 1 of 20 water supplies in New York State. The only congener groups detected in this water were tetraCDF at a concentration 2.6 ppq ( $\text{pg}/\text{L}$ ) and octaCDF at a concentration of 0.8 ppq. The levels of CDFs in contaminated water, such as effluents from a kraft pulp mill, can be three orders of magnitude higher than the levels in drinking water. The levels of CDF in various foods consumed in Germany, Japan, Canada, and the United States are also available, and the level in individual food products is on the order of  $\text{pg}/\text{kg}$ .

The general population is exposed to CDFs by inhaling air, ingesting food, soil, and water, and from consumer products (e.g., paper towels, tampons). The estimated total intake of CDDs/CDFs from all these sources in a Canadian background population is 2.4  $\text{pg}$  toxic equivalent to 2,3,7,8-TCDD/ $\text{kg}$  body weight/day. The intake from food constitutes  $\approx 96\%$  of the total toxic intake. Fish and fish products, milk and milk products, and meat and meat products each constitute  $\approx 30\%$  of CDF food intake in Germany. Because of this CDF body burden in background populations and the tendency of

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CDFs to bioconcentrate in fat, the levels of CDFs in adipose tissue, human milk, and the lipid portion of blood in both background and exposed populations have been determined.

Workers in saw mills, in the textile industry, in the leather industry, in the pulp and paper industries, in certain chemical manufacturing and in PCB user industries (repairing transformers or capacitors, using casting waxes containing PCBs) may be exposed to a higher level of CDFs than the background population. Among the general population, groups who consume high amounts of fatty fish, people who are exposed to accidental fires involving PCBs, and nursing babies are potentially exposed to higher levels of CDFs. People living near incinerators may be exposed to elevated levels of CDFs. The levels will depend on the nature of the waste being incinerated. People who live adjacent to uncontrolled landfill sites containing high concentration of CDFs may also be exposed to higher concentrations of CDFs. Diverse studies indicate that the levels of CDFs in the adipose tissue of exposed populations are higher than those in unexposed or background populations.

### 5.2 RELEASES TO THE ENVIRONMENT

CDFs in the environment are primarily of anthropogenic origin (Czuczwa and Hites 1986a, 1986b). Trace amounts of CDFs may come from sources, such as forest fires, which may not be anthropogenic in origin (Bumb et al. 1980). The levels of CDDs and CDFs in archived soil samples collected from the same semi-rural area in southeast England between 1846 and 1986 were found to increase around the turn of the century (A.D. 1900) (Kjeller et al. 1991; Rappe 1991). Higher levels of CDFs are found in human tissue (Ligon et al. 1989; Rappe 1991) and river silt (Schechter 1991) samples collected from industrial countries than those from less industrial countries or from ancient civilization. These results suggest that most CDFs found at present are of anthropogenic origin.

The primary sources of environmental release of CDFs can be divided into the following five categories: thermal reactions, chemical reactions, photochemical reactions, enzymatic reactions, and hazardous waste sites.

#### **Thermal Reactions**

***Combustion Processes.*** The combustion processes can be divided into two categories, large systems and small systems. Municipal waste incineration (Bonafanti et al. 1990; Brna and Kilgore 1990; des

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Rosiers 1987; Hutzinger and Fiedler 1989; Siebert et al. 1987; Tiernan et al. 1985; Tong and Karasek 1986), incineration of industrial and hazardous wastes (des Rosiers 1987; Muto et al. 1991), and power plants with fossil fuels (des Rosiers 1987; Hutzinger and Fiedler 1989) are examples of large systems. Small combustion systems include home heating and fireplaces (Clement et al. 1985; Safe 1990a), household waste incineration (Harrad et al. 1991a), automobile exhaust (Ballschmiter et al. 1986; Marklund et al. 1987), and medical waste incineration (des Rosiers 1987; Glasser et al. 1991; Lindner et al. 1990). Incineration of industrial and hazardous wastes that produce CDFs include wastes containing PCBs (Choudhury and Hutzinger 1982; Hutzinger and Fiedler 1989; Sedman and Esparza 1991), polychlorinated diphenyl ethers (Choudhury and Hutzinger 1982), 2,4,5-trichlorophenol esters (Choudhury and Hutzinger 1982) and chlorinated benzenes (Choudhury and Hutzinger 1982; Öberg and Bergstrom 1987), chlorophenols (Narang et al. 1991; Gberg and Bergstrom 1987), waste oil (Taucher et al. 1992), biosludge from paper and pulp mills (des Rosiers 1987; Mantykoski et al. 1989; Someshwar et al. 1990) polyvinyl chloride (Christmann et al. 1989a), municipal sewage sludge (Clement et al. 1987; des Rosiers 1987), and chlorinated fluorenones and 9,10-anthraquinones (Boenke and Ballschmiter 1989). The typical concentrations of total tetraCDFs, pentaCDFs, hexaCDFs, heptaCDFs, and octaCDF in municipal waste incineration fly ash are 79.5, 120.3, 116.3, 108.2, and 42.9 ppb, respectively (Safe 1990a). The corresponding CDF concentrations in soot from home heating oil are 28.9, 16.6, 6.2, 1.8, and 0.3 ppb and in soot from coal/wood burning for home heating are 50.8, 30.0, 11.7, 3.2, and 0.5 ppb. The concentrations of 2,3,7,8-tetraCDF congener in municipal fly ash, soot from heating oil and soot from coal/wood burning are 2.5, 1.1, and 1.9 ppb, respectively. The combined bottom and fly ash from five state-of-the-art mass-burn municipal waste combustors, with a variety of pollution control equipment, were analyzed for CDFs. The concentrations of CDFs (ng/kg or ppt) in ash samples were determined to be: 2,3,7,8-tetraCDF, 176-626; 1,2,3,7,8-pentaCDF, 52-194; 2,3,4,7,8-pentaCDF, 43-171; 1,2,3,4,7,8-hexaCDF, 74-654; 1,2,3,6,7,8-hexaCDF, 131-660; 1,2,3,7,8,9-hexaCDF, 36-479; 2,3,4,6,7,8-hexaCDF, 5-124; 1,2,3,4,6,7,8-heptaCDF, 139-1,842; 1,2,3,4,7,8,9-heptaCDF, 8-119 (EPA 1990).

Three mechanisms have been postulated for the formation of CDFs in combustion processes. They are: (1) CDFs are already present in trace amounts within the fuel and are not destroyed during combustion; (2) CDFs are formed during combustion from precursors (e.g., PCBs, PCPs), which are present in the fuel; and (3) *de novo* synthesis from nonchlorinated organic substance and chlorine-containing molecules (Hutzinger and Fiedler 1989). Details about the mechanisms of CDF formation in combustion processes are available (Choudhury and Hutzinger 1982; Hutzinger and Fiedler 1989;

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Jay and Stieglitz 1991; Stieglitz et al. 1989). Other investigators have studied the control technologies available for the reduction of CDF emissions from municipal waste combustors (Brna and Kilgore 1990; Jordan 1987; Takeshita and Akimoto 1989). A significant reduction of CDF-concentrations in the flue gas from municipal and industrial waste incinerators and fossil fuel-fired power stations can be achieved either by the addition of a mixture of anhydrous calcium hydrate and coke to the flue gas or by treating the flue gas with titanium dioxide catalyst in the presence of ammonia (Hagenmaier et al. 1991).

***Accidental Fires or Malfunction of PCB-filled Transformers and Capacitors.*** Some of the major fires/ malfunctions involving PCB transformers and capacitors in the United States include a transformer fire inside the state office building in Binghamton, New York, in 1981; a transformer fire inside an office building in Boston, Massachusetts, in 1982; a transformer fire adjacent to a high-rise building in San Francisco, California, in 1983; a transformer fire inside an office building in Chicago, Illinois, in 1983; and a capacitor fire inside an office building in Columbus, Ohio, in 1984 (des Rosiers and Lee 1986; Hryhorczuk et al. 1986; Stephens 1986; Tiernan et al. 1985). CDFs were detected in air, soot, or wipe samples from all these fire incidents. However, it was determined that in the absence of fire, CDF levels do not appear to increase in PCB fluids in electrical equipment from normal usage (des Rosiers and Lee 1986). The concentrations of total tetraCDFs, pentaCDFs, hexaCDFs, heptaCDFs, and octaCDF in air samples from different locations of a building following a transformer fire in San Francisco ranged from not detected to 53.9, not detected to 11 .0, not detected to 1.3, not detected to 3.7, and not detected to 165.0  $\text{pg}/\text{m}^3$ , respectively (Stephens 1986). A maximum concentration of 2,3,7,8-tetraCDF inside the building air was 18.5  $\text{pg}/\text{m}^3$  (Stephens 1986). The concentration range of 2,3,7,8-tetraCDF in soot samples from other transformer/capacitor fires in the United States was 3-1,000  $\mu\text{g}/\text{g}$  (des Rosiers and Lee 1986). Other reports of international fires/accidents involving PCBs that lead to the formation of CDFs and the mechanism of CDF formation from PCBs are also available (Erickson 1989; Hutzinger et al. 1985).

***Certain Industrial Processes.*** Certain high-temperature industrial processes like copper smelting, electrical arc furnaces in steel mills, production of metallic magnesium and refined nickel emit CDFs in the atmosphere and process waste waters at concentrations higher than those found in emissions from municipal incineration and automobile exhausts (Oehme et al. 1989; Rappe 1987). It has been theorized that contamination/coating with polyvinyl chloride or polychlorinated paraffins are the precursors for the formation of CDFs in copper smelting and steel production from scrap metals

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(Rappe 1987). It has been speculated, in the case of magnesium and nickel production, that heavy metals in the presence of chlorine catalyze the formation of CDFs. But the precursors of CDFs have not been identified (Oehme et al. 1989).

***Cigarette Smoke.*** Both mainstream and sidestream cigarette smoke contain CDFs. The smoke contained 2,3,7,8-substituted congeners of CDFs, and the concentrations of total CDFs in mainstream and sidestream smoke of one common commercial brand of Swedish cigarette were 720 and 1,670 pg per 20 cigarettes, respectively (Lofroth and Zeburh 1992). The concentrations of CDFs in the smoke is likely dependent on the manner in which a cigarette is smoked and the tobacco chlorine concentration (Lofroth and Zeburh 1992).

### **Chemical Reactions**

***Certain Chemical Products.*** CDFs occur as contaminants in a number of chemical products, such as chlorinated phenols, PCBs, phenoxy herbicides, chlorodiphenyl ether herbicides, hexachlorobenzene, tetrachlorobenzoquinones, and certain dyes. These chemical products containing CDFs may be released into the environment during their manufacture, use, or disposal.

The level of CDFs in commercial chlorinated phenols from different countries are given in Table 5-1. The difference in the levels of isomeric congeners is due to different degrees of chlorination and different methods of synthesis. The major CDF isomers identified were 1,2,4,6,8-penta-, 1,2,3,4,6,8-hexa-, 1,2,4,6,7,8-hexa-, 1,2,4,6,8,9-hexa-, 1,2,3,4,6,7,8-hepta-, and 1,2,3,4,6,8,9-heptaCDF (Rappe and Buser 1981). Commercial pentachlorophenol and sodium pentachlorophenate, used extensively for the preservation of wood, contained trace amounts of CDFs (Hagenmaier and Brunner 1987). These substances have the potential to migrate away or volatilize from wood surfaces and contaminate indoor air. The concentrations of CDFs in indoor ambient air of a kindergarten building in West Germany using PCP-treated wood were as follows: non-2,3,7,8-tetraCDF, 0.27 pg/m<sup>3</sup>; 1,2,3,7,8-pentaCDF, 0.1 pg/m<sup>3</sup>; non-2,3,7,8-pentaCDFs, 3.51 pg/m<sup>3</sup>; 1,2,3,4,7,8-hexaCDF, 0.37 pg/m<sup>3</sup>; 1,2,3,6,7,8-hexaCDF, 0.60 pg/m<sup>3</sup>; 1,2,3,7,8,9-hexaCDF, 0.16 pg/m<sup>3</sup>; non-2,3,7,8-hexaCDFs, 12.3 pg/m<sup>3</sup>; 1,2,3,4,6,7,8-heptaCDF, 10.7 pg/m<sup>3</sup>; 1,2,3,4,7,8,9-heptaCDF, 0.38 pg/m<sup>3</sup>; non-2,3,7,8-heptaCDFs, 12.2 pg/m<sup>3</sup>; and octaCDF, 6.0 pg/m<sup>3</sup> (Mukerjee et al. 1989). Therefore, use of certain commercial products can be a source of CDFs in air.

