

Chapter 2 Profiles of the POPs

The scientific literature on persistent organic pollutants (POPs) is voluminous, complex, and intriguing. These are some of the most researched chemicals in existence, yet that research has served to stimulate even more investigation, down to their effects on the intricacies of DNA replication control and cellular differentiation. With this as the backdrop, this chapter seeks to demystify what these chemicals are, why they were developed, what they do, what was discovered about their toxic effects, and why they are the focus of global action.

Twelve substances or substance groups were initially included under the Stockholm Convention on Persistent Organic Pollutants (Table 2-1). These POPs all exhibit the properties of prolonged environmental persistence, bioaccumulation, toxicity, and the potential for long-range environmental transport (see Chapter 9). They can be divided into three general categories of pesticides, industrial chemicals, and unintentional byproducts. Several of the POPs occur under more than one category, such as hexachlorobenzene, which has been used as a fungicide and an industrial feedstock and product, and is also emitted as an unintentional byproduct from incineration and the manufacture of other pesticides. Several of the substances represent groups of chemicals with similar structures and properties, namely the congener families of polychlorinated dioxins and furans, polychlorinated biphenyls (PCBs), and the mixed chlorinated camphenes (toxaphene).

This chapter provides a narrative introduction to each of the POPs. To avoid repetition, narratives are combined for similar chemical groups, such as the cyclodiene pesticides and polychlorinated dioxins and furans. More detailed information can be found from a variety of federal databases and texts, examples of which are included in an appendix at the end of this chapter. Each chemical description

includes a table of technical and numerical data on the POP. These tabular data categories, an explanation of their relevance to understanding the chemical's potential environmental impact, and the information sources (unless otherwise specified in the table) are as follows:

- * Chemical information and structure (SETAC, 2000; a subset of chemical structure drawings is used with permission of SETAC)
- * Environmental persistence estimates, recognizing the wide variability of these parameters in different physical environments (i.e., light, temperature, moisture, bacteria, etc.) (SETAC, 2000)
- * Chemical properties important for evaluating the potential for long-range environmental transport, such as the vapor pressure and the air-water partition coefficient or Henry's Law constant, which measures the pressure in air over the concentration in water at a constant temperature (Ritter et al., 1995). A high air-water partition coefficient indicates that movement of the chemical is facilitated to the vapor phase, increasing the likelihood that it can be transported long-range in the atmosphere.
- * Bioaccumulation, through both the octanol-water partition coefficient (equilibrium concentration in an n-octanol solution over the concentration in contiguous water; SETAC, 2000) and measured estimates from fish species (summarized in Rodan et al., 1999; whole body lipid-adjusted to 5%)
- * Acute toxicity in rats, estimated as the acute dose that would kill half the experimental rats (lethal dose 50%; LD₅₀), noting that within species there is a spectrum of individual resistance to toxic effects, and that between-species LD₅₀ values can vary to a large degree (Meister, 2000)

Table 2-1. The 12 POPs under the Stockholm Convention and their current U.S. regulatory status

POP	2001 Regulatory Status for Production and/or Emissions under TSCA, ^a FIFRA, ^b CAA, ^c and CWA ^d
Aldrin	<ul style="list-style-type: none"> * No registrations, most uses canceled in 1969, all uses by 1987 * No production, import, or export * All tolerances on food crops revoked in 1986 * Priority toxic pollutant under the CWA
Chlordane	<ul style="list-style-type: none"> * No registrations, most uses canceled in 1978, all uses by 1988 * No production (stopped in 1997), import, or export * All tolerances on food revoked in 1986 * Regulated as a hazardous air pollutant (CAA) * Priority toxic pollutant under the CWA
Dichlorodiphenyl-trichloroethane (DDT)	<ul style="list-style-type: none"> * No registrations, most uses canceled in 1972, all uses by 1989 * No production, import, or export * All tolerances on food and feed crops revoked in 1986 * The metabolite DDE regulated as a hazardous air pollutant (CAA) * DDT, <i>p,p'</i>-DDE, and <i>p,p'</i>-DDD priority toxic pollutants under the CWA
Dieldrin	<ul style="list-style-type: none"> * No registrations, most uses canceled in 1969, all uses by 1987 * No production, import, or export * All tolerances on food crops revoked in 1986 * Priority toxic pollutant under the CWA
Endrin	<ul style="list-style-type: none"> * No registrations, most uses canceled in 1979, all uses by 1984 * No production, import, or export * Priority toxic pollutant under the CWA
Heptachlor	<ul style="list-style-type: none"> * Most uses canceled by 1978, registrant voluntarily canceled use to control fire ants in underground cable boxes in early 2000 * No production (stopped in 1997), import, or export * All tolerances on food crops revoked in 1989 * Regulated as a hazardous air pollutant (CAA) * Heptachlor and heptachlor epoxide priority toxic pollutants under the CWA
Hexachlorobenzene (HCB)	<ul style="list-style-type: none"> * No registrations as a pesticide, all uses canceled by 1985 * No production, import, or export as a pesticide * Production and use as a closed-system intermediate consistent with the Stockholm Convention * Regulated as a hazardous air pollutant (CAA) * Priority toxic pollutant under the CWA
Mirex	<ul style="list-style-type: none"> * No registrations, all uses canceled by 1977 * No production, import, or export * Recommended nonpriority toxic water pollutant (U.S. EPA, 1999^e)
Polychlorinated biphenyls (PCBs)	<ul style="list-style-type: none"> * No manufacture and new use prohibited in 1978 (TSCA) * Regulated as a hazardous air pollutant (CAA) * Priority toxic pollutant under the CWA
Polychlorinated dibenzo- <i>p</i> -dioxins (dioxins)	<ul style="list-style-type: none"> * As a contaminant in production, regulated under TSCA and FIFRA * Hazardous air pollutant and emission standards regulated under the CAA * Dioxin effluent limits and 2,3,7,8-TCDD a priority toxic pollutant under the CWA
Polychlorinated dibenzofurans (furans)	<ul style="list-style-type: none"> * As a contaminant in production, regulated under TSCA and FIFRA * Hazardous air pollutant and emission standards regulated under the CAA * Effluent limits regulated under the CWA
Toxaphene	<ul style="list-style-type: none"> * No registrations, most uses canceled in 1982, all uses by 1990 * No production, import, or export * All tolerances on food crops revoked in 1993 * Regulated as a hazardous air pollutant (CAA) * Priority toxic pollutant under the CWA

^a Toxic Substances Control Act^b Federal Insecticide, Fungicide, and Rodenticide Act^c Clean Air Act^d Clean Water Act^e National Recommended Water Quality Criteria-Correction. US-EPA 822-Z-99-001. Office of Water.

