October 20, 2004

Lecture 15 Chlorinated Dioxins/Dibenzofurans: Environmental Chemistry, Basic Toxicology, Environmental Trends

I. Chemistry

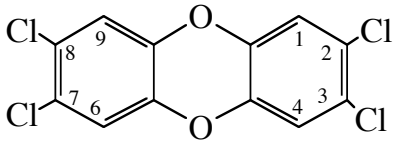
A. PCDDs (polychlorinated dibenzodioxins) and PCDFs (polychlorinated dibenzofurans) are compounds that have absolutely no utility, being unintentional by-products of certain chemical manufacturing processes and of combustion. For example, because of the inability to completely control reaction conditions in the manufacture of trichlorophenol, PCDDs were produced and became widely disseminated in the environment. Since the discovery of the most toxic PCDD, known as TCDD (**t**etra**c**hloro**d**ibenzo**d**ioxin) in the early 1960's, vast sums of money have been spent to study and control PCDD and PCDF emissions.

1. The concern over TCDD was generated because of an extremely low LD_{50} in guinea pigs (= 1 μg/kg!!). Fortunately, humans are much less susceptible, and the concerns today are not of acute toxicity but with chronic toxicity, including cancer, endocrine disruption, reproductive toxicity, and immunotoxicity.

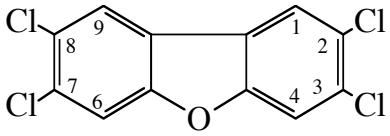
B. The term dioxin (or dioxins) refers to all the congeners of the polychlorinated dibenzo-p-dioxins; the term furans (or chlorinated furans) refers to the polychlorinated dibenzofurans. Dioxin sometimes is used to refer to TCDD, but today it is understood that all the congers are included.

1. During manufacture of 2,4,5-trichlorophenol from 1,2,4,5-tetrachlorobenzene, the most notorious and toxic dioxin, TCDD, was produced –

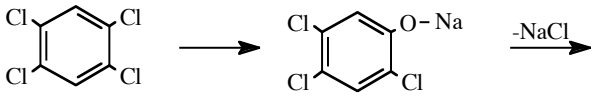
2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD)

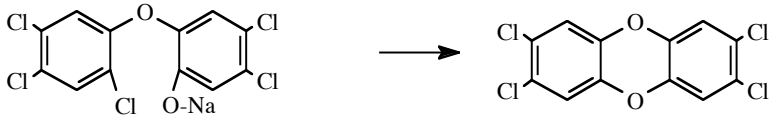


a. Analogs known as polychlorinated dibenzofurans were also produced; for ex., the benzofuran analog of TCDD is **2,3,7,8-tetrachlorodibenzofuran (TCDF):**



2. Reaction (condensation of trichlorophenol-like molecules) is favored by basic conditions and by temperatures in the range of 180 to 400 °C





C. We now know that these compounds are also produced during incineration processes when temperatures are not kept continuously above 750°C. Today, the major sources of PCDDs and PCDFs are combustion processes.

D. Structure--all dibenzo-p-dioxins have a three-ring structure consisting of two benzene rings connected by oxygen atoms; the benzofurans have a furan ring with only one oxygen.

1. There are 75 possible PCDD isomers and 135 possible PCDF isomers

Chlorine Substituted Congener	No. of Isomers	
	PCDDs	PCDFs
monochloro	2	4
dichloro	10	16
trichloro	14	28
tetrachloro	22	38
pentachloro	14	28
hexachloro	10	16
heptachloro	2	4
octachloro	1	1
TOTAL	75	135

II. Physicochemical Properties

A. 2,3,7,8-TCDD—specific properties

1. WS = 7.9 - 483 ppt
2. V.P. = 7.4 x 10^{-10} mm Hg
3. log Kow = 6.64
4. K_H = 1.65 x 10^{-5} atm m^3/mol
5. log K_{oc} = 6.44 (2 day contact time, soil OC = 0.66%); Koc = 6.66 (10 day contact time; data from Walters et al., 1989, ES&T 23:480)

B. 2,3,7,8-TCDF—specific properties

1. WS = 419 ppt
2. 1.5 x 10^{-8} mm Hg
3. log Kow = 6.53
4. K_H = 1.44 x 10^{-5} atm m^3/mol

C. Group Homolog (i.e., congener) properties

1. Data can be found EPA's final draft report on dioxin: *EPA (2000) Exposure and Human Health Reassessment of 2,4,7,8 Tetrachlorodibenzo-p-dioxin (TCDD) and Related Compounds. Part I: Estimating Exposure to Dioxin-Like Compounds, Vol. 3: Properties, Environmental Levels, and Background Exposures;* EPA/600/P-00/001Ac, www.epa.gov/ncea. The data has been summarized and tabulated in Appendix A.
   a. Note that other EPA documents regarding dioxin can be obtained or viewed at the agency's dioxin homepage at http://www.ejnet.org/dioxin/
   b. The group properties in the table below represent averages for all the congeners contained in the group