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**TABLE 5-1. Levels of CDFs in Commercial Chlorinated Phenols ( $\mu\text{g/g}$ )<sup>a</sup>**

	CDFs						$\Sigma$ CDFs	$\Sigma$ CDDs
	Tetra	Penta	Hexa	Hepta	Octa	$\Sigma$ CDFs		
2,4,6-Trichlorophenol, Sweden	1.5	17.5	36	4.8	—	60	<3	
2,4,6-Trichlorophenol, USA	1.4	2.3	0.7	<0.02	—	4.6	0.3	
2,3,4,6-Tetrachlorophenol, Finland	0.5	10	70	70	10	160	12	
Pentachlorophenol, USA	0.9	4	32	120	130	280	1,000	
Pentachlorophenol, USA	—	—	30	80	80	190	2,625	
Pentachlorophenol, USA	$\leq 0.4$	40	90	400	260	790	1,900	
Pentachlorophenol, Germany	—	—	0.03	0.8	1.3	2.1	6.8	

<sup>a</sup>Rappe and Buser 1981CDDs = chlorinated dibenzo-*p*-dioxins; CDFs = chlorinated dibenzofurans



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From the analysis of air particulates and sediment, it was concluded that the likely source of CDFs in a western Lake Ontario site was a pentachlorophenol production facility (Czuczwa and Hites 1986).

Commercial Aroclors, Clophen A-60, and Phenoclor DP-6 were analyzed for CDF concentrations (Bowes et al. 1975a). The concentrations of 2,3,7,8-tetraCDF and 2,3,4,7,8-pentaCDF in two Aroclors and two Japanese Kanechlors were also determined (Bowes et al. 1975). The concentrations of CDFs in a number of commercial PCB samples are given in Table 5-2. The CDF isomers identified in commercial PCBs are 2,3,7,8-tetra-, 2,3,6,7-tetra-, 2,3,6,8-tetra-, 2,3,4,7,8-penta-, 1,2,3,7,8-penta-, 1,2,4,7,8-penta-, 1,2,3,4,7,8-hexa-, 1,2,4,6,7,8-tetra-, 1,2,4,6,8,9-hexa-, 1,2,3,4,5,7,8-hepta-, and 1,2,3,4,6,8,9-heptaCDF (Rappe and Buser 1981).

Phenoxy herbicides generally contain higher concentrations of CDDs than CDFs. Therefore, more effort has been spent to determine the levels of CDDs in these samples. Two samples of European 2,4,5-trichlorophenoxyacetic acid contained non-2,3,7,8-tetraCDF. One sample of Agent Orange (a 50:50 mixture of n-butyl esters of 2,4-D and 2,4,5-trichlorophenoxyacetic acid) contained CDFs; they were one tri-, four tetra-, and one pentaCDF at a total concentration of 0.7 µg/g (EPA 1986a). It did not contain any 2,3,7,8-tetraCDF. Compost from municipal yard waste was also found to contain CDFs, possibly due to the presence of a PCP-based biocide (Harrad et al. 1991b).

CDFs have been detected as contaminants in commercial samples of diphenyl ether herbicides. Concentrations of tetraCDFs, pentaCDFs, and hexaCDFs in these samples were as high as 0.4, 1.0, and 0.2 ppb, respectively (Yamagishi et al. 1981).

Three early commercial hexachlorobenzene preparations were analyzed for CDFs. One sample contained a heptaCDF; all three samples contained octaCDF at concentrations ranging from 0.35 to 58.3 ppm (Villaneueva et al. 1974).

Samples of eight commercially available tetrachlorobenzoquinones (chloranils) from four different producers were analyzed for CDFs. OctaCDF was found in seven of eight samples at a maximum concentration of 6.02 ppm, while 1,2,3,4,6,7,8-heptaCDF was found in four of eight samples at a maximum concentration of 27 ppb. 1,2,3,4,7,8-HexaCDFs, pentaCDFs, and tetraCDFs were also found in some of the samples (Christmann et al. 1989b).

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**TABLE 5-2. Levels of CDFs in Commercial PCBs ( $\mu\text{g/g}$ )**

Sample	Tri-	Tetra-	Penta	Tetra	Hexa	Total
Aroclor 1248, 1969 <sup>a</sup>	—	0.5	1.2	0.3	—	2.0
Aroclor 1254, 1969 <sup>a</sup>	—	0.1	0.2	1.4	—	1.7
Aroclor 1254, 1970 <sup>a</sup>	—	0.2	0.4	0.9	—	1.5
Aroclor 1254 <sup>b</sup>	0.10	0.25	0.70	0.81	—	1.9
Aroclor 1254 (lot KK 602) <sup>b</sup>	—	0.05	0.10	0.02	—	0.2
Aroclor 1260, 1969 <sup>a</sup>	—	0.1	0.4	0.5	—	1.0
Aroclor 1260 (lot AK 3) <sup>a</sup>	—	0.2	0.3	0.3	—	0.8
Aroclor 1260 <sup>b</sup>	0.06	0.30	1.0	1.10	1.35	3.8
Aroclor 1016, 1972 <sup>a</sup>	—	<0.001	<0.001	<0.001	—	—
Clophen A 60 <sup>a</sup>	—	1.4	5.0	2.2	—	8.4
Clophen T 64 <sup>b</sup>	0.10	0.30	1.73	2.45	0.82	5.4
Phenoclor DP-6 <sup>a</sup>	—	0.7	10.0	2.9	—	13.6

<sup>a</sup>Bower et al. 1975a<sup>b</sup>Rappe and Buser 1981

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CDFs are also formed during the bleaching process for the manufacture of pulp and paper (Campin et al. 1991; Kitunen and Salinoja-Salonen 1989; Näf et al. 1992). Low levels (ppt) of 2,3,7,8-substituted congeners of tetra-, penta-, hexa-, and heptaCDF have been identified in the pulp, finished paper boards, effluents, and sludges from paper mills and 2,3,7,8-TCDF has been found in fish downstream of plant effluent.

The chloroalkali process utilizing graphite electrode is used for the production of chlorine produces CDFs. Total CDF levels as high as 650 ng/g (ppb) of sludge have been detected in sludge samples from graphite electrodes of a chloroalkali plant (Rappe et al. 1991b). The levels of tetra-, penta-, and hexaCDFs in the sludge were found to be approximately the same.

A number of commercial dyes were analyzed for CDFs. These samples contained tetra-, penta-, hexa-, hepta-, and octaCDFs at the ppb level (Heindl and Hutzinger 1989; Remmers et al. 1992; Williams et al. 1992).

### **Photochemical Reactions**

***Certain Photochemical Processes Involving Commercial Products.*** 1,3,7,9-TetraCDF was formed from the photolysis of 2,2',4,4',6,6'-hexachlorobiphenyl in hexane-methanol solution (Safe et al. 1977). The rate of photolysis was markedly higher in oxygen-degassed solutions than in oxygen-saturated solutions, indicating a triplet state as a possible intermediate for the photolysis process (Safe et al. 1977). Photolysis of chlorinated diphenyl ethers at around 300 nm in a degassed methanol solution also produced mono-, di-, tri-, and tetraCDFs (Choudhury et al. 1977). Photodegradation of polychlorobenzenes can also be a source of CDFs (EPA 1986a). In addition, dechlorination of higher CDFs can be a source of lower chlorinated CDFs (see Section 5.3.2). The relevance of laboratory photolysis to environmental sources of CDFs is unknown.

**Enzymatic Reactions.** CDFs are formed by enzyme-catalyzed oxidations of 2,4-di-, 2,4,5-tri-, 2,3,4,6-tetra-, 2,3,5,6-tetra-, and penta-chlorophenol (ijberg and Rappe 1992; Svenson et al. 1989a, 1989b). The implication of these investigations is that CDFs may be biogenically formed from wastes containing these chlorophenols, but the significance of the process in contributing to the release of CDFs in the environment has not been assessed.

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**Hazardous Waste Sites.** The improper disposal of CDF-containing wastes in landfill sites will primarily contaminate soils (see Section 5.2.3), but the air may also be contaminated by wind blown dusts.

### 5.2.1 Air

CDFs are released to air from combustion processes, accidental fires or malfunction of PCB-filled transformers and capacitors, improper disposal of chlorinated chemical wastes, certain chemical products, certain industrial processes, and certain photochemical processes involving commercial products. Toxic Release Inventory (TRI) data are not available for CDFs since releases of these compounds are not required to be reported (TRI90 1992).

### 5.2.2 Water

CDFs enter water as a result of deposition after these compounds have been emitted to the atmosphere from combustion sources. The concentrations and congener patterns of CDFs found in the sediment of three lakes and in the atmosphere led the authors to conclude that atmospheric deposition is the primary source of these compounds in lakes (Czuczwa and Hites 1986).

CDFs will enter surface water as a result of the discharge of CDF contaminated waste water, which is generated during the manufacture of chemicals containing CDFs contaminants. 2,3,7,8-TetraCDF has been detected at concentrations  $\leq 4.5$  ppb in sediment from estuaries adjacent to an industrial site in which chlorinated phenols were produced (Bopp et al. 1991). The typical waste waters from magnesium and refined nickel production are also examples of such CDF contamination (Oehme et al. 1989). Chemical manufacturing waste contaminated with CDFs that has been improperly disposed can leach from landfills into groundwater. CDF contaminated soil sites have been found in Butte, Montana, and Kent, Washington (Tiernan et al. 1989a).

Another important source of CDFs in surface water is the discharge of effluents from pulp and paper mills that use the bleached kraft process. The concentrations of 2,3,7,8-tetraCDF in the treated effluents from five bleached kraft pulp and paper mills in the United States ranged from not detected (0.007 ppt) to 2.2 ppt with a mean value of 0.54 ppt, but the waste water sludges contained 2,3,7,8-tetraCDF at a mean concentration of 0.37 ppb (Amendola et al. 1989). The effluent from a

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kraft pulp mill from Jackfish Bay, Lake Superior, contained tetraCDFs in concentrations ranging from 0.3 to 1.3 ng/L (9.3-1.3 ppt) (Sherman et al. 1990). Uncontrolled landfills can be sources of CDFs for adjacent surface waters (Clement et al. 1989c).

Chlorination of water has been shown to be a source of trace amounts (ppq level [i.e., pg/L level]) of CDFs. Apparently, impurities in the water may form CDFs on chlorination.

### 5.2.3 Soil

The main sources of CDFs in soil are atmospheric deposition from combustion and manufacturing processes and disposal of CDF-contaminated wastes. Several instances of CDF environmental contamination from improper disposal of hazardous chemical wastes have been associated with the manufacture or use of certain chlorinated organic compounds, and wastes from certain bleaching processes (Someshwar et al. 1990; Tieman et al. 1989). Soil samples around two wood-preserving facilities in Finland that used chlorophenols contained several congeners of CDFs (Kitunen et al. 1987). The concentrations of octaCDF, 1,2,3,4,6,8,9-heptaCDF, 1,2,3,4,6,7,8-heptaCDF, 1,2,4,6,8,9-hexaCDF, 1,2,4,6,7,8-hexaCDF, and 1,2,3,4,6,8-hexaCDF in the top soil from one of these facilities were 210, 840, 1,400, 440, 340, and 550  $\mu\text{g}/\text{kg}$ , respectively. In the other facility, the concentrations of CDFs decreased with soil depth, then increased at a depth of 60-80 cm, and tended to decrease at depths  $\geq 100$  cm of soil (Kitunen et al. 1987). Soil contaminated with CDFs from PCP-containing wood preserving waste sites has been found in Butte, Montana, and Kent, Washington, in the United States (Tieman et al. 1989), and in Finland (Kitunen et al. 1987). Land disposal of treated waste water sludge from magnesium and nickel production is another example of CDF soil contamination (Oehme et al. 1989). An important source of CDFs in soil is the discharge of waste water sludge from bleached kraft pulp and paper mills. The sludge from paper mills is known to contain CDFs (Amendola et al. 1989; Sherman et al. 1990; Someshwar et al. 1990). The presence of CDFs in the soil of Superfund sites also indicates that disposal of contaminated waste (e.g., waste from certain combustion processes, chemical wastes) is an important source of CDFs in soil. TetraCDFs, pentaCDFs, hexaCDFs, heptaCDFs, and octaCDF have been detected in soil samples from Superfund sites (HAZDAT 1991).

## 5.3 ENVIRONMENTAL FATE

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### 5.3.1 Transport and Partitioning

CDFs are present in the atmosphere both in the vapor and particulate phase (Hites 1990). The ratio of the vapor to particulate phase CDFs in air increases with increasing temperature. The ratio in Bloomington, Indiana was as high as 2 during the warm summer months and  $<0.5$  in the winter. However, it should be recognized that the distribution of CDFs between the vapor and particulate phase will depend on the amount and nature of the particulate matter in the atmosphere, as well as the temperature (Hites 1990). The vapor to particle ratio is also different for the different congeners. In the air, a higher proportion of tetraCDF congeners is present in the vapor phase, whereas heptaCDF and octaCDF congeners are found predominantly in the particulate phase (Hites 1990). The transport of atmospheric CDFs to soil and water occurs by dry and wet deposition. Dry deposition refers to the simple gravitational settling of particles and the removal of vapor phase compounds onto surface materials, such as water and vegetation by impaction. Wet deposition refers to the removal of the atmospheric compounds by rain, fog, or snow.