* Chronic toxicity reference dose (RfD) in the United States, which is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. The RfD is based on experimental or epidemiologically determined doses at which there is no statistically or biologically significant indication of toxic effects. RfDs include uncertainty factors to account for animal-to-human interspecies differences, variability between humans, and database deficiencies (www.epa.gov/IRIS)

* History of production and use in the United States, providing a brief summary of historical manufacturing data, years during which these activities occurred, and when they were curtailed and ultimately ceased (UNEP, 2000)

* International production and use, summarizing data collected by the United Nations Environment Programme (UNEP) during the POPs negotiation and from national requests for chemical-specific use exemptions under the Stockholm Convention (UNEP, 2000)

1. Intentionally Produced POPs: Pesticides

The nine pesticide POPs were introduced into commercial use after World War II and dramatically changed modern pest control. These compounds were effective against a wide range of pests, often for extended periods of time. Ironically, the chemical property of long environmental persistence that enhanced the pesticides' efficacies also increased their environmental destructiveness. Repeated applications of the pesticide POPs (Figure 2-1) led to widespread contamination, impacts on non-target species, and residues in foods.

Cyclodiene Insecticides

Aldrin, dieldrin, endrin, chlordane, heptachlor, and mirex are all cyclodiene organochlorine insecticides. They are highly persistent compounds, exhibiting especially high resistance to degradation



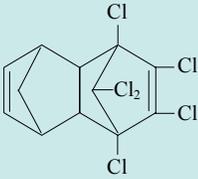
Figure 2-1. Aerial spraying of pesticides on crops.

Photo: U.S. EPA

in soil. Aldrin, dieldrin, and particularly endrin exhibit high acute mammalian toxicity (oral LD_{50} s between 7 and 90 mg/kg); chlordane, heptachlor, and mirex are moderately acutely toxic (oral LD_{50} s between 100 and 400 mg/kg) (Meister, 2000). Due to the persistence of these insecticides, surface application on food crops proved problematic because residues remained on produce after harvest. The cyclodienes were, however, widely used as soil insecticides in the United States, particularly against termites and soil-dwelling insects that attack the roots of crop plants. Although the agricultural uses of the cyclodienes were cancelled by EPA during the 1970s, they continued to be used under restricted conditions as termiticides well into the 1980s (Ware, 1989).

Aldrin, dieldrin, and endrin are extremely similar chemically, the latter two being stereoisomers of each other (Tables 2-2, 2-3, and 2-4). Aldrin is rapidly transformed into dieldrin both in air and in soil (Glotfelty, 1978; Gannon and Bigger, 1958). Endrin was used initially as a general insecticide, particularly on nonfood crops such as cotton and tobacco. It also served as an avicide (bird-killing agent) and rodenticide, exploiting its high toxicity to vertebrates. Aldrin and dieldrin, which were inexpensive to manufacture, were produced in large quantities in the United States during the 1960s and used most frequently as insecticides to control soil pests affecting corn and citrus crops, as well as termites in buildings and other structures.

Table 2-2. Aldrin

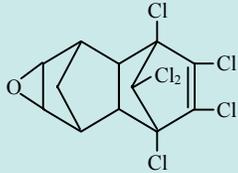
Chemical information	CAS number: 309-00-2 Molecular formula: C ₁₂ H ₈ Cl ₆ Molecular weight: 364.92	
Persistence	Half-lives: < 0.4 hours (air; conversion to dieldrin) 1.2 – 3.5 years (water) 1.2 – 3.5 years (soil)	
Properties related to environmental transport	Henry's law constant: 4.96 x 10 ⁻⁴ atm-m ³ /mol at 25°C Vapor pressure: 2.31 x 10 ⁻⁵ mm Hg at 20°C Solubility in water: 17-180 ppb at 25°C	
Bioaccumulation	K _{ow} (octanol-water partition coefficient) ~ 10 ^{6.5} BAF/BCF ~ 6100	
Acute toxicity	Oral LD ₅₀ = 38-67 mg/kg Dermal LD ₅₀ = 98 mg/kg	
Chronic toxicity	Reference dose (RfD) = 3 x 10 ⁻⁵ mg/kg/day (UF = 1000)	
US production history	Years produced ^a : 1948-1974 Peak usage in 1966 ^b : 19 million lbs. No present production, import, or export in USA	
US use history	- Insecticide on cotton, citrus, and corn crops - Termiticide All uses canceled by 1987	
Current (2001) international production and reported use	- No known current producers - Reported use as an ectoparasiticide in one country	

^aSittig, 1985.
^bATSDR, 1993a.

The long persistence of dieldrin (whether from initial dieldrin formulations or from aldrin formulations) and its acute toxicity to nontarget wildlife led to environmental concerns, particularly after numerous mass bird deaths were associated with the use of dieldrin as a seed treatment (SETAC, 1996). However, long before regulatory actions to restrict or cancel these insecticides were instigated, technical problems had emerged because of their broad-spectrum toxicity and long persistence. The production and uses of aldrin, dieldrin, and endrin declined significantly by the mid-1970s in the United States, due in large part to the development of resistance in target pests (Ware, 1989) and problems with secondary pest upsets caused by the elimination of natural predators (DeBach and Rosen, 1991). The development of other pesticides (organophosphates, carbamates, synthetic pyrethroids and, more recently, insect growth regulators) that were considered more effective and less environmentally destructive also reduced demand for the cyclodiene insecticides (ATSDR, 1993a).

Aldrin was also produced and widely used overseas, particularly for the control of cotton pests and termites, until human health and environmental concerns led to bans in many countries (Pearce, 1997). Dieldrin was initially used for indoor house spraying to control mosquitoes that carry malaria, but it is no longer used or recommended by the World Health Organization (WHO) because of its high mammalian toxicity and resistance problems among many target mosquitoes (Rozendaal, 1997; Shidrawi, 1990). Dieldrin was also donated to African countries until the late 1980s to control plagues of migratory locusts, creating numerous stockpiles of obsolete chemicals that remain an environmental hazard in many countries (FAO, 1998) (Figure 2-2). Newer pesticides, including phenylpyrazole compounds, are now available for locust control, although the economic costs and environmental damage associated with these large-scale pesticide applications suggest that information-based integrated pest management

Table 2-3. Dieldrin

Chemical information	CAS number: 60-57-1 Molecular formula: C ₁₂ H ₈ Cl ₆ O Molecular weight: 380.92	
Persistence	Half-lives: <1.3-4.1 days (air) 1.1 – 3.5 years (water) 1.1 – 3.5 years (soil)	
Properties related to environmental transport	Henry's law constant: 5.8 x 10 ⁻⁵ atm-m ³ /mol at 25°C Vapor pressure: 1.78 x 10 ⁻⁷ mm Hg at 20°C Solubility in water: 140 ppb at 20°C	
Bioaccumulation	K _{ow} (octanol-water partition coefficient) ~ 10 ^{5.2} BAF/BCF ~ 920,000	
Acute toxicity	Oral LD ₅₀ = 37-87 mg/kg Dermal LD ₅₀ = 60-90 mg/kg	
Chronic toxicity	Reference dose (RfD) = 5 x 10 ⁻⁵ mg/kg/day (UF = 100)	
US production history	Years produced ^a : 1948 – 1974 Peak US usage in 1966 ^b : 1 million lbs No present production, import, or export in USA	
US use history	– Insecticide control on cotton, citrus, and corn crops – Termiticide All uses canceled by 1987	
Current international production and use	– No known current producers – Insecticide used until 1980s for control of plague locusts. No current uses except for agricultural operations in one country (for 2 years to exhaust existing stocks)	
^a Sittig, 1985. ^b ATSDR, 1993a.		

approaches using less total pesticide are more appropriate locust control strategies (Showler and Potter, 1991).