Congener Group (Molecular Wt.)	Water Solubility (ppt)	Vapor Pressure (mm Hg)	Henry's Law Constant (atm-m^3/mol)	Log K_{ow}
Tetrachlorodibenzodioxin (321.98)	330	$1.4x10^{-8}$	$1.7x10^{-5}$	6.5
Pentachlorodibenzodioxin (356.4)	118	$5.6x10^{-10}$	$2.6x10^{-6}$	6.6
Hexachlorodibenzodioxin (390.87)	4.4	$4.4x10^{-11}$	$1.1x10^{-5}$	7.3
Heptachlorodibenzodioxin (425.31)	2.4	$5.6x10^{-12}$	$1.3x10^{-5}$	8.0
Octachlorodibenzodioxin (460.76)	0.074	$8.3x10^{-13}$	$6.8x10^{-6}$	8.2
Tetrachlorodibenzofuran (305.98)	420	$2.5x10^{-8}$	$1.4x10^{-5}$	6.2

Pentachlorodibenzofuran (340.42)	240	$2.6x10^{-9}$	$5.0x10^{-6}$	6.4
Hexachlorodibenzofuran (374.87)	13	$2.8x10^{-10}$	$1.1x10^{-5}$	7.0
Heptachlorodibenzofuran (409.31)	1.4	$4.7x10^{-11}$	$1.4x10^{-5}$	7.4
Octachlorodibenzofuran (444.76)	1.2	$3.8x10^{-12}$	$1.9x10^{-6}$	8.0

III. Environmental Loading--Sources of Dioxins and Dibenzofurans & Deposition

A. Chlorophenols--extensively used in the 1930's as insecticides, fungicides, mold inhibitors, antiseptics, and disinfectants
   1. Pentachlorophenol—widely used until the 1980's to treat wood products, even for indoor use; now its use is strictly for outdoor posts and poles.
   2. Levels (μg/g) of PCDFs and PCDDs in commercial chlorinated phenols (historical data circa 1980's):

sample	PCDFs Tetra-	Penta-	Hexa-	Hepta-	Octa-	Total	Total PCDDs
2,3,6-trichlorophenate (Sweden)	1.5	17.5	36	48	--	60	<3
2,3,4,6-tetrachlorphenate (Finland)	0.5	10	70	70	10	160	12
pentachlorophenate (U. S)	0.9	4	32	120	130	280	1000

B. Products using 2,4,5-TCP (2,4,5-trichlorophenol) as a precursor in synthesis
   1. 2,4,5-T (one of the component herbicides in the infamous Agent Orange formulation, which was the herbicide formulation containing 2,4,5-T and 2,4-D that was widely sprayed in Vietnam to control forest vegetation used to camouflage troop movements).
   2. TCDD was a contaminant of 2,4,5-T, not 2,4-D; the latter did not use trichlorophenol as a precursor in its synthesis.
   3. There were actually several herbicide formulations used in Vietnam, but of those containing, 2,4,5-T, Agent Orange had the lowest level of TCDD:

Code Name	**Herbicide**	**Quantity (gallons)**	**Period of use**	**TCDD (ppm)**
Orange	2,4-D; 2,4,5-T	10,646,000	1965-70	1.98
White	2,4-D; picloram	5,633,000	1965-71	-
Blue	cacodylic acid	1,150,000	1962-71	-
Purple	2,4,-D; 2,4,5-T	145,000	1962-65	32.8
Pink	2,4,5-T	123,000	1962-65	65.6
Green	2,4,5-T	8,200	1962-65	65.6
TOTAL		17,705,200		

Source: Chemical & Engineering News (1983)

   4. In the U.S., 2,4,5-T was sold for brush control and weed control on rice in a formulation called Silvex; it was known to be contaminated with TCDD also.

C. Hexachlorophene--had been used as an antibacterial soap
D. PCB mixtures
E. Combustion processes--industrial/incinerators
   1. Presence detected on fly ash (0.1 - 0.6 ppm)
F. Combustion processes--natural
   1. Wood (untreated) contains natural chloride (levels up to 2000 ppm); also contains phenols of various kinds; when it is burned, chlorinated dioxins and dibenzofurans are produced
      a. One source has estimated that 130 pounds of PCDDs have been produced in Canadian forest fires annually (Gribble, G. W. 1994. The natural production of chlorinated compounds. Environ. Sci. Technol. 28(7):310A-319A.)

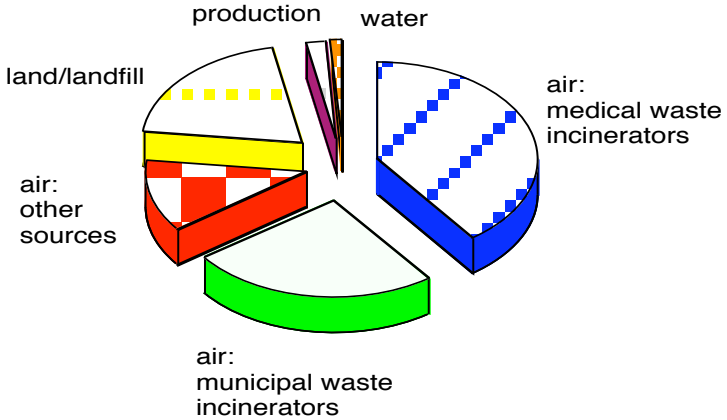
G. Industrially related accidents
   1. Monsanto Plant explosion, 250 workers affected; chloracne skin rash; recognized as caused by TCDD (1955)
   2. Seveso, Italy (1976)--chemical plant explosion released several pounds of TCDD in heavily populated area;
   3. Missouri contamination--Horse Stables & Times Beach
      a. Waste oil from hexachlorophene manufacturer sprayed on roadsides all over MO (starting in 1971, about 29 kg of TCDD-contaminated sludge wastes were mixed with waste oils and sprayed for dust control);
      b. Spraying in several horse stables resulted in 65 horse poisonings (Frontenac, MO)
      c. Times Beach neighborhood buyout--associated with flooding of Merrimac River