The overall determined average dry to wet deposition ratio for atmospheric CDFs was 5:1 (Hites 1990). Therefore, dry deposition is more important than wet deposition for removal of atmospheric CDFs. Both particulate and gas phase compounds can be removed from the atmosphere by wet deposition. Particle-scavenging is the process by which rainfall removes particles from the atmosphere. About 40% of tetraCDF and pentaCDF homologues, and 80% of the hexaCDF through octaCDF homologues in Bloomington, Indiana, air were removed by particle scavenging. Therefore, particle scavenging during wet deposition is generally a more important process than gas scavenging (Eitzer and Hites 1989a; Hites 1990). Wet deposition of vapor phase CDFs is a relatively minor loss process (Atkinson 1991).

In addition to the intermedia transport of CDFs from air to water and soil, intramedia transport of CDFs is also significant. It has been estimated that the lifetimes of all particulate phase CDFs and the vapor phase tetra- and higher CDFs are  $>10$  days. Therefore, vapor and particulate phase CDFs containing four or more chlorine atoms are expected to have sufficiently long lifetimes to undergo long-range transport (Atkinson 1991). Several authors have experimentally observed this expected long range transport of CDFs (Czuczwa et al. 1985; Oehme 1991; Rappe et al. 1989).

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The two significant processes in the transport of a chemical from water are volatilization and adsorption to sediment. The first process transfers the chemical from water to air and the second process transfers the chemical from water phase to sediment. The volatilization of CDFs from water, as with other chemicals, depends on their Henry's law constants. Since the values of the Henry's law constants for tetra- and higher CDFs are  $<1.48 \times 10^{-5}$  atm-m<sup>3</sup>/mol (see Table 3-2), the rate of volatilization of these CDFs is slow and is controlled by slow diffusion through air (Thomas 1982). The volatilization rates are further decreased because the CDFs are present in water predominantly in the adsorbed states. However, no experimental data pertaining to the volatilization of CDFs from water were located. The adsorption of CDFs to suspended solids and sediment in water depends on their  $K_{OC}$  values. The estimated log  $K_{OC}$  values for 2,3,7,8-TCDD and octaCDF are 5.61 and 8.57, respectively (see Table 3-2). Therefore, these compounds strongly adsorb to suspended solids and sediment in water. As a result, almost all the literature provides concentrations of CDFs in sediment and not in water; concentration in water is so low that it is rarely measured. Therefore, sediments are the ultimate environmental sinks for CDFs (Czuczwa and Hites 1986b).

The estimated high log  $K_{OW}$  values for 2,3,7,8-tetraCDF and octaCDF (see Table 3-2) suggest that the bioconcentration of CDFs in aquatic organisms is high. The experimental bioconcentration factor for octaCDF in the guppy (*Poecilia reticulata*) was 589 on wet weight basis and 7,760 on lipid weight basis (Frank and Schrap 1990). Similarly, steady-state concentrations of slightly  $>0.001$  µg/g (wet weight) in tissues were found in guppies after feeding the fish 10.6-40.6 µg/g octaCDF in food (Clark and Mackay 1991). In a static laboratory test, the determined bioconcentration factors for 1,2,3,7,8-pentaCDF and 2,3,4,7,8-pentaCDF in guppies were 2,400 and 5,000, respectively (Opperhuizen and Sijm 1990). In another laboratory experiment, the determination of bioconcentration of 2,3,7,8-tetraCDF in gold fish (*Carassius auratus*) was attempted by exposing the fish to fly ash (containing  $<1,400$  ppt 2,3,7,8-tetraCDF) and contaminated sediment (containing  $<68$  ppt 2,3,7,8-tetraCDF) in aquaria for 10 weeks (O'Keefe et al. 1986). Fish in both tests contained only 0.7 ppt 2,3,7,8-tetraCDF. The bioconcentration factor could not be determined because the concentration of 2,3,7,8-tetraCDF in water was too low. Laboratory experiments in fish exposed to contaminated sediments and in Wisconsin River fish showed that residues of 2,3,7,8-substituted congeners of CDFs are selectively enriched in carp (*Cyprinus carpio*) (Kuehl et al. 1987). Since the concentrations of CDF isomers were too low for determination, the authors reported the following bioavailability indices (ratio of concentration of a compound in fish lipid to concentration in sediment based on carbon content): 0.06 for 2,3,7,8-tetraCDF, 0.21 for 2,3,4,7,8-pentaCDF, 0.033 for

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1,2,3,6,7,8-hexaCDF, and 0.0033 for 1,2,3,4,6,7,8-heptaCDF (Kuehl et al. 1987). In another study, highest bioavailable indices were achieved for organisms filtering or ingesting organic particles (mussels, chironomids) and those consuming benthic organisms (crayfish suckers) (Muir et al. 1992).

It is clear from the above experiments that the bioconcentration factors for CDFs in aquatic organisms are much lower than other polychlorinated aromatic compounds such as octachlorobiphenyl (Clark and Mackay 1991). Several explanations have been proposed to explain the lower than expected bioconcentration of CDFs in fish. One possible explanation is the rapid depuration (elimination) of the chemicals from fish, probably via biotransformation through a cytochrome P-450 system mediated MFO with the formation and elimination of polar metabolites, such as hydroxylated compounds (Frank and Schrap 1990; Opperhuizen and Sijm 1990). Another explanation for the low bioconcentration factor is a low rate of membrane permeation of these highly hydrophobic compounds (Opperhuizen and Sijm 1990). The theory of low permeation is disputed by other investigators (Frank and Schrap 1990). In addition, CDF congeners are present in the water mostly in the adsorbed state and the inability to distinguish between the adsorbed and free CDFs (bioavailability will be lower in the adsorbed state) may have largely overestimated the dissolved CDFs in water. As a result, the bioconcentration factor derived from the overestimated water concentration may be responsible for underestimating the true bioconcentration potential. More reliable estimates of bioconcentration factors may be obtained when the methods for measuring dissolved and sorbed chemical fractions in water improve (Frank and Schrap 1990).

Compared to other aquatic organism such as fish, crabs lack the ability to metabolize most of the CDF isomers (Oehme et al. 1990). The concentrations of 2,3,7,8-tetra-, 2,3,4,7,8-penta-, and 1,2,3,6,7,8-hexaCDFs in the hepatopancreas of crabs collected from a contaminated river were 2.3, 1.6, and 4.6 ppb. These values are  $\approx 3$  orders of magnitude higher than those found in fish (see Kuehle et al. 1987). Therefore, bioconcentration of CDFs in crabs will be much higher than in fish that are known to metabolize CDFs, but no values for bioconcentration of CDFs in crabs were provided (Oehme et al. 1990). Apparently this is due to lack of data concerning the concentrations of CDFs in water.

The biomagnification of CDFs in a littoral food chain consisting of phytoplankton  $\rightarrow$  blue mussel (*Mytilus edulis*)  $\rightarrow$  juvenile eider duck (*Somateria mollissima*) and a pelagic food chain consisting of phytoplankton  $\rightarrow$  zooplankton  $\rightarrow$  herring (*Clupea harengus*)  $\rightarrow$  cod (*Gadus morrhua*) was studied (Broman et al. 1992). It was concluded that the total concentrations of 2,3,7,8-substituted CDFs



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decreased with increasing trophic level, whereas the toxic content of the 2,3,7,8-substituted CDFs increased with increasing trophic level. The result implied a selective enrichment of 2,3,7,8-substituted isomers with high toxic equivalency factors.

The transport of CDFs from soil to air is possible via volatilization and by wind blown dusts. The very low vapor pressures and high soil sorption coefficients of those CDFs for which data are available (see Table 3-2) indicate that volatilization of these compounds from soil is insignificant (Hutzinger et al. 1985b). The observation that essentially no loss of 2,3,7,8-TCDD, a structurally similar compound, from the contaminated soil at Times Beach, Missouri, occurred in 4 years (Yanders et al. 1989), strongly suggests that volatilization is insignificant for CDFs as well. No evidence of appreciable loss of CDFs due to volatilization was found in contaminated soils during a period of 8 years (Hagenmaier et al. 1992). CDFs may be transported from soil to water via leaching and runoff. Soil leaching experiments indicate that CDFs remain strongly adsorbed even in sandy soil and leaching of these compounds from soil by rainwater is not significant (Carsch et al. 1986). The vertical movement of CDFs was found to be very slow and >90% of CDFs were found in the top 10 cm after 3 years (Hagenmaier et al. 1992). Therefore, transport of CDF from landfill soil to adjacent land or surface water by runoff water is more likely than leaching. Leaching or vertical movement of CDFs in soil can occur under special conditions, such as saturation of the sorption sites of the soil matrix, presence of organic solvents in the soil facilitating co-solvent action, cracks in the soil, or burrowing activity of animals (Hagenmaier et al. 1992; Hutzinger et al. 1985b).

Data regarding the translocation of CDFs from the roots to the above-ground parts of plants were not located. Because there is little bioaccumulation of CDDs in plants from soil (EPA 1986a), bioaccumulation of CDFs in plants is also probably insignificant. As in the case with CDDs (EPA 1986a), due to absorption by underground roots of some plants such as carrots, the roots can accumulate more CDFs, compared to aerial parts. In most plants (plants with higher aerial surface area and leaf surfaces with compounds that enhance adsorption), higher concentrations of CDFs are likely to be found on aerial portions of plants due to deposition of airborne particles and vapor. The estimated accumulation potential of CDFs on pine needles (ratio of CDF concentration in a gram of pine needles or concentration in a gram of air) due to deposition of airborne particles for 10 months was  $10^4$  to  $10^5$  (Reisch et al. 1989).

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The biotransfer of CDFs from contaminated soil to grazing animals was studied with chickens as a model (Petreas et al. 1991). Compared to controls, the concentration of CDFs in eggs of exposed chickens increased 10-fold at low exposure levels (total CDF concentration in soil was 555 ppt) and 100-fold at high exposure levels (total CDF concentration was 11,841 ppt). The biotransfer factors (ratio of concentration in egg fat over concentration in soil) for different congeners of CDFs were <1. However, statistically significant ( $p < 0.05$ ) concentration dependence of biotransfer factors, as a result of high and low exposure, were found for only 2,3,7,8-tetraCDF and 1,2,3,4,7,8,9-heptaCDF.

### 5.3.2 Transformation and Degradation

#### 5.3.2.1 Air

The loss of vapor phase CDFs by reactions with HO<sub>2</sub> radicals, NO<sub>3</sub> radicals and ozone has been estimated to be of negligible importance in the troposphere (Atkinson 1991). The estimated rate constants for the reactions of vapor phase CDFs with OH radicals are as follows ( $-10^{-12}$  cm<sup>3</sup>/molecule-sec): tetraCDFs, 1.4-8.3; pentaCDFs, 1.0-4.3; hexaCDFs, 0.74-2.6; heptaCDFs, 0.53-0.92; and octaCDFs, 0.39. Using a 12-hour average daytime hydroxyl radical concentration of  $1.5 \times 10^6$ /cm<sup>3</sup>, the estimated tropospheric lifetimes of tetra-, penta-, hexa-, hepta-, and octaCDF are 1.9-11, 3.6-15, 5.9-22, 17-31, and 39 days, respectively. The vapor phase reaction of CDFs with hydroxyl radicals is the dominant loss process and this loss process is more important for the lower, than the higher, chlorinated congeners, because the lifetimes due to this reaction are shorter for lower chlorinated congeners and the vapor phase concentrations of lower chlorinated congeners are higher. Based on the available information, the reactions of hydroxyl radicals with particulate phase CDFs are insignificant and the principal air removal mechanism for CDFs is wet and dry deposition.

Photodegradation of CDFs bound to atmospheric particles is not an important process in removing these compounds from air (Koester and Hites 1992). No data regarding vapor phase photolysis of CDFs were located. In the absence of data, the half-lives of these compounds in the vapor phase have been estimated from aqueous phase photolysis data and it was concluded that photolysis is relatively unimportant, even when compared to reaction with hydroxyl radicals (with the possible exception of 1,3,6,8-tetraCDF) (Atkinson 1991).