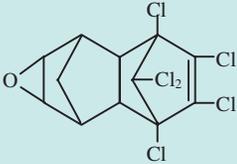


Figure 2-2. Obsolete drums of dieldrin, previously used for locust control, Morocco.

Photo: Janice Jensen

Chlordane, heptachlor, and mirex were used extensively in the United States in the 1950s and 1960s for the control of soil insects in agricultural crops, and for termites and other structural pests in buildings (Figure 2-3). Chlordane and heptachlor have very similar chemical structures (Tables 2-5 and 2-6). Chlordane was often applied directly to soil to create a chemical barrier against subterranean termites, frequently remaining effective for 25 years or more in temperate areas (Grace et al., 1993). Heptachlor was applied both directly to soil and seeds for agricultural uses and to wood for termite protection (ATSDR, 1993b). Heptachlor is converted in the environment to heptachlor epoxide, prolonging its persistence and toxicity. The last registered use for heptachlor in the United States, now cancelled, was as an insecticide in small containers placed in cable boxes in the southeast to prevent nest building by fire ants in electrical equipment. Registered chlordane uses in the

Table 2-4. Endrin

Chemical information	CAS number: 72-20-8 Molecular formula: $C_{12}H_8Cl_6O$ Molecular weight: 380.92	
Persistence	Half-lives ^a : ~2.2 days (air) 1.0 – 4.1 years (water) 4 – 14 years (soil)	
Properties related to environmental transport	Henry's law constant: 5.0×10^{-7} atm-m ³ /mol at 25°C Vapor pressure: 7×10^{-7} mm Hg at 25°C Solubility in water: 220-260 ppb at 25°C	
Bioaccumulation	K_{ow} (octanol-water partition coefficient) = $10^{5.2}$ BAF/BCF ~ 7,000	
Acute toxicity	Oral LD ₅₀ = 7-15 mg/kg Dermal LD ₅₀ = 15 mg/kg (female)	
Chronic toxicity	Reference dose (RfD) = 3×10^{-4} mg/kg/day (UF = 100)	
US production history	Years produced ^b : 1951-1986 Peak US usage in 1962 ^c : Estimated 5 to 10 million lbs No present production, import, or export in USA	
US use history	– Insecticide on cotton crops – Rodenticide in orchards – All uses canceled by 1984	
Current international production and use	– No known current producers – No current use reported	

^aAir: HSDB, 1997; Burton and Pollard, 1974. Water: Sharom et al., 1980; Callahan et al., 1979.
Soil: Menzie, 1972; HSDB, 1997.
^bATSDR, 1996a.
^cIARC, 1974.

United States were cancelled by 1988 in response to evidence of human exposure through accumulation of chlordane in fat, and human cancer risks based on animal bioassay results. Both chlordane and heptachlor are still used in several African,



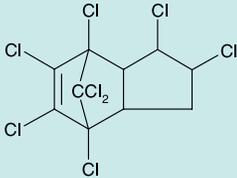
Figure 2-3. Subterranean worker termites, a target of chlordane and some other POPs pesticides.

Photo: Clemson University Cooperative Extension Service - USDA joint project

Asian, and Eastern European countries for termite control (UNEP, 2000). Mirex, structurally similar to the now deregistered cyclodiene insecticide chlordane (Kepone), was produced in smaller quantities and used for ant control, often in the form of a bait (Table 2-7). Mirex was also used in the United States as a fire retardant additive (U.S. EPA, 1998).

A number of alternative chemical control strategies can now be used effectively to replace the cyclodienes, although most do not exhibit the same persistence in soil. These include long-acting organophosphate pesticides and several synthetic pyrethroids (Mauldin et al., 1987; Su et al., 1993; Kard, 1996). Nonchemical alternatives, such as physical barriers and heat treatment, can provide effective and less toxic termite control in buildings (Grace and Yates, 1999; Pearce, 1997; Woodrow and Grace, 1998).

Table 2-5. Chlordane

Chemical information	CAS number: 57-74-9 Molecular formula: C ₁₀ H ₆ Cl ₈ Molecular weight: 409.78 ^b	
Persistence	Half-lives: ~1.3–4.2 days (air) ~1.2–3.5 years (water) ~1.2–3.5 years (soil)	
Properties related to environmental transport	Henry's law constant: 4.8 x 10 ⁻⁵ atm·m ³ /mol at 25°C Vapor pressure: 1 x 10 ⁻⁶ mm Hg at 20°C Solubility in water: 56 ppb at 25°C	
Bioaccumulation	K _{ow} (octanol-water partition coefficient) ~ 10 ⁶ BAF/BCF ~ 250,000	
Acute toxicity ^a	Oral LD ₅₀ = 283 mg/kg Dermal LD ₅₀ = 580 mg/kg (rabbit)	
Chronic toxicity	Reference dose (RfD) = 5 x 10 ⁻⁴ mg/kg/day (UF = 300)	
US production history	Years produced ^b : 1946 – 1997 Average annual US usage prior to 1983 ^b : >3.6 million lbs No present production, import, or export in USA	
US use history	– Insecticide in agriculture and home gardens – Termiticide – All uses canceled by 1988	
Current (2001) international production and use	– China, Singapore ^c – Chlordane is still used in a number of countries in Africa and Asia, primarily as a termiticide	

^aWare, 1989.
^bEPA, 1998.
^cThe basic producers are Sino Agro-Chemical Industry Ltd. (China) and Agsin Pte. Ltd. (Singapore) (Meister, 2000).

Dichlorodiphenyl trichloroethane (DDT)

DDT was the first organochlorine insecticide developed, and is probably the most famous and controversial pesticide ever made. Worldwide, an estimated 4 billion pounds have been produced and applied since 1940, primarily in agriculture (Table 2-8) (Ware, 1989; ATSDR, 2000). Unlike many of the other synthetic organic pesticides developed later, DDT exhibited relatively low mammalian toxicity, was initially highly effective at controlling a variety of insect pests, and, perhaps most importantly, was very inexpensive to produce. This unique combination of properties led to DDT's widespread use in public health, beginning with the control of louse-borne typhus during World War II. DDT was a central tool in the malaria eradication programs of the 1950s and 1960s (Figure 2-4). Although the malaria eradication goal proved elusive in much of the tropical world, DDT nonetheless contributed to improved health and saved countless lives in many malarious countries (Oaks et al., 1991).