Degree of TCDD contamination in soil due to "accidents"

Location	**Source of Contamination**	**ppb (w/w)**	**mg/m^2**	**Sampling Depth (cm)**
Horse Arena A (MO), 1971	waste oil spread on arena	32,000	4,500	10
Horse Arena C (MO), 1974	waste oil spread on arena	540	220	30
Elgin AFB (FL) site 1	Agent Orange spills	170	24	10
Seveso (Italy), zone A, highest closest to factory	industrial accident	55	5.5	7
Seveso, Zone A2/A3, highest formerly inhabited area	industrial accident	20	2	7
Midland (MI), plant, highest	incinerators	100	1	1
Elgin AFB (FL) site 2	practice area for herbicide application	1.5	0.21	10
Seveso, borderline Zones A/B, limit for evacuation	industrial accident	0.15	0.015	7

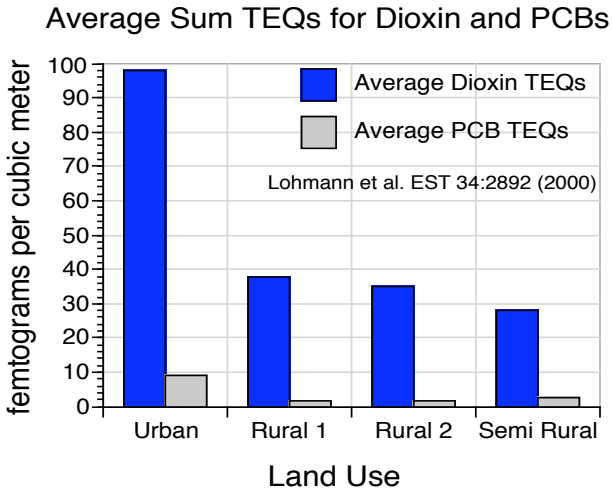
H. Electrical fires—transformers containing PCBs (Erickson, M. D. and et.al. 1989. Polychlorinated dibenzofurans and other thermal combustion products from dielectric fluids containing polychlorinated biphenyls. Environmental Science & Technology 23(4):462-470.)
   1. It has been shown that PCB fires, where heat is under 700°C, produce mainly PCDFs, and only minor amounts of PCDDs

I. Current source contributions (EPA estimates)



J. Differences in emission loads between rural and urban areas of the U.K. have been noted in studies on domestic burning. In the graph below, note that the emission flux (femtograms per cubic meter of surface area) is expressed as toxic equivalents (TEQs) of dioxin and PCBs (see lecture 14 on calculation of TEQs)

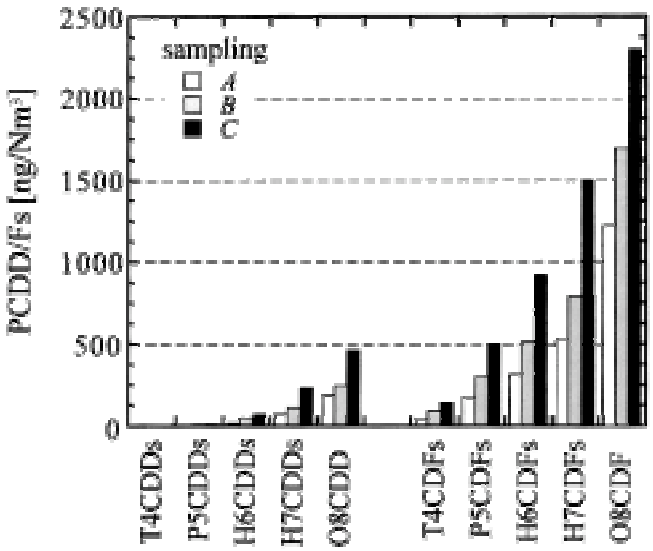
1. Source: Lohmann, R., g. L. Northcott, and K. C. Jones. 2000. Assessing the contribution of diffuse domestic burning as a source of PCDD/Fs, PCBs, and PAHs to the U. K. atmosphere. Environ. Sci. Technol. 34(14):2892-2899.



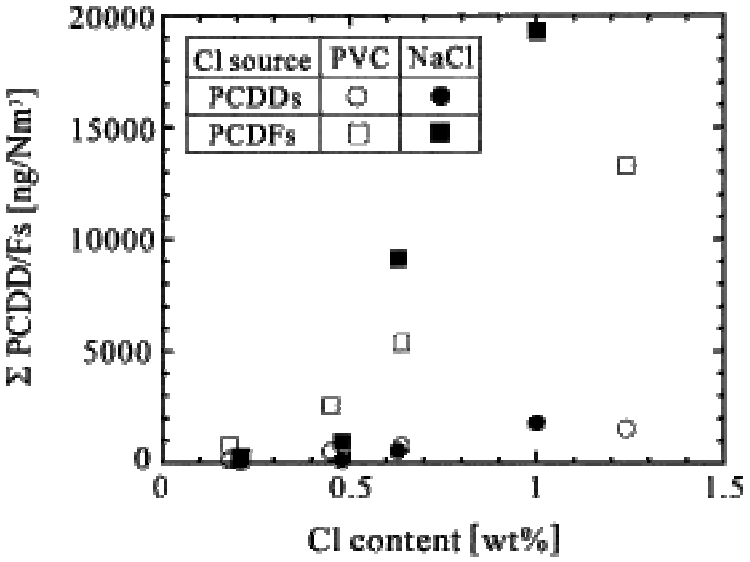
K. Estimated average annual worldwide emission sources of PCDDs and PCDFs (Brzuzy and Hites 1996, Environ. Sci. Technol. 30:1797-1804.)