#### 5.3.2.2 Water

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The loss of CDFs in water by abiotic processes such as hydrolysis and oxidation is not likely to be significant (EPA 1986a). The photolysis of CDFs in solution indicates that significant photolysis occurs in hydrogen donating solvents. Photolysis was faster in methanol than in hexane. Photolysis in these solvents proceeds with rapid dechlorination and eventual formation of unidentified resinous polymeric products (Hutzinger et al. 1973). Photolysis may proceed at a much faster rate at shorter wavelengths (254 nm) than are available from sunlight (>290 nm). It was also concluded that the rate of photolysis in hexane is faster for CDFs than CDDs and that the higher chlorinated congeners photodegrade faster than lower chlorinated congeners (Muto and Takizawa 1991). The rates of photolysis of 2,3,7,8-substituted congeners in solution are faster than the rates of non-2,3,7,8-substituted congeners (Tysklind and Rappe 1991). During the photolysis of octaCDF in dioxane under xenon lamp, hexa- and pentaCDFs were the major products, with small amounts of hepta- and tetraCDFs (Koshioka et al. 1987).

The estimated photolysis lifetimes of CDDs by sunlight in surface waters at 40° latitude range from 0.4 to 225 days, depending upon the specific congener and the season of the year (shorter lifetimes in summer than in winter) (Atkinson 1991). If the photolysis rates of CDFs are assumed to be faster than CDDs (Muto and Takizawa 1991), the photolysis lifetimes of CDFs are expected to be shorter than those for CDDs. However, the persistence of CDFs in natural water (based on a half-life of 1 year for CDDs in a model aquatic ecosystem) (EPA 1986a), contradicts the estimated photolytic lifetimes in natural water. This discrepancy is possibly due to the fact that CDDs/CDFs in natural water are present predominantly in particulate-sorbed phase. The rate of photolysis is much slower in the sorbed phase compared to solution phase photolysis (the estimated lifetimes data of Atkinson [1991] is based on solution phase photolysis) (Tysklind and Rappe 1991).

No data in the literature indicate that biodegradation of CDFs in water is significant. Biodegradation studies in sediments of a lake water indicate that 2,3,7,8-TCDD resists biodegradation (EPA 1986a). Therefore, biodegradation of CDFs in water may also be insignificant.

### 5.3.2.3 Sediment and Soil

The photodegradation of thin film CDIs of fly ash bound CDFs under sunlight was much slower than solution phase photolysis (Hutzinger et al. 1973; Tysklind and Rappe 1991). Direct evidence of sunlight initiated photolysis of CDFs in soil was not located. Given the fact that sunlight cannot

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penetrate beyond the surface layer of soil and the lack of photolysis of CDFs adsorbed to fly ash (Koester and Hites 1992; Tysklind and Rappe 1991), the photolysis of CDFs in soil and sediment may not be significant. It may be significant for airborne particles.

No significant changes in the concentration patterns of homologous or isomeric CDFs could be detected in contaminated soil samples taken in 1981, 1987, and 1989 at the same sites and from the same depth (Hagenmaier et al. 1992). This underlines the persistence of CDFs in soil. No direct evidence was located in the literature suggesting that biodegradation of CDFs in soil and sediments is significant. The lack of biodegradation of CDDs in soil and sediments (although a few microbes degraded 2,3,7,8-TCDD at a slow rate) (EPA 1986a) and the lack of evidence for any degradation of CDFs in dated lake sediments (Czuczwa et al. 1985; Czuczwa and Hites 1986) indirectly suggest that biodegradation of CDFs in soil or sediments is not significant.

### 5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

#### 5.4.1 Air

The levels of CDFs determined in the ambient air in North America are presented in Table 5.3. As expected, the concentrations of CDFs in air show geographical variability based on the sources of emissions. Generally, the levels show the following trend: industriavauto tunnel > urban > suburban > rural (Eitzer and Hites 1989a). Even in a particular area, the level shows daily and seasonal variability. For example, the concentrations of CDFs are generally higher on rainy days with high humidity and on less windy days (Nakano et al. 1990). The levels are also higher *in* winter than in summer, due to increases in the contribution from combustion sources (heating) (Hunt et al. 1990). Table 5-3 indicates that the concentrations of total tetra-, penta-, hexa-, hepta-, and octaCDFs in ambient urban/suburban air can vary within the ranges of 0.13-7.34, 0.09-5.10, <0.09-12.55, 0.08-12.71, and 0.13-3.78 pg/m<sup>3</sup>, respectively. In rural areas, the concentrations of total tetra-, penta-, hexa-, hepta-, and octaCDFs are below their detection limits. It has also been determined that the vapor/particulate phase ratio of the CDFs in ambient air depends on the season of the year and the number of chlorine substituents. Generally, the tetra- and pentaCDFs are present at higher ratios in the vapor phase, while hepta- and octaCDF are present predominantly in the particulate phase in the atmosphere. This ratio of vapor/particulate phase increases during summer, compared to winter (Eitzer and Hites 1989a; Hunt et al. 1990; Nakano et al, 1990). The congener profile in the atmosphere

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**TABLE 5-3. Concentrations of CDFs in Ambient Indoor and Outdoor Air in North America**

Site	Sampling year	CDF	Concentration (pg/m <sup>3</sup> )	Reference
Bridgeport, CT (outdoor)	1987–1988	2,3,7,8-tetraCDF	0.078	Hunt and Maisel 1990
		total tetraCDF	0.856	
		1,2,3,7,8-pentaCDF	0.031	
		2,3,4,7,8-pentaCDF	0.047	
		total pentaCDF	0.547	
		1,2,3,4,7,8-hexaCDF	0.106	
		1,2,3,6,7,8-hexaCDF	0.039	
		2,3,4,6,7,8-hexaCDF	0.087	
		1,2,3,7,8,9-hexaCDF	0.007	
		total hexaCDF	0.580	
		1,2,3,4,6,7,8-heptaCDF	0.212	
		1,2,3,4,7,8,9-heptaCDF	0.033	
		total heptaCDF	0.369	
octaCDF	0.211			
Toronto Island, Canada (outdoor)	1988–1989	total tetraCDF	0.404	Steer et al. 1990
		total pentaCDF	0.118	
		total hexaCDF	0.204	
		total heptaCDF	0.240	
		octaCDF	0.142	
Dorset, Canada (outdoor)	1988–1989	total tetraCDF	0.164	Steer et al. 1990
		total pentaCDF	0.200	
		total hexaCDF	0.074	
		total heptaCDF	0.52	
		octaCDF	0.194	
Windsor, Canada (outdoor)	1988–1989	total tetraCDF	0.733	Steer et al. 1990
		total pentaCDF	0.383	
		total hexaCDF	0.333	
		total heptaCDF	0.550	
		octaCDF	0.182	
Boston, MA office building (indoor)	No data	2,3,7,8-tetraCDF	(0.37) <sup>a</sup> –1.4	Komsky and Kuoka 1989
		total tetraCDF	(0.64) <sup>a</sup> –6.2	
		total pentaCDF	(0.12) <sup>a</sup> –1.9	
		total hexaCDF	(0.39)–(1.5) <sup>a</sup>	
		octaCDF	(0.54)–(1.8) <sup>a</sup>	
Albany, NY (outdoor)	1987–1988	total tetraCDF	3.86	Smith et al. 1990
		2,3,7,8-tetraCDF/unknown isomer	0.89	
		total pentaCDF	2.00	
		total hexaCDF	0.28	
		total heptaCDF	<0.34	
		octaCDF	<0.50	
Binghamton, NY (outdoor)	1988	total tetraCDF	0.94	Smith et al. 1990
		2,3,7,8-tetraCDF/unknown isomer	0.18	
		total pentaCDF	0.25	
		total hexaCDF	<0.09	
		total heptaCDF	<0.14	
		octaCDF	<0.30	

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**TABLE 5-3. Concentrations of CDFs in Ambient Indoor and Outdoor Air in North America (continued)**

Site	Sampling year	CDF	Concentration (pg/m <sup>3</sup> )	Reference
Utica, NY (outdoor)	1988	total tetraCDF	7.34	Smith et al. 1990
		2,3,7,8-tetraCDF/unknown isomer	1.15	
		total pentaCDF	3.16	
		total hexaCDF	<0.36	
		total heptaCDF	<0.24	
		octaCDF	<0.61	
Niagara Falls, NY (outdoor)	1987–1988	total tetraCDF	1.53	Smith et al., 1990
		2,3,7,8-tetraCDF/unknown isomer	<0.11	
		total pentaCDF	0.98	
		total hexa CDF	1.45	
		total heptaCDF	1.37	
		octaCDF	0.51	
United States and Canada ambient air (outdoor)	No data	total tetraCDF	1.09	Waddell et al., 1990
		total pentaCDF	0.63	
		total hexa CDF	0.72	
		total heptaCDF	1.14	
		octaCDF	0.62	
Bloomington, IN	1986	2,3,7,8-/2,3,4,8-/2,3,4,6-tetraCDF	0.048	Eitzer and Hites 1989b
		total tetraCDF	0.263	
		1,2,3,7,8-/1,2,3,4,8-pentaCDF	0.017	
		2,3,4,7,8-/1,2,3,6,9-pentaCDF	0.017	
		total pentaCDF	0.20	
		1,2,3,4,7,8-/1,2,3,4,6,7-hexaCDF	0.023	
		1,2,3,6,7,8-/1,2,3,4,7,9-hexaCDF	0.016	
		2,3,4,6,7,8-hexaCDF	0.015	
		1,2,3,7,8,9-hexaCDF	0.0007	
		total hexaCDF	0.113	
		1,2,3,4,6,7,8-heptaCDF	0.039	
		1,2,3,4,7,8,9-heptaCDF	0.005	
		total heptaCDF	0.071	
		octaCDF	0.028	
Southern California (outdoor)	1987–1989	2,3,7,8-tetraCDF	<0.007–0.482	Hunt et al. 1990
		1,2,3,7,8-pentaCDF	<0.010–1.9	
		2,3,4,7,8-pentaCDF	<0.009–0.110	
		1,2,3,4,7,8-hexaCDF	<0.001–0.27	
		1,2,3,6,7,8-hexaCDF	<0.001–0.800	
		2,3,4,6,7,8-hexaCDF	<0.001–0.280	
		1,2,3,4,6,7,8-heptaCDF	<0.002–1.58	
		1,2,3,4,7,8,9-heptaCDF	<0.002–0.092	

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**TABLE 5-3. Concentrations of CDFs in Ambient Indoor and Outdoor Air in North America (continued)**

Site	Sampling year	CDF	Concentration (pg/m <sup>3</sup> )	Reference
Los Angeles,, CA (outdoor)	1987	2,3,7,8-tetraCDF	0.021	Maisel and Hunt 1990
		other tetraCDF	0.30	
		1,2,3,7,8-pentaCDF	0.077	
		2,3,4,7,8-pentaCDF	0.077	
		other pentaCDF	0.41	
		1,2,3,4,7,8-hexaCDF	0.151	
		1,2,3,6,7,8-hexaCDF	0.25	
		2,3,4,6,7,8-hexaCDF	<0.069	
		1,2,3,7,8,9-hexaCDF	<0.083	
		other hexaCDF	<0.080	
		1,2,3,4,6,7,8-heptaCDF	<0.190	
		1,2,3,4,7,8,9-heptaCDF	<0.018	
		other heptaCDF	0.26	
octaCDF	0.056			
Dayton, OH (outdoor—suburban/roadside)	1988	total tetraCDF	0.13	Tieman et al. 1989
		total pentaCDF	0.24	
		total hexaCDF	0.14	
		total heptaCDF	0.11	
		octaCDF	<0.07	
Dayton, OH (outdoor—municipal solid waste incinerator)	1988	total tetraCDF	1.23	Tieman et al. 1989
		2,3,7,8-tetraCDF	0.11	
		total pentaCDF	5.10	
		1,2,3,7,8-pentaCDF/unknown isomer	0.46	
		2,3,4,7,8-pentaCDF	0.53	
		total hexaCDF	12.55	
		1,2,3,4,7,8-hexaCDF/unknown isomer	1.18	
		1,2,3,6,7,8-hexaCDF	2.27	
		1,2,3,7,8,9-hexaCDF	<0.06	
		2,3,4,6,7,8-hexaCDF	<0.41	
		total heptaCDF	12.71	
		1,2,3,4,6,7,8-heptaCDF	8.22	
		1,2,3,4,7,8,9-heptaCDF	0.56	
octaCDF	3.78			
Dayton, OH (outdoor—rural area)	1988	total tetraCDF	<0.02	Tieman et al. 1989
		total pentaCDF	<0.02	
		total hexaCDF	<0.05	
		total heptaCDF	<0.07	
		octaCDF	<0.17	
Windsor, Canada (outdoor)	1987–1988	total tetraCDF	0.21	Bobet et al. 1990
		total pentaCDF	0.09	
		total hexaCDF	0.10	
		total heptaCDF	0.08	
		octaCDF	0.13	
Walpole Island, Canada (outdoor)	1987–1988	total tetraCDF	<0.05	Bobet et al. 1990
		total pentaCDF	<0.07	
		total hexaCDF	<0.10	
		total heptaCDF	<0.07	
		octaCDF	<0.14	

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**TABLE 5-3. Concentrations of CDFs in Ambient Indoor and Outdoor Air in North America (continued)**