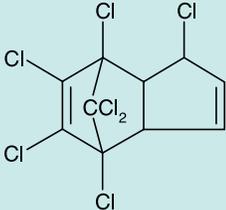
In the United States, malaria had been largely eradicated prior to the introduction of DDT, although DDT was widely used for nuisance mos-



Figure 2-4. *Anopheles* mosquito, vector of malaria and target of DDT.

Photo: WHO/TDR/Gwadz

Table 2-6. Heptachlor

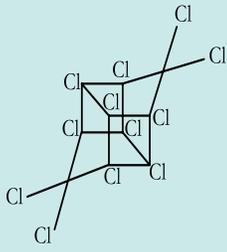
Chemical information	CAS number: 76-44-8 Molecular formula: C ₁₀ H ₅ Cl ₇ Molecular weight: 373.32	
Persistence	Half-lives: ~1.3-4.2 days (air; conversion to heptachlor epoxide) ~0.03–0.12 years (water) ~0.12–0.35 years (soil)	
Properties related to environmental transport	Henry's law constant: 2.3 x 10 ⁻³ atm·m ³ /mol at 25°C Vapor pressure: 3 x 10 ⁻⁴ mm Hg at 20°C Solubility in water: 180 ppb at 25°C	
Bioaccumulation	K _{ow} (octanol-water partition coefficient) ~ 10 ^{5.27} BAF/BCF ~ 8,500	
Acute toxicity	Oral LD ₅₀ = 147-220 mg/kg Dermal LD ₅₀ > 2000 mg/kg (rat); 119-320 mg/kg (rabbit)	
Chronic toxicity	Reference dose (RfD) = 5 x 10 ⁻⁴ mg/kg/day (UF = 300)	
US production history	Years produced ^a : 1953-1997 No present production, import, or export in USA	
US use history	– Termiticide – Insecticide for control of fire ants in underground cable boxes – Most uses canceled by 1978, all uses canceled 2000	
Current (2001) international production and use	– No known current producers, although the Russian Federation has requested a production exemption as a pesticide and pesticide solvent – Insecticide for control of termites and other soil insects by several countries – Solvent in pesticides by two countries	
^a ATSDR, 1993b; EPA Office of Pesticide Programs.		

quito control. The primary use of DDT was as a broad-spectrum insecticide on agricultural crops, principally cotton (~90% of total use), but also on potatoes, corn, tobacco, and apples, and against forest pests (Ware, 1989; U.S. EPA, 1998; ATSDR, 2000). DDT use in the United States peaked in 1961, but began to decline thereafter because of several technical complications. One problem was mounting resistance, as continual exposure to the heavily used and persistent chemical selected for resistant insects. DDT resistance was observed in apple pests as early as 1954 (Cutright, 1954). By 1984, DDT resistance was documented in 233 species of insects and mites worldwide, including many important agricultural pests (Georghiou, 1986). DDT's broad spectrum of activity against virtually all insects, pests and beneficials alike, and its long environmental persistence also led to serious secondary pest problems. Secondary pests are normally suppressed by natural predators, but their populations spiral upward

out of control when the predators are killed by DDT. For example, an important pest of California citrus, the cottony cushion scale, was controlled by the Vedalia beetle until growers in 1946 applied DDT to control a different pest (Figure 2-5). The DDT applications killed off the predator but not the white-colored scale, whose populations exploded, covering trees so densely the orchards looked snow-covered. The Vedalia beetle had to be reintroduced at a cost of up to \$1 per beetle to regain control of the scale (DeBach and Rosen, 1991).

At the same time that DDT use peaked in the 1950s and 1960s, there was mounting evidence of the environmental impacts from DDT and its long-lived metabolites, DDE and DDD (Ratcliffe, 1967; Wurster et al., 1965; Riseborough, 1972). Impacts were particularly severe on bird populations through eggshell thinning and chick mortality in raptors (e.g., bald eagles, falcons) and oceanic birds (e.g., pelicans) (SETAC, 1996) (Figure 2-6). Al-

Table 2-7. Mirex

Chemical information	CAS number: 2385-85-5 Molecular formula: C ₁₀ Cl ₁₂ Molecular weight: 545.5	
Persistence	Half-lives: ~4.2-12.5 days (air) ~0.35-1.16 years (water) > 3.5 years (soil)	
Properties related to environmental transport	Henry's law constant: 8.3 x 10 ⁻³ atm·m ³ /mol at 20°C Vapor pressure: 3 x 10 ⁻⁷ mm Hg at 25°C Solubility in water ^a : 0.07 ppb at 25°C	
Bioaccumulation	K _{ow} (octanol-water partition coefficient) ~ 10 ^{6.9} BAF/BCF ~ 2,400,000	
Acute toxicity	Oral LD ₅₀ = 360 mg/kg Dermal LD ₅₀ = 800 mg/kg (rabbit)	
Chronic toxicity	Reference dose (RfD) = 2 x 10 ⁻⁴ mg/kg/day (UF = 300)	
Past production in USA	Years produced ^b : 1954-1976 Peak US usage between 1963 and 1968 ^c : 3.3 million lbs total No present production, import, or export in USA	
History of use(s) in USA	- Insecticide for fire ant control - Industrial fire retardant additive All uses canceled by 1977	
Current (2001) international production and use	No known current producers. China has requested a production exemption for termiticide manufacture No current uses, except one country requested an exemption for termite control	

^aWauchope et al., 1992; Augustijn-Beckers et al., 1994.
^bEPA, 1998.
^cEPA, 1998. Total is for Hooker Chemical Company only. Two other US companies also manufactured mirex during this time.

though DDT was considered to exhibit relatively low acute mammalian toxicity, concerns were being expressed about potential chronic reproductive impacts on humans (O'Leary et al., 1970;



Figure 2-5. *Vedralia* beetles, a nontarget species killed by DDT, eating cottony cushion scale.

Photo: J.K. Clark, University of California IPM project

Saxena et al., 1981; Wassermann et al., 1982). Subsequent information has shown p,p'-DDE, a DDT metabolite, to bind to the androgen receptor, antagonizing androgen action (Kelce et al., 1995, 1997; Gray et al., 1999; Maness et al., 1998; NAS, 1999). A recently published human epidemiological study has demonstrated an association

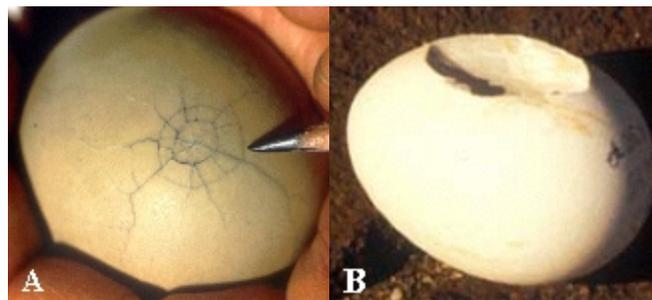
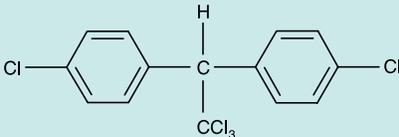


Figure 2-6. Bird eggshell effects after population DDE exposure. A. Cracked shell. B. Dented shell.