Source	kilograms/year
Municipal waste incineration	1130
Biomass combustion	350
Iron metals production	350
Cement kilns (burning hazardous waste)	680
Cement kilns (no hazardous waste)	320
Secondary copper smelting	78
Medical waste incineration	84
Unleaded fuel combustion	1
Leaded fuel combustion	11
TOTAL	3004

L. It is currently recognized that municipal and medical incinerators probably contribute the most to dioxin emissions.
   1. Some environmental advocacy groups contend that burning of chlorine containing synthetic materials (like PVC plastics) is the cause of these emissions.
   2. However, mechanistic studies have shown that dioxin congeners are synthesized and emitted from incinerators regardless of whether the source fuel is PVC or NaCl (sodium chloride). (Hatanaka, et al. 2000. Environ. Sci. Technol. 34(18):3920-3924.)
      a. In the graph below (from Hatanaka et al.), there is no doubt that dioxin congeners are emitted from combustion processes; but the higher chlorinated congeners dominate.
         1. The fuel source did contain PVC (chlorine content was 0.64%)



b. Note in the graph below that dioxin congeners form regardless of the fuel source (Hatanaka et al. 2000), and the extent of formation is influenced by the total chlorine content (weight % of fuel mixture).

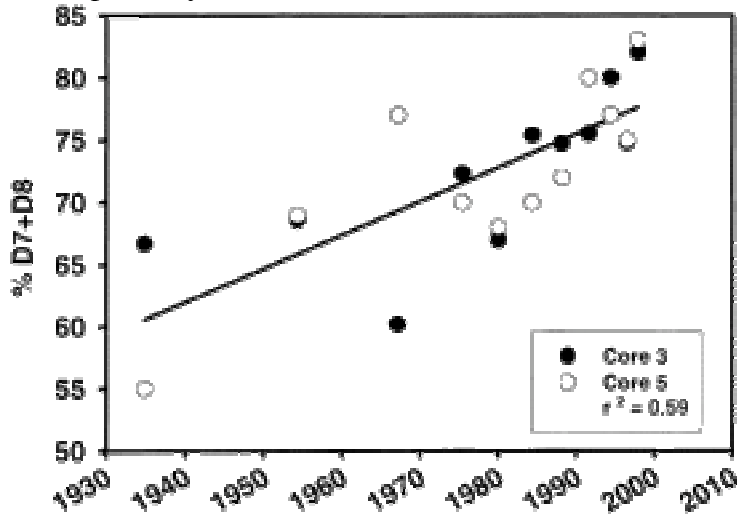


M. Mass Balance Estimations (Emissions vs. Deposition)

1. Exposure route of dioxins is believed to be through the food chain
   a. Atmospheric deposition leads to plant residues/water residues;
   b. Residues on plants eaten by cattle; people eat cattle
   c. Residues in water consumed by phytoplankton/zooplankton; fish eat phytoplankton and zooplankton; people eat fish.
2. Thus, knowing the emission and deposition rates contributes to our understanding of exposure.
3. Efforts to quantify emissions of dioxins vs. deposition have only been able to account for approximately 10 percent of the estimated deposition.
   a. In other words, estimated deposition sources exceed emission sources by nearly 10 fold.