Site	Sampling year	CDF	Concentration (pg/m <sup>3</sup> )	Reference
Lake Trout, WI (outdoor)	1987	total tetraCDF	0.083	Edgerton et al. 1989
		total pentaCDF	0.067	
		total hexaCDF	0.031	
		total heptaCDF	0.012	
		octaCDF	0.006	
Akron, OH (outdoor)	1987	2,3,7,8-tetraCDF	0.200	Edgerton et al. 1989
		total tetraCDF	1.23	
		1,2,3,7,8-pentaCDF	0.029	
		2,3,4,7,8-pentaCDF	0.036	
		total pentaCDF	0.590	
		1,2,3,4,7,8-hexaCDF	0.083	
		1,2,3,6,7,8-hexaCDF	0.065	
		2,3,4,6,7,8-hexaCDF	<0.021	
		1,2,3,7,8,9-hexaCDF	0.032	
		total hexaCDF	0.620	
		1,2,3,4,6,7,8-heptaCDF	0.237	
		1,2,3,4,7,8,9-heptaCDF	<0.029	
		total heptaCDF	0.383	
octaCDF	0.180			
Columbus, OH (outdoor)	1987	2,3,7,8-tetraCDF	0.405	Edgerton et al. 1989
		total tetraCDF	2.85	
		1,2,3,7,8-pentaCDF	0.045	
		2,3,4,7,8-pentaCDF	<0.056	
		total pentaCDF	0.995	
		1,2,3,4,7,8-hexaCDF	0.165	
		1,2,3,6,7,8-hexaCDF	0.141	
		2,3,4,6,7,8-hexaCDF	<0.02	
		1,2,3,7,8,9-hexaCDF	0.079	
		total hexaCDF	0.785	
		1,2,3,4,6,7,8-heptaCDF	0.335	
		1,2,3,4,7,8,9-heptaCDF	<0.021	
		total heptaCDF	0.450	
octaCDF	<0.260			
Waldo, OH (outdoor)	1987	2,3,7,8-tetraCDF	0.130	Edgerton et al. 1989
		total tetraCDF	0.890	
		1,2,3,7,8-pentaCDF	0.021	
		2,3,4,7,8-pentaCDF	<0.033	
		total pentaCDF	0.500	
		1,2,3,4,7,8-hexaCDF	0.098	
		1,2,3,6,7,8-hexaCDF	0.014	
		2,3,4,6,7,8-hexaCDF	<0.008	
		1,2,3,7,8,9-hexaCDF	0.097	
		total hexaCDF	0.510	
		1,2,3,4,6,7,8-heptaCDF	0.220	
		1,2,3,4,7,8,9-heptaCDF	0.019	
		total heptaCDF	0.290	
octaCDF	0.077			

\*Detection limit



## 5. POTENTIAL FOR HUMAN EXPOSURE

follows the congener profile of their sources, that is, if the major source of CDFs in the atmosphere is a municipal incinerator, the congener pattern in the air follows the congener pattern in flue gas from that municipal incinerator (Edgerton et al. 1989; Eitzer and Hites 1989a).

The majority of CDFs found in the air are non-2,3,7,8-substituted congeners, which are much less toxic than 2,3,7,8-substituted congeners. Among the 2,3,7,8-substituted isomers in the air, the 1,2,3,4,6,7,8-heptaCDF congener dominates, followed by 2,3,7,8-tetraCDF. It has been shown that 2,3,7,8-tetraCDF constitutes  $\approx 9\%$  of total tetraCDFs; 1,2,3,7,8-penta- and 2,3,4,7,8-pentaCDF constitute  $\approx 9\%$  and  $10.4\%$ , respectively, of total pentaCDFs; 1,2,3,4,7,8-hexa-, and 1,2,3,6,7,8-hexaCDF constitute  $\approx 9.4\%$  and  $18.1\%$ , respectively, of the total hexaCDFs; and 1,2,3,4,6,7,8-hepta and 1,2,3,4,7,8,9-heptaCDF constitute  $\approx 64.7\%$  and  $4.4\%$ , respectively, of the total heptaCDFs present in the air near a municipal solid waste incinerator in Dayton, Ohio (Tiernan et al. 1989).

Considerably higher concentrations of CDFs have been detected in the indoor air and wipe samples of buildings after accidental fires involving PCB capacitors/transformers. For example, the concentrations of total CDFs and 2,3,7,8-tetraCDF (plus co-eluting isomers) in wipe samples from the transformer vault after the 1983 transformer fire in Chicago were  $12,210$  and  $410$  ng/100 cm<sup>2</sup>, respectively (Hryhorczuk et al. 1986). The concentrations of total tetraCDFs in air and wipe samples inside the vault 4 months after the 1983 San Francisco transformer fire were  $1,000$ - $3,000$  pg/m<sup>3</sup> and  $1,000$ - $23,000$  ng/100 cm<sup>2</sup>, respectively (Stephens 1986). Seven months following the fire, the maximum concentration of 2,3,7,8-substituted CDFs in air of the building that contained the transformer vault was  $19.5$  pg/m<sup>3</sup>. The concentrations of total tetraCDFs, 2,3,7,8-tetraCDF (plus co-eluting isomers) and total pentaCDFs of indoor air in a Binghamton, New York, office building 1.5-2 years after cleanup following a 1981 electric fire were  $\leq 23$ ,  $195$ , and  $60$  pg/m<sup>3</sup>, respectively (Smith et al. 1986). Similarly, concentrations of tetraCDF, pentaCDF, hexaCDF, heptaCDF and octaCDF  $\leq 0.4$ ,  $0.6$ ,  $2.2$ ,  $4.4$ , and  $4.8$  ng/100 cm<sup>2</sup>, respectively, were present in the wipe samples of a building used for the improper incineration of PCBs over 12 years ago (Thompson et al. 1986).

### 5.4.2 Water

The concentrations of CDFs in most waters are so low that it is difficult to determine the levels in drinking water and surface water, unless the surface water is sampled close to points of effluent discharge containing CDFs. Because of their low water solubilities and high  $K_{OC}$  values, the CDFs

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partition from the water to sediment in environmental water or in sludge during the treatment of waste waters. Therefore, more monitoring data are available for CDFs levels in the latter two media.

A drinking water sample in Sweden contained 2,3,4,7,8-pentaCDF at a concentration of 0.002 ppq (Rappe 1991). The levels of CDFs in drinking water from 20 communities in New York state were measured (Meyer et al. 1989). Total tetraCDFs at a concentration of 2.6 ppq (pg/L) and octaCDF at a concentration 0.8 ppq are the only two congener groups detected in 1 of 20 water supplies (Lockport, New York). The concentration of 2,3,7,8-tetraCDF in water from Lockport was 1.2 ppq. The raw water that served as the source of this drinking water contained several CDFs at the following concentrations (ppq): total tetraCDF, 18.0; 2,3,7,8-tetraCDF, not detected (detection limit 0.7); 1,2,3,7,8-pentaCDF, 2.0; total pentaCDF, 27.0; 1,2,3,4,7,8-hexaCDF, 39.0; 1,2,3,6,7,8-hexaCDF, 9.2; total hexaCDF, 85.0; 1,2,3,4,6,7,8-heptaCDF, 210; total heptaCDF, 210; and octaCDF, 230. Since the finished drinking water contained 2,3,7,8-tetraCDF, and the raw water did not contain any detectable level of this compound, the source of 2,3,7,8-tetraCDF in the drinking water must be the chlorination process. Considerably higher concentrations of CDFs were detected in the sediment of the raw water. This provides more indirect evidence that chlorination may be partially responsible for the *in situ* production of CDFs.

Effluents from bleached kraft and sulfite mill pulp in the United States, Canada, and Europe contained total tetraCDFs in the concentration range of <0.01-4,100 ppt, whereas the concentrations of 2,3,7,8-tetraCDF varied from <0.002 to 8.4 ppt. The octaCDF levels in these effluents ranged from <0.05 to 0.5 ppt. The sludge from the treated effluents from paper mills contained much higher concentrations of CDFs. In one case, the sludge from a chloralkali process contained  $\leq$ 52,000 ppt of 2,3,7,8-tetraCDF and 81,000 ppt of octaCDF (Clement et al. 1989a, 1989b; Rappe et al. 1990a; Waddell et al. 1990; Whitmore et al. 1990).

Surface water adjacent to a landfill near Tonawanda, New York, contained the following concentrations of CDFs (ppt): total tetraCDFs, 0.2-77; total pentaCDFs, 0.3-130; total hexaCDFs, 0.8-200; total heptaCDFs, 1.0-980; and octaCDF, 1.2-1,500 (Clement et al. 1989c). Leachates from bottom and fly ash disposal facilities of five state-of-the-art mass burn municipal waste combustors, with a variety of pollution control equipment, were analyzed for CDFs. With the exception of the leachate from one facility, leachates from four other facilities contained CDFs below the detection

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level (0.01-0.06 ppb). HeptaCDF at a concentration of 0.076 ppb was detected in the remaining leachate sample (EPA 1990).

The level of CDFs has also been determined in rain water. The concentrations of total tetraCDFs, total pentaCDFs, total hexaCDFs, total heptaCDFs and octaCDF in rain water from Bloomington, Indiana; Dorset, Canada; and Toronto, Canada, ranged from <0.6 to 5.7, 0.2 to 6.0, 0.7 to 6.0, <0.8 to 2.4, and <0.8 to 0.8 ppq, respectively (Eitzer and Hites 1989b; Reid et al. 1990). As expected, the concentrations of CDFs were lower in rain water from the rural site (Dorset) than from the urban site (Toronto) (Reid et al 1990). The levels of CDFs in fog have also been determined, and the congener profile was similar to rain water; however, the concentrations of CDFs were higher in fog than in rain water, due to enhanced particle scavenging by fog (Czuczwa et al. 1989).

### 5.4.3 Sediment and Soil

The maximum 2,3,7,8-tetraCDF and 2,3,7,8-substituted CDF concentrations of 0.3 ppt (ng/kg) and 11.0 ppt, respectively, were determined for sediments from an uncontaminated river (Elk River) in Minnesota (Reed et al. 1990). The maximum concentrations of total pentaCDFs, hexaCDFs, heptaCDFs, and octaCDF in sediment samples from the same river were 25.0, 12.0, 30.0, and 23.0 ppt, respectively. In all cases, the analyte was not detected in some samples. The concentrations of 2,3,7,8-tetraCDF in sediment from the lower Hudson River (New York), Cuyahoga River (Ohio), Menominee River (Wisconsin), Fox River (Wisconsin), Raisin River (Michigan), and Saginaw River (Wisconsin) ranged from 5 to 97 ppt (O'Keefe et al. 1984; Smith et al. 1990b). The concentration of 2,3,7,8-tetraCDF in sediment from an uncontaminated lake (Lake Pepin) in Wisconsin was <1 ppt, while its concentration in sediment from Lake Michigan in Green Bay (Wisconsin) was 24 ppt (Smith et al. 1990a). The concentrations of 2,3,7,8-tetraCDF in estuarine sediment varied from 15.0 ppt for an uncontaminated sediment in Long Island Sound (New York) to 4,500 ppt in sediment from an estuary adjacent to a 2,4,5- production facility in Newark, New Jersey (Bopp et al. 1991; Norwood et al. 1989). A concentration  $\leq 1,400$  ppt was also detected in sediment from New Bedford Harbor (Massachusetts) near a Superfund site (Norwood et al. 1989). The concentrations of 2,3,7,8-tetraCDF and other 2,3,7,8-substituted congeners of pentaCDF were higher in contaminated sediments than uncontaminated sediments (Norwood et al. 1989). In a survey of harbor sediment near a wood treatment facility at Thunder Bay (Ontario), the concentration of tetraCDFs and pentaCDFs were below

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the detection limit, while the levels of the higher congeners increased with the degree of chlorination (maximum of 6.5 ng/g for H<sub>6</sub>CDF to 400 ng/g for O<sub>8</sub>CDF) (McKee et al. 1990).