Photo: US FWS

Table 2-8. DDT

Chemical information	CAS number: 50-29-3 Molecular formula: C ₁₄ H ₉ Cl ₅ Molecular weight: 354.49	
Persistence	Half-lives: ~4.2-12.5 days (air) ~0.35-1.16 years (water) ~0.35-1.16 (soil)	
Properties related to environmental transport	Henry's law constant: 1.29 x 10 ⁻⁵ atm·m ³ /mol at 23°C Vapor pressure: 1.46 x 10 ⁻⁷ mm Hg at 25°C Solubility in water: 1.2-5.5 ppb at 25°C	
Bioaccumulation	K _{ow} (octanol-water partition coefficient) ~ 10 ^{6.19} BAF/BCF ~ 1,800,000	
Acute toxicity in mammals ^a	Oral LD ₅₀ = 87 mg/kg Dermal LD ₅₀ = 1,931 mg/kg (rabbit)	
Chronic toxicity	Reference dose (RfD) = 5 x 10 ⁻⁴ mg/kg/day (UF = 100)	
US production history	Years produced ^b : 1940 – (none by 1993) Peak US production in 1962 ^b : 170 million lbs. (Metcalf, 1995) No present production, import, or export in USA	
US use history	– Broad spectrum insecticide on many crops – Most uses canceled by 1972. All uses canceled by 1989	
Current (2001) international production and use	Production: China, India Insecticide used in at least 25 countries for control of insect vectors of human disease, particularly malaria	

^aWare, 1989.
^bEPA, 1998.

between DDT concentrations and increased preterm human births, a major contributor to infant mortality. Longnecker et al. (2001) analyzed frozen maternal serum samples that had been collected between 1959 and 1965 and stored as part of the U.S. Collaborative Perinatal Project (CPP). During this time of peak DDT use in the United States, the median DDE concentration of 25 mcg/L was several-fold higher than current U.S. levels. Taking into consideration data on potential confounding variables collected during this study (age, birth order, socioeconomic status, etc.), the association of increasing serum DDE concentrations with preterm birth was highly statistically significant (Figure 2-7). Dose-response data were consistent with serum DDE levels above 10 mcg/L affecting the risk of preterm birth. These human epidemiological findings warrant consideration when balancing the risks of DDT against its benefits for malaria vector control and the costs of alternatives.

All uses of DDT in the United States were cancelled by EPA in 1972, primarily because of positive cancer results in rodent bioassays. DDT production in the United States for export occurred until at least 1985 (ATSDR, 2000). DDT use for

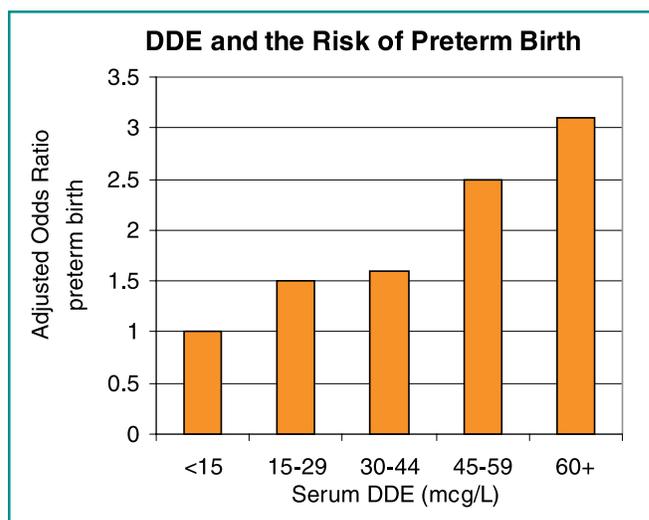
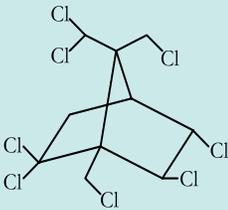


Figure 2-7. Graph of the association between maternal serum DDE levels and preterm birth risk (from Longnecker et al., 2001).

Table 2-9. Toxaphene

Chemical information	CAS number: 8001-35-2 Molecular formula: C ₁₀ H ₁₀ Cl ₈ Molecular weight: 413.82	
Persistence	Half-lives: ~4.2-12.5 days (air) >3.5 years (water) >3.5 years (soil)	
Properties related to environmental transport	Henry's law constant: 6.3×10^{-2} atm·m ³ /mol at 25°C Vapor pressure: 0.2-0.4 mm Hg at 25°C Solubility in water: 550 ppb at 20°C	
Bioaccumulation	K _{ow} (octanol-water partition coefficient) ~ 10 ^{5.5} BAF/BCF ~ 1,100,000	
Acute toxicity in mammals ^a	Oral LD ₅₀ = 40 mg/kg Dermal LD ₅₀ = 600 mg/kg (rabbit)	
Chronic toxicity	Reference dose (RfD) = under development	
US production history	Years produced ^b : 1946-1990s Peak US production in 1972 ^c : 46 million lbs No present production, import, or export in USA	
US use history	– Insecticide to control cotton pests and plague grasshoppers and for mange control on cattle – Most uses canceled by 1982 – All uses canceled by 1990	
Current (2001) international production and use	No known producers No known registered uses	

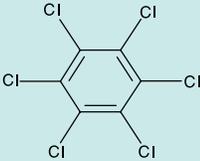
^aWare, 1989.
^bEPA, 1998.
^cATSDR, 1996b.

disease (mostly malaria) vector control continues in an estimated 25 or more developing countries, primarily because of its low cost and persistence (WHO, 1999). Many other insecticides are available for indoor house spraying (Chavasse and Yap, 1997), but DDT's lower cost remains an advantage, at least in some countries (Walker, 2000). Other approaches to disease control such as case detection and treatment, or pyrethroid-treated bednets, may prove more cost-effective and sustainable in the long term (Goodman et al., 1999). For the future, the Stockholm Convention strives for a balance among the public health benefits of DDT for malaria control, the availability and cost of alternatives, and the impacts of DDT on ecosystems and, potentially, human health. While working toward a goal of reducing and ultimately eliminating the use of DDT, parties may use DDT only for disease vector control in accordance with World Health Organization recommendations (UNEP, 2000).