   b. A recent modeling exercise has estimated the discrepancy in deposition and emission at 6-20 fold (Eisenberg, J. N. S., D. Bennett, and T. E. McKone. 1998. Chemical dynamics of persistent organic pollutants: a sensitivity analysis relating soil concentration levels to atmospheric emissions. Environ. Sci. Technol. 32(1):115-123.)
4. It is possible, that much of the dioxin deposited is due to re-entrainment of "old" dioxin already in the soil (blowing dust, etc.)
5. While combustion sources are now the most important factors (>95%) in dioxin emission and subsequent distribution, the particles emitted from these sources tend to be under 2.5 μm in effective diameter, indicating they deposit very slowly.
6. However, most of the particulate deposition is due to larger diameter particles (crustal materials) >2.5 μm
   a. The particle sizes account for a large percentage of the crustal contributions to particulate deposition).
7. Calculations by Kao and Venkataraman (1995. Estimating the contribution of reentrainment to the atmospheric deposition of dioxin. Chemosphere 31(10):4317-4331) suggested that re-entrainment of old dioxin in soil could account for as much as 70-90% of the total dioxin deposition to environmental surfaces in urban areas, and 20-40% in rural regions.
   a. These calculations are based on knowing the average soil residues (rural, 73 ng/kg; urban 2,075 ng/kg; industrial 8,314 ng/kg); typical ambient dioxin-bound particulate concentrations (1.36 pg m^3 in Bloomington, IN; considered a good model and reliable study); and crustal contributions to ambient atmospheric particle loads
   b. Furthermore, the calculations rely on a knowledge of the contribution of vapor vs. particle-bound dioxin to deposition.
      1. Ambient measurements indicate that vapor to particle ratios for individual PCDD/F can range from 0.01 – 30.
         a. The less chlorinated congeners have higher vapor pressures than the more chlorinated congeners and are found to a greater extent in the vapor phase. Thus, the higher chlorinated congeners are largely in the particulate phase.
      2. Dioxin deposition occurs via wet and dry deposition, with dry deposition dominating by a factor of 5-6;
      3. Vapor phase dioxin is very susceptible to photolysis (see below) or uptake directly by vegetation;
      4. Thus, particulate-bound deposition of dioxin dominates
8. A recent hypothesis has been forth by Hite's research group at Indiana University.
   a. They suggest that the missing emissions are due to de novo synthesis of hepta and octachlorodibenzodioxins (HCDDs and OCDDs, respectively) and dibenzofurans (HCDFs, OCDFs) from photocatalyzed condensation reactions of pentachlorophenol. (Baker, J. I. and R. A. Hites. 2000. Is combustion the major source of polychlorinated dibenzo-p-dioxins and dibenzofurans to the environment? A mass balance investigation. Environ. Sci. Technol. 34(14):2879-2886.)
      1. In addition to doing some lab work that shows OCDD formation from irradiated PCP (pentachlorophenol) in the presence of water vapor, they hypothesize from two limnological cores that the formation of HCDDs and OCDDs is greater than what would be predicted from combustion sources alone.
      2. They claim the hypothesis is partly suggested by EPA data showing that combustion emissions of dioxin have significantly decreased over the last twenty years, yet OCDDs relative to all dioxins (i.e., PCDDs) has increased.
         a. Note that PCP had been used commonly to treated wood, especially for use as telephone poles and fence posts; thus, PCP continually volatilizes into the environment.

b. Note in the figure below that D7 and D8 refer to HCDDs and OCDDs, respectively.



IV. Environmental Degradation

A. Photodegradation
   1. Comparatively high lability in sunlight for an otherwise very stable compound--thus might expect the photolysis half-lives to be very rapid
      a. Surface water, 40° latitude north in summer = 4.6 d
      b. Summer = 21 h; fall = 51 h; winter = 118 h; spring = 27 h
      c. Pond water, experimental = 3.5 days

B. Compared to photodegradation, volatilization, mobility and degradation are minor pathways
   1. Half-life in soils has been estimated to range from 1-10 yr
   2. Half-life in sediments ~ 550 - 590 d.

V. Basic Toxicology

A. Because discussion of environmental trends and exposure potential to chlorinated dioxins and dibenzofurans tends to involve not the actual mass per unit matrix concentrations but rather an expression of toxic equivalents (TEQs), we will first take a short digression into some basic toxicological considerations to better understand TEQs.

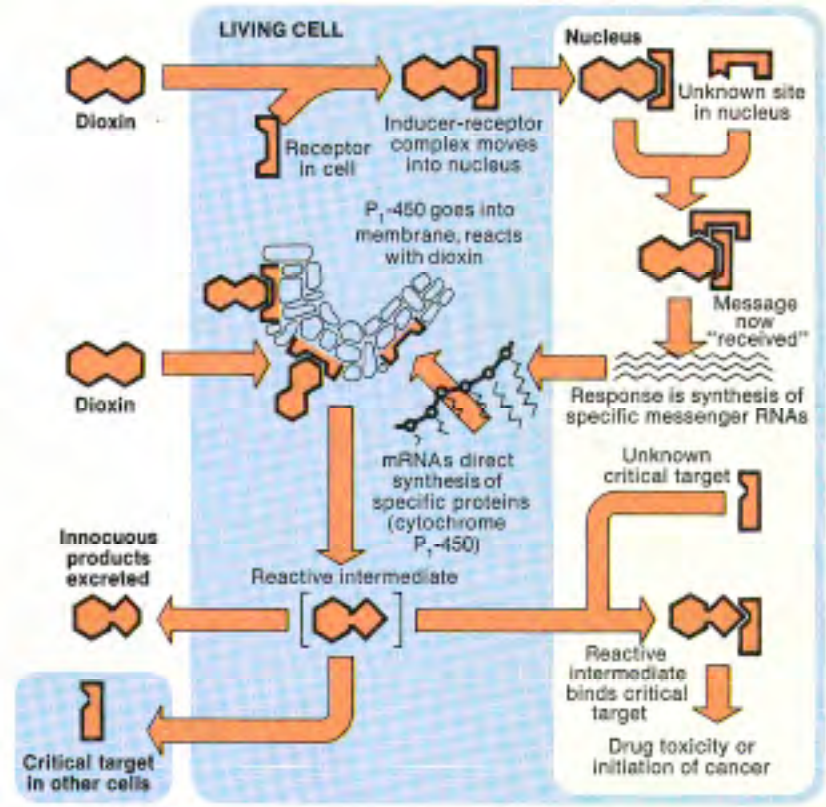
B. Discussion of acute toxicity usually involve a listing of LD50's after a single oral dose administration (or other route).
   1. Dioxins (i.e., TCDD) are somewhat unique in that acute toxicity is related more to the body burden rather than to the route of exposure (as is commonly observed with other contaminants).
      a. Species vary widely with respect to doses causing acute toxicity, partly because of wide differences in body half life and partly because of biochemical interactions with the putative receptor (the Ah receptor) (see data table on the next page)
      b. For example, TCDD half-life in mice is ~10-15 days, in rats it is ~12-31 days, but in humans the half-life has been estimated to be 5.8-11.3 years (Martinez et al., 2003, Toxicology of dioxins and dioxin like compounds. Pp. 137 –157 in Dioxins and Health, second ed., Schecter, A., and Gasiewicz, T. A. ed., John Wiley & Sons, Inc.)
         1. Body burdens for lipophilic chemicals are dependent on the weight and body fat of an animal, which are highly variable among different species.
         2. In cases of acute TCDD toxicity, the nondigestible fat substitute olestra can increase the excretion rate of TCDD