The concentrations (ppt) of CDFs in uncontaminated soils from the vicinity of Elk River, Minnesota were as follows (detection limit in parentheses): 2,3,7,8-tetraCDF, not detected (0.8); total tetraCDF, not detected (0.8) to 1.2; total hexaCDFs, 6.7-150; 1,2,3,4,6,7,8-heptaCDF, 26-72; total heptaCDFs, 30-260; and octaCDF, not detected (3) to 270 (Reed et al. 1990). The concentrations (ppt) of CDFs in soils adjacent to a refuse incineration facility in Hamilton, Ontario, were as follows (detection limit in parenthesis): total tetraCDFs, not detected (0.3) to 71; total pentaCDFs, not detected (1.3) to 6.0; total hexaCDFs, not detected (1.3); total heptaCDFs, not detected (1.3) to 180; and octaCDF, not detected (0.8) to 811 (McLaughlin et al. 1989). These levels were not elevated compared to urban control samples. Similarly, the levels of CDFs in soils adjacent to a municipal incinerator in England were indistinguishable from background levels (Mundy et al. 1989). On the other hand, much higher levels of CDFs were detected in soils from PCP-containing waste landfill in Germany. For example, the concentrations (ppt) of CDFs in the landfill soil were as follows: 1,2,3,7,8/1,2,3,4,8-pentaCDF, 17,000; 2,3,4,7,8-pentaCDF, 7,000; 1,2,3,4,7,8/1,2,3,4,7,9-hexaCDF, 152,000; 1,2,3,6,7,8-hexaCDF, 48,000; 1,2,3,7,8,9-hexaCDF, 3,000; and 2,3,4,6,7,8-hexaCDF, 24,000 (Hagenmaier and Berchtold 1986).

### 5.4.4 Other Environmental Media

The concentrations of CDFs in meat, fish, and dairy products purchased from a supermarket in upstate New York were 0.14-7.0, 0.07-1.14, and 0.3-5 ppt (wet weight), respectively (Schechter et al. 1993). The concentrations of 2,3,7,8-TCDF in these meat, fish, and dairy products were 0.01-0.1, 0.02-0.73, and 0.02-0.15 ppt (wet weight), respectively (Schechter et al. 1993).

A large number of data concerning the levels of CDFs in fish collected from different waters are available (De Vault et al. 1989; Gardner and White 1990; O'Keefe et al. 1984; Petty et al. 1983; Smith et al. 1990b; Zacharewski et al. 1989) and representative data on the concentrations of CDFs, particularly the 2,3,7,8-substituted congeners are presented in Table 5.4. It is evident from the table that 2,3,7,8-tetraCDF is the prevalent CDF congener present in fish, followed by 2,3,4,7,8-pentaCDF. The concentrations of CDFs are significantly higher in the hepatopancreas than in the meat of crabs and lobster. Among the Great Lakes, Lake Erie and Lake Superior are cleaner in

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TABLE 5-4. Levels of CDFs in Fish and Other Aquatic Organisms

Species	Sampling area	CDF	Concentration (ppt [wet weight])	Reference
Striped bass ( <i>Morone saxatilis</i> ) meat	Newark Bay and New York Bight	2,3,7,8-tetraCDF	68.7	Rappe et al. 1991
		total tetraCDF	92.5	
		1,2,3,7,8-/1,2,3,4,8-pentaCDF	7.1	
		2,3,4,7,8-pentaCDF	30.3	
		total pentaCDF	58.5	
		1,2,3,4,7,8-/1,2,3,4,7,9-hexaCDF	1.1	
		1,2,3,6,7,8-hexaCDF	0.4	
		1,2,3,7,8,9-hexaCDF	<0.1	
		2,3,4,6,7,8-hexaCDF	<2.6	
		total hexaCDF	3.2	
		1,2,3,4,6,7,8-heptaCDF	1.6	
		1,2,3,4,7,8,9-heptaCDF	<0.4	
		octaCDF	<3.0	
Blue crab ( <i>Callinectes sapidus</i> ) meat	Newark Bay and New York Bight	2,3,7,8-tetraCDF	13.3	Rappe et al. 1991
		total tetraCDF	148.7	
		1,2,3,7,8-/1,2,3,4,8-pentaCDF	5.5	
		2,3,4,7,8-pentaCDF	7.3	
		total pentaCDF	91.9	
		1,2,3,4,7,8-/1,2,3,4,7,9-hexaCDF	2.6	
		1,2,3,6,7,8-hexaCDF	0.6	
		1,2,3,7,8,9-hexaCDF	<0.2	
		2,3,4,6,7,8-hexaCDF	<2.3	
		total hexaCDF	9.4	
		1,2,3,4,6,7,8-heptaCDF	3.2	
		1,2,3,4,7,8,9-heptaCDF	<0.9	
		total heptaCDF	3.2	
octaCDF	<7.1			
Blue crab ( <i>Callinectes sapidus</i> ) hepatopancreas	Newark Bay and New York Bight	2,3,7,8-tetraCDF	628.3	Rappe et al. 1991
		total tetraCDF	7,049.3	
		1,2,3,7,8-/1,2,3,4,8-pentaCDF	185.7	
		2,3,4,7,8-pentaCDF	391.4	
		total pentaCDF	4,219.1	
		1,2,3,4,7,8-/1,2,3,4,7,9-hexaCDF	261.0	
		1,2,3,6,7,8-hexaCDF	43.3	
		1,2,3,7,8,9-hexaCDF	<5.0	
		2,3,4,6,7,8-hexaCDF	9.8	
		total hexaCDF	803.3	
		1,2,3,4,6,7,8-heptaCDF	184.6	
		1,2,3,4,7,8,9-heptaCDF	7.1	
		octaCDF	<51	
Lobster ( <i>Homarus americanus</i> ) meat	Newark Bay and New York Bight	2,3,7,8-tetraCDF	<0.3	Rappe et al. 1991
		total tetraCDF	27.1	
		1,2,3,7,8-/1,2,3,4,8-pentaCDF	2.4	
		2,3,4,7,8-pentaCDF	1.8	
		total pentaCDF	33.6	
		1,2,3,4,7,8-/1,2,3,4,7,9-hexaCDF	0.4	
		1,2,3,6,7,8-hexaCDF	<0.2	
		1,2,3,7,8,9-hexaCDF	<0.2	
		2,3,4,6,7,8-hexaCDF	<2.0	
		total hexaCDF	7.8	
		1,2,3,4,6,7,8-heptaCDF	<0.9	
		1,2,3,4,7,8,9-heptaCDF	<0.9	
		octaCDF	<7.7	

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TABLE 5-4. Levels of CDFs in Fish and Other Aquatic Organisms (*continued*)

Species	Sampling area	CDF	Concentration (ppt [wet weight])	Reference
Lobster ( <i>Homarus americanus</i> ) hepatopancreas	Newark Bay and New York Bight	2,3,7,8-tetraCDF	365.7	Rappe et al. 1991
		total tetraCDF	1,568.6	
		1,2,3,7,8-/1,2,3,4,8-pentaCDF	79.5	
		2,3,4,7,8-pentaCDF	179.2	
		total pentaCDF	1,008.4	
		1,2,3,4,7,8-/1,2,3,4,7,9-hexaCDF	10.7	
		1,2,3,6,7,8-hexaCDF	<6.0	
		1,2,3,7,8,9-hexaCDF	<3.0	
		2,3,4,6,7,8-hexaCDF	7.0	
		total hexaCDF	172.1	
		1,2,3,4,6,7,8-heptaCDF	<3.8	
		1,2,3,4,7,8,9-heptaCDF	<3.8	
		octaCDF	<29.2	
Lobster ( <i>Homarus americanus</i> ) digestive gland	Mipamichi Bay and Limestone Point, New Brunswick; Sydney Harbor and Port Morien, Nova Scotia	total tetraCDF	189.8	Clement et al. 1987b
		total pentaCDF	52.2	
		total hexaCDF	37.9	
		total heptaCDF	<9.1	
		octaCDF	(2-10) <sup>a</sup>	
Carp ( <i>Cyprinus carpio</i> )	Lake Ontario	total pentaCDFs	1,015	Stalling et al. 1985
		total tetraCDFs	327	
Coho salmon ( <i>Oncorhynchus kisutch</i> )				
Lake Trout ( <i>Salvelinus namaycush</i> )				
Bloater ( <i>Copegonus hoyi</i> )				
Brown trout ( <i>Salmo trutta</i> )				
Walleye trout ( <i>Stizostedion vitreum</i> <i>vitreum</i> ) (composite)				
Lake trout ( <i>Salvelinus namaycush</i> )	Lake St. Clair	2,3,7,8-tetraCDF	24.8	Zacharewski et al. 1989
		1,2,3,7,8-pentaCDF	3.7	
		2,3,4,7,8-pentaCDF	5.4	
		1,2,3,4,7,8-hexaCDF	0.5	
		1,2,3,6,7,8-hexaCDF	0.5	
		1,2,3,7,8,9-hexaCDF	<0.05	
		2,3,4,6,7,8-hexaCDF	0.9	
		1,2,3,4,6,7,8-heptaCDF	0.5	
		1,2,3,4,7,8,9-heptaCDF	<0.2	
		octaCDF	0.8	
Walleye trout ( <i>S. vitreum vitreum</i> ) (composite)	Lake St. Clair	2,3,7,8-tetraCDF	34.8	Zacharewski et al. 1989
		1,2,3,7,8-pentaCDF	4.9	
		2,3,4,7,8-pentaCDF	10.2	
		1,2,3,4,7,8-hexaCDF	1.4	
		1,2,3,6,7,8-hexaCDF	1.1	
		1,2,3,7,8,9-hexaCDF	<0.05	
		2,3,4,6,7,8-hexaCDF	1.3	
		1,2,3,4,6,7,8-heptaCDF	0.9	
		1,2,3,4,7,8,9-heptaCDF	<0.2	
		octaCDF	<2.0	

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TABLE 5-4. Levels of CDFs in Fish and Other Aquatic Organisms (*continued*)

Species	Sampling area	CDF	Concentration (ppt [wet weight])	Reference	
Lake trout ( <i>Salvelinus namaycush</i> )	Lake Ontario	2,3,7,8-tetraCDF	20.6	Zacharewski et al. 1989	
		1,2,3,7,8-pentaCDF	4.7		
Walleye trout ( <i>S. vitreum vitreum</i> ) (composite)	Lake Ontario	2,3,4,7,8-pentaCDF	20.2		
		1,2,3,4,7,8-hexaCDF	12.7		
		1,2,3,6,7,8-hexaCDF	1.9		
		1,2,3,7,8,9-hexaCDF	<0.1		
		2,3,4,6,7,8-hexaCDF	1.2		
		1,2,3,4,6,7,8-heptaCDF	0.9		
		1,2,3,4,7,8,9-heptaCDF octaCDF	<0.1 <0.9		
Lake trout ( <i>Salvelinus namaycush</i> )	Lake Huron	2,3,7,8-tetraCDF	22.8	Zacharewski et al. 1989	
		1,2,3,7,8-pentaCDF	6.2		
		Walleye trout ( <i>S. vitreum vitreum</i> ) (composite)	2,3,4,7,8-pentaCDF		12.8
		1,2,3,4,7,8-hexaCDF	1.6		
		1,2,3,6,7,8-hexaCDF	1.2		
		1,2,3,7,8,9-hexaCDF	<0.07		
		2,3,4,6,7,8-hexaCDF	1.4		
		1,2,3,4,6,7,8-heptaCDF 1,2,3,4,7,8,9-heptaCDF octaCDF	0.5 <0.1 <0.3		
Lake trout ( <i>Salvelinus namaycush</i> )	Lake Erie	2,3,7,8-tetraCDF	11.3	Zacharewski et al. 1989	
		1,2,3,7,8-pentaCDF	1.4		
		Walleye trout ( <i>S. vitreum vitreum</i> ) (composite)	2,3,4,7,8-pentaCDF		2.7
		1,2,3,4,7,8-hexaCDF	0.2		
		1,2,3,6,7,8-hexaCDF	0.3		
		1,2,3,7,8,9-hexaCDF	<0.1		
		2,3,4,6,7,8-hexaCDF	0.5		
		1,2,3,4,6,7,8-heptaCDF	0.6		
		1,2,3,4,7,8,9-heptaCDF octaCDF	<0.2 <1.1		
Lake trout ( <i>Salvelinus namaycush</i> )	Lake Superior	2,3,7,8-tetraCDF	15.7	Zacharewski et al. 1989	
		1,2,3,7,8-pentaCDF	1.7		
		Walleye trout ( <i>S. vitreum vitreum</i> ) (composite)	2,3,4,7,8-pentaCDF		2.8
		1,2,3,4,7,8-hexaCDF	0.5		
		1,2,3,6,7,8-hexaCDF	0.3		
		1,2,3,7,8,9-hexaCDF	<0.06		
		2,3,4,6,7,8-hexaCDF	0.4		
		1,2,3,4,6,7,8-heptaCDF	0.4		
		1,2,3,4,7,8,9-heptaCDF octaCDF	<0.2 <0.8		

<sup>a</sup>Detection limit

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terms of CDF contamination than the other three lakes (see Table 5-4). The mean level of total 2,3,7,8-substituted CDFs in gutted whole fish from the St. Maurice River, Quebec, caught immediately downstream of a kraft mill was 260 pg/g (ppt), but the level declined to 112 ppt at 95 km downstream (Hodson et al. 1993). Data on 2,3,7,8-substituted CDF congeners in aquatic fauna were analyzed by principal component analysis. In this method, the congener profile in aquatic fauna can be used to predict the principal source of contamination such as pulp mill effluent, deposition from combustion source, and effluent from magnesium production (Zitko 1992).