Toxaphene

Toxaphene is a mixture of at least 670 chlorinated terpenes, produced through chlorinating camphene (Table 2-9). Its primary use was on cotton, where it was generally applied with another insecticide, first DDT and subsequently organophosphate insecticides such as methyl parathion. U.S. production of toxaphene peaked in 1972, when it was the most heavily manufactured pesticide in the country, largely as a replacement for DDT. Toxaphene was also used as a piscicide to eradicate fish species considered undesirable for sport fishing in Canada and the northern United States (U.S. EPA, 1998). Fish restocking efforts were sometimes difficult because of the longevity of active toxaphene residues, highlighting the problem of environmental persistence. Most registered uses in the United States were withdrawn in 1982, on the basis of studies showing tumors in toxaphene-exposed laboratory animals, evidence of acute

Table 2-10. Hexachlorobenzene (HCB)

Chemical information	CAS number: 118-74-1 Molecular formula: C ₆ Cl ₆ Molecular weight: 284.78	
Persistence	Half-lives: ~ 438-1277 days (air) >3.5 years (water) >3.5 (soil)	
Properties related to environmental transport	Henry's law constant: 7.1 x 10 ⁻³ atm-m ³ /mol at 20°C Vapor pressure: 1.089 x 10 ⁻⁵ mm Hg at 20°C Solubility in water: 40 ppb at 20°C	
Bioaccumulation	K _{ow} (octanol-water partition coefficient) ~ 10 ^{5.5} BAF/BCF ~ 110,000	
Acute toxicity in mammals	Oral LD ₅₀ = 3,500 mg/kg	
Chronic toxicity	Reference dose (RfD) = 8 x 10 ⁻⁴ mg/kg/day (UF = 100)	
US production history	Years produced as a fungicide ^a : 1945–late 1970s HCB is produced as a by-product or contaminant of certain chemicals. Estimated annual US production as a by-product, intermediate, or impurity range from 11.3 to 13 million lbs, the vast majority of which is destroyed onsite	
US use and source history	– Fungicide for seed and wheat – Currently imported for use as an intermediate; anticipated to cease in future to comply with the closed-system, site-limited exemption	
Current (2001) international production and use	– No current production for fungicide applications. China has requested a production exemption for use as a closed-system intermediate. – No current reported uses as a fungicide. Several countries have requested exemptions as a closed-system, site-limited intermediate, or contaminant in pesticides.	

^aATSDR, 1996c.

toxicity to aquatic organisms, and impacts on non-target animals including endangered species.

Worldwide, toxaphene was one of the most widely used agricultural insecticides during the 1960s and 1970s, primarily for control of cotton pests. Between 1950 and 1993, when all production ceased in the United States, an estimated 2.6 billion pounds had been manufactured worldwide (ATSDR, 1996b). Stockpiles of toxaphene continue to threaten the environment in some areas. For example, in Nicaragua, 230 metric tonnes of toxaphene are stockpiled in a zone at high risk for earthquakes near Lake Managua, a unique ecosystem and home to many rare species of wildlife (EARTH, 2000).

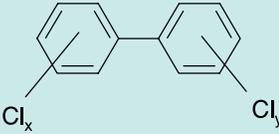
Hexachlorobenzene

Hexachlorobenzene (HCB) is included under all three general categories of POPs: as a pesticide, an industrial chemical, and an unintended byproduct (Table 2-10). HCB was introduced as a pesticide in the United States in 1945 for antifun-

gal seed and soil treatment. All U.S. pesticide uses were canceled in 1985 (Ware, 1989; ATSDR, 1996c). The human toxicity of HCB was sadly demonstrated in Turkey during the late 1950s, when an estimated 3,000- 4,000 people ingested bread inadvertently made from HCB-treated grain at approximately 2 kg HCB per 1,000 kg wheat. The HCB led to porphyria cutanea tarda in adults, a metabolic defect of blocked hemoglobin synthesis that causes light-sensitive skin lesions, colored urine, and, in some cases, death. All children born to porphyric mothers during this epidemic died, with an estimated 1,000 to 2,000 children dying from related skin lesions, exacerbated by the HCB transfer in breast milk (Peters et al., 1982, 1987).

Industrial uses of HCB have varied, including pyrotechnic coloring in military ordnance, synthetic rubber production, and as a chemical intermediate in dye manufacture and organic chemical synthesis (Bailey, 2001). There are no current uses of HCB as an end product in the United States, although it is imported for use as a production intermediate.

Table 2-11. Polychlorinated Biphenyls (PCBs)

Chemical information	CAS number: various; 11097-69-1 Arochlor 1254 mixture Molecular formula: C ₁₂ Cl _x Molecular weight: various; 188.7 – 498.7	
Persistence	Half-lives ^a : ~ 22.9 – 229.2 days (air) ~ 2.0 – 6.4 years (water) ~ 2.0 – 6.4 years (soil)	
Properties related to environmental transport ^b	Henry's law constant: 2.0 x 10 ⁻³ atm·m ³ /mol at 25°C [Arochlor1254] Vapor pressure: 7.7 x 10 ⁻⁵ mm Hg at 20°C Solubility in water: 57 ppb at 24°C	
Bioaccumulation	K _{ow} (octanol-water partition coefficient) ~ 10 ^{6.5} BAF/BCF ~ 3,000,000	
Acute toxicity in mammals	Oral LD ₅₀ = 1,010 mg/kg [Arochlor 1254 mixture]	
Chronic toxicity	Reference dose (RfD) Arochlor 1254 = 2 x 10 ⁻⁵ mg/kg/day (UF = 300), under review ATSDR ^b chronic MRL = 0.02 mcg/kg/day (UF = 300) FDA edible portion fish tolerance 2 ppm	
US production history	Years produced: 1929–1977; banned under TSCA Section 6(e) effective 1979 Peak production 1970, 8.5 million pounds annually No present production, import, or export in USA	
Current (2001) US source and use history	Use allowed if in certain existing equipment; environmentally sound destruction/disposal after service life of equipment	
Current (2001) international production and use	Uncertain if production continues in Russia No recorded new uses; widespread residual use in existing equipment and products	

^aMackay, 1991; rate constant for 3,3',5,5'- TetraCB.
^bATSDR, 1997.

An exemption is available under the Stockholm Convention for the use of HCB as a closed-system, site-limited intermediate. HCB is still produced as an unintended byproduct during the manufacture of chlorinated solvents and as an impurity of certain pesticides (picloram, PCNB, chlorothalonil, DCPA, and PCP) (ATSDR, 1996c). It is also created and emitted during incineration practices. Due to its chemical structure, HCB is extremely stable, globally distributed, and considered among the most persistent of all POPs.