   c. Thus, a single exposure to dioxins results in an exposure duration that is dependent on the chemical half-life in the body.
2. Nevertheless, toxicity is correlated with structure because congeners with halogenation at the 2,3,7,8 positions are toxic.
   a. The one exception is octachlorodioxin; it is not very toxic, but it is extremely stable.

Survey of Acute Toxicity Differences Among Species (Adopted from Martinez et al. 2003); Oral Exposures to TCDD

Animal	LD_{50} (μg/kg body weight)	Clinical Toxic Effects
Guinea pig	0.6 – 2.1	Body weight loss; thymus gland & lymphatic tissue atrophy; hepatic vit. A depletion; adverse contraction of atrial muscle
Sprague-Dawley rat (male & female)	25-50	Thymic atrophy, interference with bone growth, mechanical strength; porphyria; hepatic vit. A depletion; changes in liver enzyme function; anorexia; body weight loss; wasting syndrome; lung hemorrhage, infection, perivascular edema
Hamsters	5050	Body weight loss; liver & thymus alterations
Chicken	<25	Body weight loss; stunted growth; edema; sudden death
Monkey	25-70	Body weight loss; anemia; cutaneous lesions; thymic atrophy; wasting syndrome; increases in serum triglycerides; other enzyme responses
Mice	2.6 – 620	Body weight loss; wasting syndrome; vit. A depletion; enzyme changes; liver necrosis; bone marrow effects

C. Toxicity is believed mediated through binding to a cytosolic protein receptor called Ah (see figure below, "receptor in cell" is the Ah receptor)
   1. The figure on the next page is from a 1983 edition of Chemical and Engineering News, a weekly science magazine published by the American Chemical Society. Although the figure is somewhat dated and the interactions with the Ah receptor have been updated, it is remarkably correct in its basic hypothesis of how TCDD might trigger a cascade of reactions leading to biochemical changes and adverse biochemical/physiological effects
      a. Today, the interactions of bound Ah receptor with specific genetic elements is better characterized than 20 years ago.
   2. In brief, the mechanism was hypothesized to works as follows:
      a. Bound Ah receptor complex moves into the nucleus which induces new m-RNA synthesis leading to synthesis of AHH (aromatic hydrocarbon hydroxylase), which uses the cytochrome P-448 (now called **cyt P-4501A**);
      b. In 1983, one hypothesis stated that AHH metabolized TCDD to some reactive intermediate that then had unknown effects (i.e., mechanism not known) on target cellular constituents.
      c. Today, however, it is believed that certain cell regulatory processes may be controlled by unbound Ah receptor. Furthermore, induction of cyt P450 synthesis has many downstream biochemical effects besides biotransformation.
         1. A plethora of research and consequently research articles have appeared over the last 20 years that have examined a large number of possible mechanistic consequences of TCDD exposure in experimental animals.



3. However, there is a correlation between toxicity and the degree of induction and binding to the receptor. (See the next table based on Safe 1990 (Polychlorinated biphenyls (PCBs), dibenzo-p-dioxins (PCDDs), dibenzofurans (PCDFs), and related compounds: environmental and mechanistic considerations which support the development of toxic equivalency factors (TEFs). Critical Reviews in Toxicology 21(1):51-88)
   a. Indeed, toxicity differences among species may not be due to the amount of Ah receptor in a cell but rather to its affinity for a contaminant substrate (Martinez et al. 2003, p. 149)

Isomer (Chlorine position)	**Guinea Pigs LD_{50}-30 day exposure (μmol/kg)**	**Mice LD_{50}-30 day exposure (μmol/kg)**	**Chick LD_{50} (μg/egg)**	**ED_{50} for AHH induction (pmol/plate) Rat hepatoma cell**
Dibenzodioxins				
2,8-dichloro-	>1,180	--	6.3	>50,000
2,3,7-trichloro	120	>10	1.08	>4,000
2,3,7,8-tetrachloro	**0.006**	**0.88**	**0.007**	**1.5**
1,2,3,7,8-penta	0.009	0.94	0.003	22
1,2,4,7,8-penta	3.2	>14	0.012	> 5,000
1,2,3,4,7,8-hexa	0.19	2.1	0.16	31
1,2,3,6,7,8-hexa	0.18 - 0.26	3.2	0.12	128
1,2,3,7,8,9-hexa	0.15 - 0.26	>3.7	0.01	189
1,2,3,4,6,7,8-hepta	>1.4	--	1.61	551
Dibenzofurans				
2,3,7,8-	0.016 - 0.032	19.6	--	13
2,3,4,7,8-	0.009 - 0.029	--	--	8