CDF levels have been determined in a multitude of environmental samples, including cork and wall paper (Frommberger 1991); foods of animal and vegetable origin (Fürst et al. 1990; Glidden et al. 1990; Ryan et al. 1985b; Schecter et al. 1989b); commercial detergents and related products (Rappe et al. 1990b); coffee filters (Fricker and Hardy 1990; LeBel et al. 1992; Wiberg et al. 1989); several consumer products, including diapers, shopping bags, cigarette paper, tampons, and cotton (LeBel et al. 1992; Wiberg et al. 1989); paper products (LeBel et al. 1992; Keenan and Sullivan 1989); latex nipples (Gorski 1981); pine needles (Safe et al. 1992); marine mammals (Norstrom et al. 1990); and eggs of Great Blue Herons (Elliott et al. 1989). Comparison of data for bulk milk and milk in cartons indicates that 2,3,7,8-tetraCDF migrates in small amounts from some bleached paper cartons to bulk milk (Glidden et al. 1990; Ryan et al. 1992). The transfer of CDFs from cardboard and plastic-coated bleached paperboard milk cartons to bulk milk has been observed by other investigators (Beck et al. 1990; Ryan et al. 1992). The mean concentrations of tetraCDF in bond paper composite, paper towel composite, and composite diaper pulp were 265, 33, and 8 ppt, respectively (Keenan and Sullivan 1989). The concentrations of 2,3,7,8-tetraCDF in bleached coffee filters, shopping bags, and tampons were 22, 7.6, and 0.9 ppt, respectively (Wieberg et al. 1989). On the other hand, no CDFs (detection limit  $\leq 1$  ppt) were detected in commercially available coffee filters in the United States (Fricker and Hardy 1990).

The percent migration of 2,3,7,8-tetraCDF from commercial articles of food contact products (e.g., milk packaged in cartons, coffee filters, paper cups and plates, popcorn bags) to foods may range from 0.1% to 35% under normal use conditions (Cramer et al. 1991). Therefore, the concentration of CDFs in packaged whole milk depends on the packaging material. Usually, commercial milk packaged in glass contains less CDFs than milk packaged in cartons (Rappe et al. 1990c). The mean concentration of 2,3,7,8-tetraCDF in whole milk packaged in cartons from California was 0.45 pg/g wet weight (Hayward et al. 1991). All other 2,3,7,8-substituted CDFs were either not detected or detected at very



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low levels (Hayward et al. 1991). Commercial milk from Sweden contained significant levels of other 2,3,7,8-substituted CDFs (Rappe et al. 1990c). The intake of CDDs/CDFs from all bleached paper food-contact articles was estimated to be 8.8 pg toxic equivalent (TE)/person/day (see Section 2.4) (Cramer et al. 1991). However, with the reduction of CDD/CDF levels in paper pulp available at the present time, the exposure may be considerably less than this estimate (Cramer et al. 1991).

The levels of CDFs in the tissues of aquatic and terrestrial birds and in dolphins from contaminated areas are also available (Ankley et al. 1993; Jarman et al. 1993; Jones et al. 1993; Kuehl et al. 1991). Generally, CDDs/CDFs contribute a small portion of the total TCDD-equivalent toxicity in the aquatic birds, while most of the TCDD-equivalent toxicity is contributed by non-*ortho*-substituted PCBs. In terrestrial birds, the contribution of CDDs/CDFs towards the total TCDD-equivalent toxicity is greater than in aquatic birds (Jones et al. 1993).

### 5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

The general population is exposed to CDFs by inhalation, ingestion of drinking water, consumption of food, and through the use of certain consumer products. Since the concentrations of CDFs in ambient air and drinking water are low (see Section 5.4), the intake of CDFs by inhalation and ingestion of drinking water would be low. It has been shown that inhalation exposure was not a major pathway of human exposure to CDFs (Travis and Hattermer-Frey 1989). The estimate that inhalation exposure contributes 2% of the total average human intake of CDDs/CDFs (Hattermer-Frey and Travis 1989) has been questioned as too low by other investigators (Goldfarb and Harrad 1991). The concentrations of CDD/CDF in foods consumed by a typical German were determined, and the intake of total CDD/CDF from food expressed as TE (see Section 2.4) to 2,3,7,8-TCDD was estimated to be 1.2 pg TE/kg body weight/day (International dioxin toxic equivalent) (Fürst et al. 1990). The estimated intake of CDD/CDF from typical Canadian food was 1.5 pg TE/kg body weight/day (Birmingham et al. 1989a). From detailed determinations of the levels of TCDD/TCDF in air, water, soil, food, and consumer products in Canada, the estimated intakes of CDD/CDF were 0.07 pg TE/kg body weight/day from air, 0.002 pg TE/kg body weight/day from water, 0.02 pg TE/kg body weight/day from ingestion of soil, 2.328 pg TE/kg body weight/day from food, and 0.005 pg TE/kg body weight/day from consumer products (Birmingham et al. 1989b). Therefore, based on toxic equivalency, inhalation constitutes 2.9% of the estimated total intake, ingestion of drinking water constitutes 0.1%, ingestion of soil 0.8%, ingestion of food 96% and consumer products the residual

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0.2% of the estimated total daily intake of TCDDs/TCDFs. The estimated daily intakes of 2,3,7,8-tetraCDF and 2,3,4,7,8-pentaCDF in the United States are 0.05 and 0.068 ng, respectively (Graham et al. 1986), but data for the daily intake of total CDFs and all the 2,3,7,8-substituted CDFs from the different routes of exposure in the United States were not located. However, data for the daily intake of the combination of CDDs and CDFs from different exposure routes in Canada are available. The total average daily intake of CDDs/CDFs in the industrialized countries is estimated at 1.9 pg TE/kg body weight/day (Fishbein et al. 1992).

Occupational exposure to CDFs may occur. For example, the level of CDFs in the blood of workers in the saw mill industry (exposure to 2,3,4,6-tetrachlorophenolate), textile industry (PCP exposure during fabric impregnation), and leather industry (PCP exposure during tanning) were measured, and the pattern of CDFs in the blood of exposed workers correlated with the CDFs in the exposed compounds (Rappe and Buser 1981). The intake from dermal exposure to CDD/CDF for workers in pulp mill (exposing hands in wet pulp) can be  $\leq 7$  pg TE/day (Kelada 1990). The concentrations of CDFs in adipose tissues of workers of a chemical plant (producing chlorophenols and 2,4,5-trichlorophenol among other chemicals) was much higher than those of a control population (Beck et al. 1989). Small but significantly ( $p < 0.05$ ) higher levels of 2,3,4,7,8-pentaCDF and 1,2,3,4,7,8-hexaCDF were found in lipid-adjusted serum of workers in a pesticide plant (2,4,5-trichlorophenol or its derivatives) compared to the levels in a control group (Piacitelli et al. 1992). Occupational exposure to CDFs may also occur in factories manufacturing and repairing transformers and capacitors, in factories with heat exchange systems containing PCBs, in factories using casting waxes containing PCBs or in industrial incinerators where materials containing chlorinated phenols, PCBs, and PCB ethers are incinerated (Rappe et al. 1979). The concentrations of CDDs/CDFs expressed as 2,3,7,8-tetraCDD TE in air of a municipal incinerator and an electrical transformer metal reclamation plant were significantly higher than ambient levels for these compounds (Crandall et al. 1992). However, no significant risk of exposure to tetraCDFs was found in modern resource recovery plants in Bristol, Connecticut, and Hillsborough County, Florida (Hahn et al. 1989).

Numerous data are available regarding the levels of CDFs in body tissue and fluids of exposed and background (no obvious source of exposure) population (Nagayama et al. 1977; Ryan 1986; Schecter et al. 1987; Tiernan et al. 1984; Young 1984). CDFs are lipophilic and tend to concentrate in fatty tissues. A positive correlation between 2,3,4,7,8-pentaCDF, 1,2,3,4,7,8-hexaCDF, 2,3,4,6,7,8-hexaCDF in adipose tissue and age of donor (higher concentrations at older age) was found (Le Bel et al. 1990).

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A similar correlation between 1,2,3,4,7,8-/1,2,3,6,7,8-hexaCDF and age of donor was also reported among the urban population in California (Stanley et al. 1989). No significant correlation between either the level of 2,3,7,8-tetraCDF, 1,2,3,4,6,7,8-heptaCDF, and octaCDF in adipose tissue and age of donor or between any CDFs and sex was discernable (Le Bel et al. 1990). The latter findings are different from the case of 2,3,7,8-tetraCDD where higher concentrations of 2,3,7,8-tetraCDD were detected in female donors than male donors and a positive correlation between 2,3,7,8-tetraCDD levels and age of donors was found (Patterson et al. 1986). The average levels of 2,3,7,8-substituted CDFs in human fat of exposed and background populations of different countries have been reviewed (Jensen 1987). More recent data for the background levels of 2,3,7,8-substituted CDFs in human adipose tissues from different countries are given in Table 5-5. A comparative study of CDF contents in liver and adipose tissue of control humans (Germany) showed that on a fat basis, the concentrations of CDFs were higher in the liver than in adipose tissue (Beck et al. 1990; Thoma et al. 1990).

Several studies indicate that the levels of CDFs in the adipose tissue of exposed populations exceeds the levels detected in background or control populations. For example, adipose tissue levels of CDFs in an exposed patient of the Binghamton State Office Building (Schechter et al. 1985a, 1985c, 1986; Schechter and Ryan 1989), Yusho victims in Japan (Miyata et al. 1989; Ryan et al. 1987a), and three patients with fatal PCP poisoning (Ryan et al. 1987b) are all higher than control populations. However, no conclusive evidence of higher CDF exposure was found in seven people exposed during the Missouri dioxin episode and in Vietnam veterans (Kang et al. 1991; Needham et al. 1987). Certain municipal incinerator workers, such as those engaged in ash cleaning are exposed to higher levels of CDFs. The whole blood level of total CDFs in pooled blood of 56 such workers was 102.8 ppt (on lipid basis) compared to 47.0 ppt in pooled blood of 14 control subjects (Schechter et al. 1991c). The concentrations of 2,3,7,8-tetraCDF, 1,2,3,7,8-pentaCDF, 1,2,3,4,7,8-hexaCDF, 1,2,3,7,8,9-hexaCDF, 2,3,4,6,7,8-hexaCDF, 1,2,3,4,7,8,9-heptaCDF, and octaCDF were also higher in the pooled blood of workers compared to pooled blood of control subjects. No information on CDF levels in the tissues of sport fishermen or subsistence fishermen in the United States is available (Kimbrough 1991), although the levels of 1,2,3,4,7,8-hexaCDF and 1,2,3,4,6,7,8-heptaCDF in the serum lipids of people in Baltic regions who eat fish regularly was higher than those of a control population (Svensson et al. 1991). The estimated bioconcentration factor for 2,3,7,8-tetraCDF in human fat (on lipid basis) was 591 and was higher than other chlorinated aromatics including PCBs, octachlorostyrene, OCDD, and octaCDF (Geyer et al. 1987).

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**TABLE 5-5. Levels of CDFs in Human Adipose Tissue**

Congener	Sample source and mean concentrations (ppt on fat basis)				
	Japan <sup>a</sup>	Sweden <sup>a</sup>	Germany <sup>a</sup>	Canada <sup>b</sup>	United States <sup>c</sup>
2,3,7,8-tetraCDF	9	3.9	0.9	3.3	9.1 <sup>d</sup>
2,3,4,7,8-pentaCDF	25	54	44	33.3	40.0 <sup>e</sup>
1,2,3,4,7,8-hexaCDF	15	6	10	} 37 <sup>f</sup>	9.3
1,2,3,6,7,8-hexaCDF	14	5	6.7		5.4
2,3,4,6,7,8-hexaCDF	8	2	3.8	5.2	1.8
1,2,3,4,6,7,8-heptaCDF	No data	11	19.5	37.1	21.0 <sup>e</sup>
octaCDF	No data	4	<1	12.0	60.0 <sup>d</sup>

<sup>a</sup>Rappe et al. 1987<sup>b</sup>Lebel et al. 1990<sup>c</sup>Derived from Rappe 1989, unless otherwise stated<sup>d</sup>Stanley et al. 1986<sup>e</sup>EPA 1989<sup>f</sup>These isomers were not separated

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A large number of data is available on the levels of CDFs in human milk from different countries (Dewailly et al. 1991; Schechter and Gasiewicz 1987a, 1987b; Schechter et al. 1989b). In general, CDF levels seem to be lower in the less industrialized countries than in more industrialized countries. Certain differences in specific isomers may exist in different countries, reflecting sources of contamination (Schechter et al. 1989d). The levels of CDFs in human milk derived from different countries are shown in Table 5-6. Levels of CDFs in human milk from other countries including South and North Vietnam and the former Soviet Union are also available (Schechter et al. 1989d, 1990c). From these data, it appears that the most prevalent congener in human milk is 2,3,4,7,8-pentaCDF, followed by 1,2,3,4,7,8-hexaCDF. In one study, no correlation was found between consumption of contaminated fish and accumulation of CDFs in the milk from nursing mothers (Hayward et al. 1989). During the breast feeding period, the level of CDFs in milk lipid is highest in the first week and slowly decreases thereafter (Beck et al. 1992; Fürst et al. 1989b). The level of CDFs in breast milk is highest for women having their first child and distinctly lower for women having their second and third child (Beck et al. 1992).