2. Intentionally Produced POPs: Industrial Chemicals

Polychlorinated Biphenyls (PCBs)

PCBs are a mixture of synthetic organic chemicals with the same basic chemical structure and similar physical properties, ranging from oily liquids to waxy solids (Table 2-11). Because of their non-

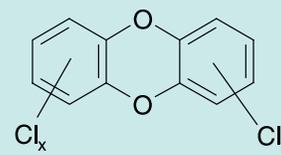
flammability, chemical stability, high boiling point, and electrical insulating properties, PCBs were used in hundreds of industrial and commercial applications, including electrical, heat transfer, and hydraulic equipment; as plasticizers in paints, plastics, and rubber products; and in pigments, dyes, and carbonless copy paper. First manufactured in 1929, more than 1.5 billion pounds of PCBs were manufactured in the United States (plus elsewhere in the world) before domestic production ceased in 1977.

PCBs are principally addressed under the Stockholm Convention as intentionally produced industrial chemicals. PCBs are also closely linked to the polychlorinated dioxin and furan byproduct POPs for the following reasons:

- * Coplanar PCBs have a similar chemical structure and spatial configuration to the polychlori-

Table 2-12. Polychlorinated Dibenzo-p-Dioxins

Table 2-12. Polychlorinated Dibenzo-p-Dioxins	
<i>2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)</i>	
Chemical information for TCDD	CAS number: 1746-01-6 Molecular formula: C ₁₂ H ₄ Cl ₄ O ₂ Molecular weight: 322.0
Persistence	Half-lives: 4.2 – 12.5 days (air) ~ 0.12 – 0.35 years (water) ~ 0.35 – 1.2 years (soil) – for all dioxins
Properties related to environmental transport	Henry's law constant: 3.29 x 10 ⁻⁵ Vapor pressure: 1.5 x 10 ⁻⁹ mm Hg at 25°C Solubility in water: 0.019 ppb at 25°C
Bioaccumulation	K _{ow} (octanol-water partition coefficient) ~ 10 ^{6.8} BAF/BCF ~ 130,000
Acute toxicity in mammals ^a	Hamster oral LD ₅₀ = 5051 mcg/kg Rat oral LD ₅₀ = 22 – 165 mcg/kg Mink oral LD ₅₀ = 4.2 mcg/kg Guinea pig oral LD ₅₀ = 0.6 mcg/kg
Chronic toxicity	Under EPA review: www.epa.gov/ncea/dioxin.htm ATSDR chronic MRL = 0.000001 mg/kg/day (UF = 100)
Major sources (US and international)	Municipal and medical waste incineration Open and barrel burning of waste Elemental chlorine bleach pulp and paper manufacture Certain thermal processes in the metallurgical industry Selected chemical manufacturing processes, e.g., 2,4,5-trichlorophenol production (now ceased)
^a ATSDR, 1998.	



nated dioxins and furans, and much of the toxicity of all three congener groups is linked through a common mode of action (Ah receptor-mediated) and the concept of dioxin toxicity equivalence (see under byproduct POPs).

- * Burning and high-temperature treatment of PCB mixtures can lead to the creation of polychlorinated dibenzofurans (PCDFs), further exacerbating the potential toxicity from PCBs. This occurred during the Yusho and Yu Cheng poisoning incidents in Japan and Taiwan, respectively, where the cooking of rice oil contaminated with PCBs resulted in the production of PCDFs. The combined presence of PCBs and PCDFs in the cooked food caused chloracne and other toxic effects in the adults, and fetal mortality and developmental defects in their offspring (Rogan et al., 1988; Hsu et al., 1994).
- * Like polychlorinated dioxins and furans, PCBs can be produced in small amounts during incin-

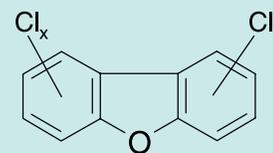
eration processes and are therefore included in the unintentional byproduct category under the Stockholm Convention.

Beyond the rice oil contamination poisonings, PCB toxicity has been demonstrated in wildlife and humans following environmental exposures. As detailed in the chapters to follow, PCBs have been associated with reproductive effects in wildlife populations in the Great Lakes (Chapter 3) and far out in the North Pacific Ocean (Chapter 6). For humans, increased PCB concentrations in children from environmental exposures are associated with neurodevelopmental impacts (Fein et al., 1984; Jacobson and Jacobson, 1996), findings supported by followup studies in the Great Lakes region (Lonky et al., 1996; Stewart et al., 2000) and in Dutch children (Patandin et al., 1999) (Chapter 4).

Concern over the toxicity and persistence of PCBs in the environment led Congress in 1976 to enact Section 6(e) of the Toxic Substances Control Act (TSCA). This includes prohibitions on the manu-

Table 2-13. Polychlorinated Dibenzofurans

2,3,7,8-Tetrachlorodibenzofuran (TCDF)	
Chemical information for TCDF	CAS number: 51207-31-9 Molecular formula: C ₁₂ H ₄ Cl ₄ O Molecular weight: 306.0
Persistence	Half-lives: 4.2 – 12.5 days (air) ~ 0.12 – 0.35 years (water) ~ 1.2 – 3.5 years (soil) – for all furans
Properties related to environmental transport ^b	Henry's law constant: 1.44 x 10 ⁻⁵ atm-m ³ /mol Vapor pressure: 1.5 x 10 ⁻⁸ mm Hg at 25°C Solubility in water: 0.42 ppb at 22.7°C
Bioaccumulation	K _{ow} (octanol-water partition coefficient) ~ 10 ^{6.1} BAF/BCF ~ 61,000
Acute toxicity in mammals	See for dioxins, based on TEQ values
Chronic toxicity	Under review: www.epa.gov/ncea/dioxin.htm
Major sources (US and international)	See for dioxins



ufacture, processing, and distribution in commerce of PCBs. Under the Stockholm Convention there is a global ban on the manufacture of PCBs (UNEP 2000). Because of the magnitude of past use of PCBs and the continuing economic importance of previously manufactured PCB-containing equipment, countries must make determined efforts to identify, label, and remove PCB-containing equipment from use by 2025. During this interval, the Stockholm Convention mandates a series of measures to reduce exposures and risk from further releases of PCBs to the environment, accompanied by prohibitions on reuse and export and import, except for the purpose of environmentally sound waste disposal.

3. Byproduct POPs

Polychlorinated dibenzo-*p*-dioxins (PCDD), polychlorinated dibenzofurans (PCDF)

The term "dioxin" refers to a group of chemical compounds that share certain similar chemical structures and toxicological characteristics. Thirty toxic dioxin-like compounds exist and are members of three closely related families: PCDDs, PCDFs, and coplanar PCBs. The term dioxin is also used for the most well-studied and toxic of the dioxins, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) (Table 2-12). PCDDs and PCDFs (Table 2-13) are not created intentionally, but can be produced inadvert-

ently in nature and by a number of human activities. Combustion (Figure 2-8), elemental chlorine bleaching of pulp and paper (Figure 2-9), certain types of chemical manufacturing and processing, and other industrial processes all can create small quantities of dioxins. PCBs are no longer manufactured in the United States, but formerly were widely used in electrical equipment as coolants and lubricants. PCBs can also be formed in a similar manner to dioxins as byproducts of combustion processes (see previously).