D. Toxic Equivalency Factors (TEFs) and Toxic Equivalents (TEQs)
   1. Because environmental & food matrices may be contaminated by numerous congeners, and not all congeners are as toxic as TCDD (some may even have no biological effect), the amounts of chlorinated dioxins and dibenzofurans are expressed as toxic equivalents
   2. This scheme of expressing the total PCDDs and PCDFs as TEQs is currently used to express total concentrations in environmental samples and tissue samples.
      a. The validity of using TEQs for abiotic matrices is questionable because of physicochemical limitations (i.e., soil sorption, rate of uptake bioaccumulation factors)
      b. Once the PCDD/F is in the tissues, however, TEQs become more relevant.
   3. The TEQ assumes that all the compounds have the same mode of toxicity or interaction with the same receptors or induce the same enzymes; all PCDD/Fs interact with the Ah receptor and induce cyt P4501A1
   4. All isomers are assigned a Toxic Equivalency Factor (see next table) based on the toxicity of TCDD (this could be the LD_{50} to a guinea pig or other animal or it could be units of induction in the hepatoma assay)
      a. Residues of each isomer are multiplied by the TEF, and then all residues are summed to calculate the amount of TEQs in a sample
      b. Potential exposure in different matrices or body burden can then be estimated by comparing the TEQs

$$\mathbf{TEQ}_{2,3,7\text{-}8TCDD} = \text{sum}[PCDD_i \times TEF_i] + \text{sum}[PCDF_i \times TEF_i]$$

Current TEF values used by the EPA (for mammals; based on in vivo data) (Van den Berg et al. 1998, Environ. Health Perspectives 106:775-792)

Congener	**EPA**	**Recent WHO recommendation**
2,3,78-TetraCDD (TCDD)	1	1
1,2,3,7,8-PentaCDD	0.5	1
1,2,3,4,7,8-HexaCDD	0.1	0.1
1,2,3,6,7,8-HexaCDD	0.1	0.1
1,2,3,7,8,9-HexaCDD	0. 1	0.1
1,2,3,4,6,7,8-HeptaCDD	0.01	0.01
OctaCDD	0.001	0.0001
2,3,78-TetraCDF	0.1	0.1
1,2,3,7,8-PentaCDF	0.05	0.05
2,3,4,7,8-PentaCDF	0.5	0.5
1,2,3,4,7,8-HexaCDF	0.1	0.1
1,2,3,6,7,8-HexaCDF	0.1	0.1
1,2,3,7,8,9-HexaCDF	0.1	0.1
2,3,4,6,7,8-HexaCDF	0.1	0.1
1,2,3,4,6,7,8-HeptaCDF	0.01	0.01
1,2,3,4,7,8,9-HeptaCDF	0.01	0.01
OctaCDF	0.001	0.0001

VI. Environmental Trends

A. In addition to recent articles that have attempted to estimate the global mass balance of PCDD/Fs (for example, Brzuzy, L. P., and R. A Hites. 1996. Global mass balance for

polychlorinated dibenzo-p-dioxins and dibenzofurans. Environ. Sci. Technol. 30:1797-1804), trends in concentrations are beginning to be elucidated (for ex., Alcock, R. E., K. C. Jones. 1996. Dioxins in the environment: a review of trend data. Environ. Sci. Technol. 30:3133-3143).

B. PCDD/Fs have been detected in paleolimnological cores dating to the 1600s, but there is no doubt that the concentrations really increased in the mid 20th century. However, examination by Alcock and Jones (1996) of lake data indicate the concentrations may be declining from what they were even a decade ago. The sediment concentrations from the lakes may not be showing definitive evidence of decline yet. These kinds of declines would be predicted based on tremendous control and reduction of chemical (production) sources of dioxins, and controls on incinerator emissions.