The levels of CDFs in human whole blood from various countries are listed in Table 5-7. Plasma levels of CDFs in people from different countries have been measured and the individual congener concentrations on a fat basis in control populations (not exposed to obvious sources of CDFs) vary from a minimum of <0.1 ppt for 2,3,7,8-tetraCDF to a maximum of 80 ppt for 2,3,4,7,8-pentaCDF (Chang et al. 1990; Nygren et al. 1988; Rappe 1991; Schechter 1991). The highest 2,3,4,7,8-pentaCDF concentration was found in a high fish-consuming population around the Baltic Sea (Svensson et al. 1991). The most prevalent congener in human plasma lipids in the United States was 1,2,3,4,6,7,8-heptaCDF, followed by 1,2,3,7,8- and 2,3,4,7,8-pentaCDF. This pattern was reversed in the plasma lipids of Swedish people where 2,3,4,7,8-pentaCDF was the prevalent congener followed by 1,2,3,4,6,7,8-heptaCDF (Chang et al. 1990). A similar pattern of high 2,3,4,7,8-pentaCDF level in blood was observed in human blood from Germany (Schechter et al. 1991b). Using a multivariate analysis, the concentration of CDFs in the plasma of exposed Vietnam veterans from the United States were determined to be slightly higher than matched controls (Nygren et al. 1988). It was also determined that higher chlorinated CDFs do not appear to partition according to the lipid content of whole blood. As the degree of chlorination increases, the percent associated with the protein fraction also increases. Therefore, it was concluded that partitioning of higher chlorinated CDFs is not dependent on lipid content, but specific binding to the protein fraction of serum and whole blood (Patterson et al. 1989; Schechter et al. 1991a).

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**TABLE 5-6. Levels of CDFs in Human Milk**

Congener	Sample source and mean concentration (ppt on fat basis)			
	Sweden <sup>a</sup>	West Germany <sup>b</sup>	United States <sup>c</sup>	Japan <sup>d</sup>
2,3,7,8-tetraCDF	4.2	1.7	2.85	2.9
1,2,3,7,8-pentaCDF	<1.0	0.5	0.45	1.8
2,3,4,7,8-pentaCDF	21.3	26.7	7.3	23.0
1,2,3,4,7,8-hexaCDF	4.7	7.8	5.55	3.9
1,2,3,6,7,8-hexaCDF	3.4	6.5	3.2	2.5
2,3,4,6,7,8-hexaCDF	1.4	3.4	1.85	1.9
1,2,3,4,6,7,8-heptaCDF	7.4	5.5	4.05	3.3
octaCDF	3.2	1.4	4.1	<2.0

<sup>a</sup>Rappe 1987<sup>b</sup>Fürst et al. 1992<sup>c</sup>Schechter et al. 1991<sup>d</sup>Rappe 1992

TABLE 5-7. Mean Levels of CDFs in Human Whole Blood (ppt Lipid) From Various Countries<sup>a</sup>

Congener	Germany		USA	Vietnam		
	N=85	Standard deviation	n=100 <sup>b</sup>	Ho Chi Minh City N=50 <sup>b</sup>	Dong Nai N=33 <sup>b</sup>	Hanoi N=32 <sup>b</sup>
2,3,7,8-tetraCDF	2.5	1.8	3.1	4.6	3.9	2.6
1,2,3,7,8-pentaCDF	Not detected		2.8	3.2	2.9	<1.1
2,3,4,7,8-pentaCDF	36.8	16.8	13.0	21	22	8.6
total pentaCDF	36.8		15.8	24.2	24.9	9.2
1,2,3,4,7,8-hexaCDF	17.5 <sup>c</sup>		15.0	14.0	27.0	6.5
1,2,3,6,7,8-hexaCDF	13.7 <sup>c</sup>		14.0	11.0	27.0	6.4
1,2,3,7,8,9-hexaCDF	Not detected <sup>c</sup>		Not detected (1.2) <sup>d</sup>	Not detected (1.4) <sup>d</sup>	Not detected (1.2) <sup>d</sup>	Not detected (1.1) <sup>d</sup>
2,3,4,6,7,8-hexaCDF	Not detected <sup>c</sup>		3.6	3.3	5	1.8
total hexaCDF	32.1 <sup>c</sup>	20.8	32.6	28.3	59	14.7
1,2,3,4,6,7,8-heptaCDF	23.8 <sup>c</sup>		36.0	22	31	12
1,2,3,4,7,8,9-heptaCDF	Not detected <sup>c</sup>		Not detected (1.8) <sup>d</sup>	2.6	2.7	<1.2
total hepta-CDF	24.1 <sup>c</sup>	12.0	36.0	24.6	33.7	12.6
octaCDF	5.5	3.5	4.2	Not detected (5.5) <sup>d</sup>	11.0	<3.0

<sup>a</sup>Schecter 1991<sup>b</sup>These samples were pooled into one.<sup>c</sup>These values are derived from Pöpke et al. 1989.<sup>d</sup>The values in the parenthesis are the detection limits.

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### 5.6 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Workers in industries that manufacture or use chemicals contaminated with CDFs are one segment of the population at high risk for CDF exposure (see Section 5.5). Among the general population, especially in more industrial countries, higher exposures to CDFs may occur among populations that consume high amounts of fatty fish contaminated with high levels of CDFs. This conclusion is based on a study of plasma CDF levels in fishermen and workers in the fish industry in Sweden (Svensson et al. 1991). However, the clinical significance of such exposures remains uncertain. Some emergency situations, such as accidental malfunction, fires, and explosions involving PCB capacitors and transformers may entail high exposures to CDFs (see section 5.4) (Vainio et al. 1989). Several 2,3,7,8-substituted CDFs are present in human milk at concentrations much higher than those in cow milk (Vainio et al. 1989). Therefore, consumption of human milk containing high levels of CDFs may pose a risk to infants consuming breast milk (Schechter and Gasiewicz 1987a, 1987b). Because of the relatively short period of intake and the accepted benefits of breastfeeding, the World Health Organization did not recommend limitations on breastfeeding (Vainio et al. 1989). Another population group that may be exposed to higher concentrations of CDFs includes people who live adjacent to uncontrolled landfill sites with soils containing high concentrations of CDFs (see Section 5.2). However, data correlating the levels of CDFs in body tissues or fluids (e.g., blood) with levels of exposure among this population group was not located.

### 5.7 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 CDFs is available. Where adequate information is not available, ATSDR, in conjunction with the 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 CDFs.

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



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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.

### 5.7.1 Identification of Data Needs

**Physical and Chemical Properties.** The synthesis and purification of a specific CDF congener is a difficult task. The low water solubilities and vapor pressures contribute to the difficulty in determining the basic physico-chemical properties of the CDFs. In addition, the toxicity of some of the compounds requires extra care in their handling. Consequently, experimental data regarding the fundamental physical and chemical properties, such as melting point, boiling point, vapor pressure, and chemical reactivity for most of the CDF congeners remain unknown (see Table 3-2). Determination of experimental data on water solubility,  $K_{OW}$ , Henry's law constant, and  $K_{OC}$ , particularly for the 2,3,7,8-substituted CDFs (because of higher toxicity) would be useful for predicting the environmental fates and transport of these compounds.

**Production, Import/Export, Use, Release, and Disposal.** CDFs are produced on a small scale for chemical and biological laboratory use. These compounds have no other known use. Therefore, further development of data on the production, import/export, and use of these compounds would not be useful. The release of CDFs in the environment is one of the most intensively studied subjects in the literature (see Section 5.2). The regulations governing the disposal of CDF-containing wastes are well defined (see Section 4.4). However, it would be helpful to develop alternative methods of waste disposal that would not require treating the wastes at high temperatures or with harsh chemicals. Development of a biological degradation process capable of efficiently decontaminating CDF wastes within reasonable time would be useful.

**Environmental Fate.** The understanding of the environmental fate and transport of CDF has made major strides in the past few years (Atkinson 1991; Koester and Hites 1992). The estimated lifetimes of CDFs in air are such (see Section 5.3.2) that they will transport long distances in the air. Sediment will be the ultimate sink for CDFs present in air and water (Czuczwa and Hites 1986b). However, it would be helpful to develop more data on the photodegradability of CDFs present in the vapor phase in the air and in the adsorbed state as they are naturally present in water. The development of additional data regarding the biodegradability of these compounds in soil would also be useful.

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**Bioavailability from Environmental Media.** No data were located in the literature that either determine or estimate the bioavailability of CDFs from air, water, or soil as a result of inhalation of air, ingestion of water or soil, or dermal contact with soil. However, it is known that the CDFs would be present predominantly in the particulate phase in the air (Hites 1990), and in the adsorbed states in water and soil (Carsch et al. 1986; Czuczwa and Hites 1986b). Because of the strong adsorption of CDFs in soil, the bioavailability of these compounds due to dermal contact with soil is expected to be low. Since CDFs are present predominantly in the particulate-sorbed state in both air and in water, the bioavailability of CDFs from these media, as a result of inhalation exposure and ingestion of drinking water or soil, would be lower than the bioavailability of the compounds in the unadsorbed states (e.g., administered in solution or vapor form).

**Food Chain Bioaccumulation.** CDDs are bioconcentrated in aquatic organisms and in marine and terrestrial animals, but the magnitude of bioconcentration is lower than expected from predictive methods (e.g.,  $K_{OW}$ ). This is due to the fact that, at least some of these compounds are metabolized in aquatic organisms and animals (Frank and Schrap 1990; Norstrom et al. 1990; Opperhuizen and Sijm 1990). It would be helpful to develop a method that would circumvent the principal difficulty in determining the bioconcentration factors in aquatic organisms, that is, to develop a method for determining low concentrations of CDFs present in the solution phase in water (as opposed to the adsorbed state in particles in water). Development of more data regarding biomagnification of CDFs from lower trophic to higher trophic animals would also be useful. It would be useful to develop data on the biotransfer ratio of CDFs from soils to different plants.

**Exposure Levels in Environmental Media.** Data on the levels of CDFs in air, water, soil, sediment, and vegetation have been extensively developed (see Section 5.4). There is a paucity of data on the level of CDFs in drinking water. More comprehensive data on the levels of CDFs in the air and water of people who live near CDF-containing hazardous waste sites would be desirable. It would also be useful to develop data on typical daily intake of CDFs for a person in the United States due to inhalation of ambient air, and ingestion of drinking water and particularly food.

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

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**Exposure Levels in Humans.** The levels of CDFs in tissues and body fluids of both exposed and control population groups in the United States have been extensively studied (see Section 5.4.4). However, more data on the levels of CDFs in body fluids and tissues of specific groups from the general population, such as those living near hazardous waste sites containing CDFs or those eating large amounts of fish, would be useful. This information is necessary for assessing the need to conduct health studies on these populations.

**Exposure Registries.** No exposure registries for CDFs were located. These substances are not currently on a subregistry of the National Exposure Registry. These substances will be considered in the future when chemical selection is made for subregistries 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 a substance.

### 5.7.2 On-going Studies

A study sponsored by the U.S. Department of Agriculture is being conducted by B. Eitzer in Connecticut to determine the levels and sources of CDFs in Housatonic River sediments (FEDRIP 1992).

Dr. Miller of the University of Nevada is conducting a study to determine the chemical and biochemical processes that affect the persistence of CDFs and their transformation products in plants, animals, and other environmental compartments (FEDRIP 1992).

A study is being conducted by the Arkansas Department of Health in collaboration with ATSDR/Division of Health Studies to determine whether people living near an incineration site are exposed to higher than background concentrations of CDFs and related compounds. It will study whether statistically significant higher levels of 2,3,7,8-substituted CDDs and CDFs are found in blood of residents compared with levels in the background population.

Other studies include investigations being conducted by Dr. A. Schecter (Clinical Campus of State University of New York (SUNY) Health Science Center in Binghamton, New York) on the levels of CDFs in human tissue and environmental samples from South and North Vietnam. Dr. Schecter is also conducting investigations in Russia to determine population exposure to CDFs due to a paper and

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pulp mill in a remote part of Russia and occupational exposure to CDFs in another part of Russia. He is also conducting a serial tissue analysis of an occupationally exposed worker in Binghamton, New York, to determine the rate of decrease of several CDF congeners (Schechter 1992).