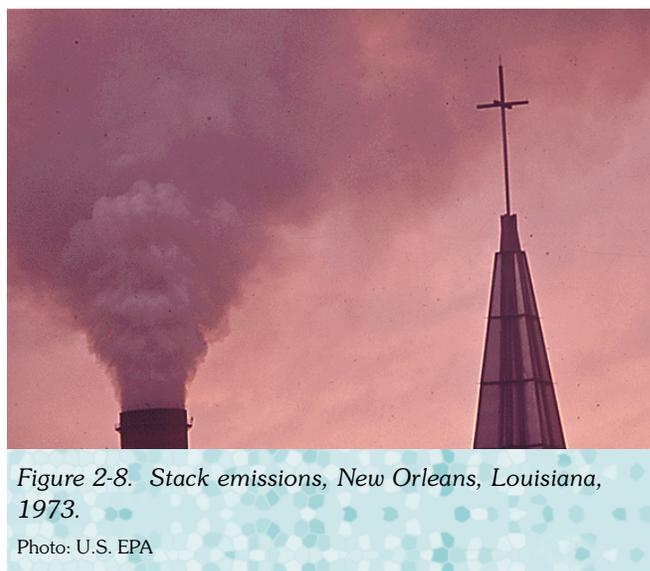


Figure 2-8. Stack emissions, New Orleans, Louisiana, 1973.

Photo: U.S. EPA



Figure 2-9. Pulp mill effluent, a source of polychlorinated dioxins and furans, Columbia River, 1970s.

Photo: U.S. EPA

Dioxins have been central to a number of environmental controversies in recent decades. Dioxin (2,3,7,8-TCDD in particular) was a contaminant of the herbicide 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) sprayed in Agent Orange defoliant during the Vietnam War (Figure 2-10). Ensuing sprayer (Operation Ranch Hand personnel), soldier, and civilian exposures have resulted in ongoing inquiries, research, and veterans' health benefits compensation (IOM, 1994). In 1976, an explosion at a trichlorophenol herbicide production plant in Seveso, Italy, led to widespread environmental contamination, local livestock and wildlife mortality, very high human exposures and clinical illness (e.g., chloracne, a severe and prolonged acneform condition) (Figure 2-11), and evacuation of the surrounding region (Bertazzi et al., 1998). Residential di-

oxin exposure and evacuation also occurred at Times Beach, Missouri, following the spraying of dioxin contaminated waste oil for dust control in the early 1970s (Webb et al., 1984). In occupational studies, cancer mortality increases have been reported in several groups of workers exposed to dioxin during herbicide production (Steenland et al., 2001; Ott and Zober, 1996; Becher et al., 1998). EPA is currently assessing the impacts of dioxin on the general public in its draft document "Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-*p*-Dioxin (TCDD) and Related Compounds" (www.epa.gov/ncea/dioxin.htm).

Dioxins have the potential to produce an array of adverse effects in wildlife and humans. Dioxins can alter the growth and development of cells in ways that can lead to many kinds of impacts. These include adverse effects upon reproduction and development, suppression of the immune system, chloracne, and cancer. Although data on risks to children are limited, fetuses, infants, and children may be more sensitive to dioxin exposure because they are exposed during critical windows of development and during rapid growth.

Dioxins are believed to exert these toxic effects in similar ways; that is, they share a common mode of toxicity. As a result, scientists use an approach that adds together the toxicity of individual dioxins



Figure 2-10. Aircraft spraying Agent Orange, contaminated with dioxin, in Vietnam.

Photo: USAF



Figure 2-11. Chloracne caused by high exposure to dioxin.
Photo: A. Geusau (Geusau et al., 2001)

in order to evaluate complex environmental mixtures to which people are exposed. Because dioxins differ in their toxic potential, the contribution of each component in the mixture must be accounted for in estimating the overall toxicity. To do so, international teams of scientists have developed toxicity equivalence factors (TEFs) that compare the toxicity of different dioxins to the most toxic congener, 2,3,7,8-TCDD. Given these factors, the toxicity of a mixture can be expressed in terms of its toxicity equivalents (TEQ), which is the amount of 2,3,7,8-TCDD exposure it would take to equal the combined toxic effect of all the dioxins found in that mixture.

Most dioxin enters ecological food webs by being deposited from the atmosphere, either directly following air emissions or indirectly by processes

that return dioxins already present in the environment to the atmosphere. Once they reach the environment, dioxins are highly persistent and can accumulate in the tissues of animals. Most dioxin exposure occurs through the diet, with more than 95% of dioxin intake for a typical person coming through dietary intake of animal fats. Fortunately, dioxin levels in the environment have declined significantly since the 1970s, following EPA regulatory controls and industry actions. EPA's best estimates of emissions from sources that can be reasonably quantified indicate that dioxin emissions in the United States decreased by about 75% between 1987 and 1995, primarily through reductions in air emissions from municipal and medical waste incinerators. Substantial further declines continue to be documented.

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Appendix. Selected Federal Sites for POPs Toxicity Information

- * U.S. Department of Health and Human Services, National Library of Medicine (NLM; www.nlm.nih.gov)
 - Medline/PubMed, covering medical literature;
 - Toxnet, toxicology data network;
 - HSDB, Hazardous Substances Data Bank, focusing on the toxicology of potentially hazardous chemicals, with information on human exposure, industrial hygiene, emergency handling procedures, environmental fate, regulatory requirements, and related data
- * U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry (ATSDR; www.atsdr.cdc.gov)
 - ToxFAQs, summaries of hazardous substance information;
 - Toxicological Profiles of hazardous substances (www.atsdr.cdc.gov/toxpro2.html)
- * U.S. Environmental Protection Agency (U.S. EPA; www.epa.gov)
 - IRIS, Integrated Risk Information System (IRIS), a database of human health effects that may result from exposure to various substances found in the environment (www.epa.gov/iris)
 - PBT, Persistent Bioaccumulative Toxin, home page, containing summaries of PBT chemicals, EPA action plans, and regulatory initiatives (www.epa.gov/pbt)
 - ECOTOX database system, providing chemical-specific toxicity values for aquatic life, terrestrial plants, and terrestrial wildlife (www.epa.gov/med/databases/databases.html#aquire)
- * U.S. Department of the Interior, U.S. Geological Survey, Patuxent Wildlife Research Center (www.pwrc.nbs.gov/research/ecr/)
 - Contaminant Exposure and Effects Terrestrial Vertebrates Database
 - Contaminant Hazards Review On-Line

For further information on toxicology data sources, see Toxicology, Volume 157, Issues 1-2, Pages 1–164, 12 January 2001. For Federal sources, see specifically Brinkhuis, 2001.