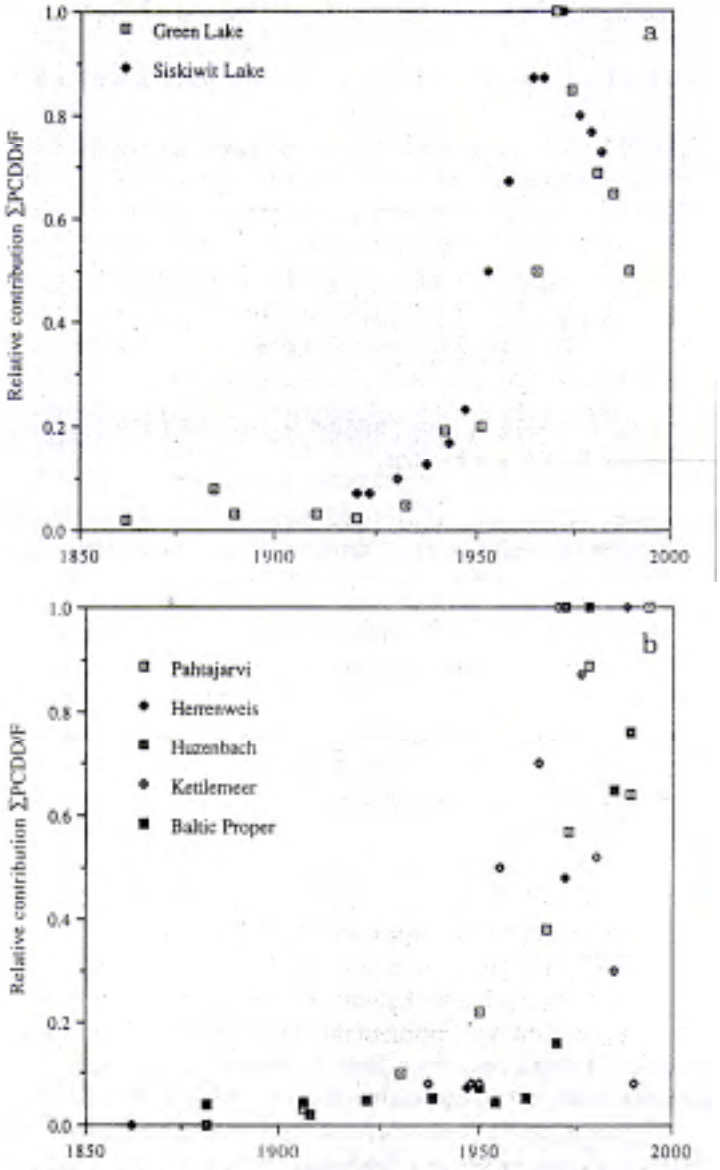
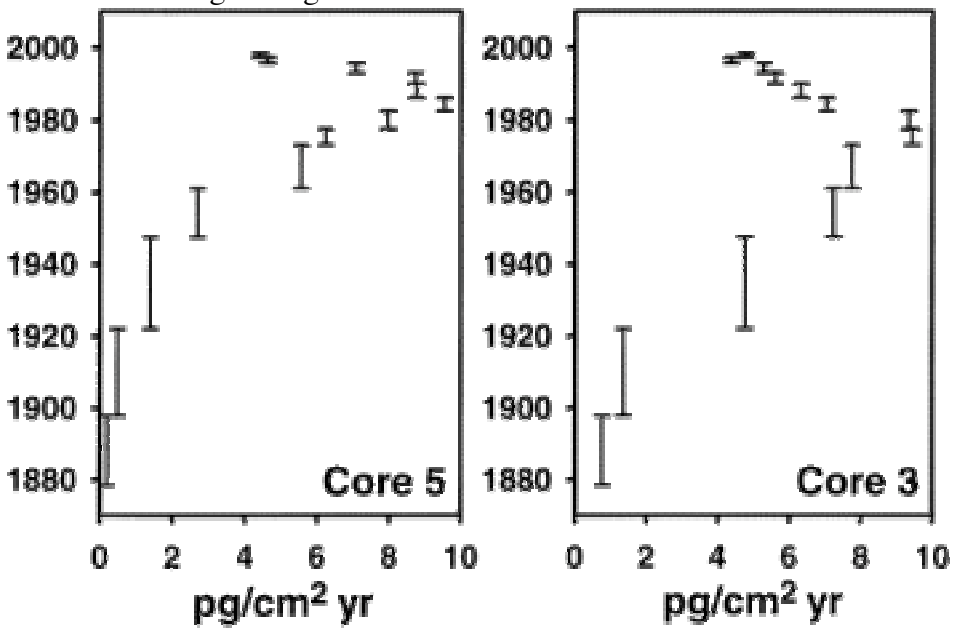
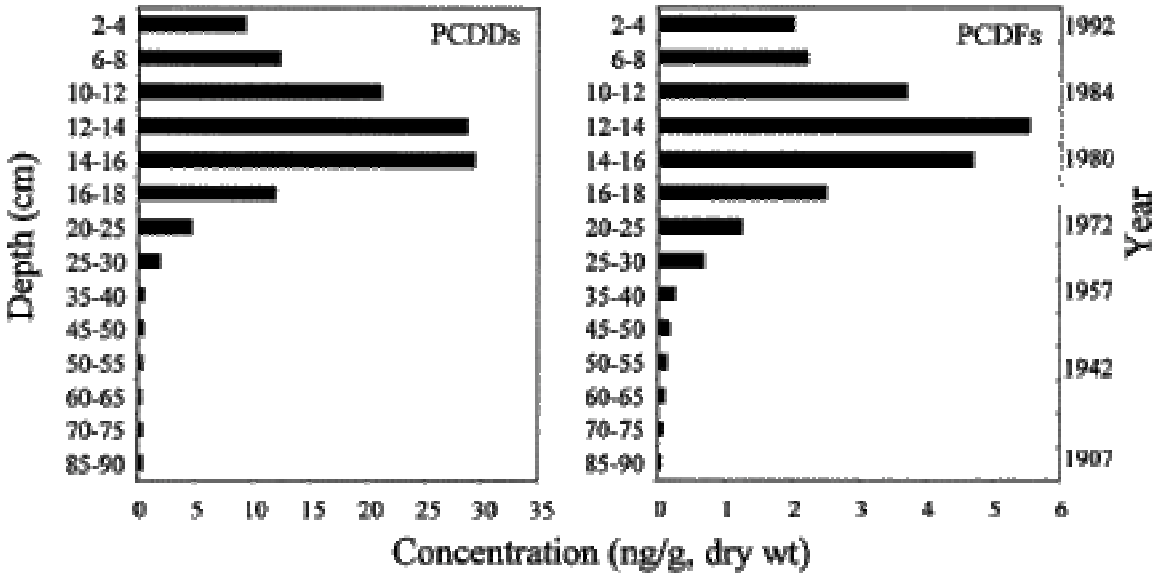


FIGURE 1. (a) Generalised plot of ∑PCDD/F trends from Green Lake and Siskiwit Lake. Data scaled relative to the peak year (set at 1.0) in each study. (b) ∑PCDD/F trends from European sedimentary studies. Data scaled relative to the peak year (set at 1.0) in each study.

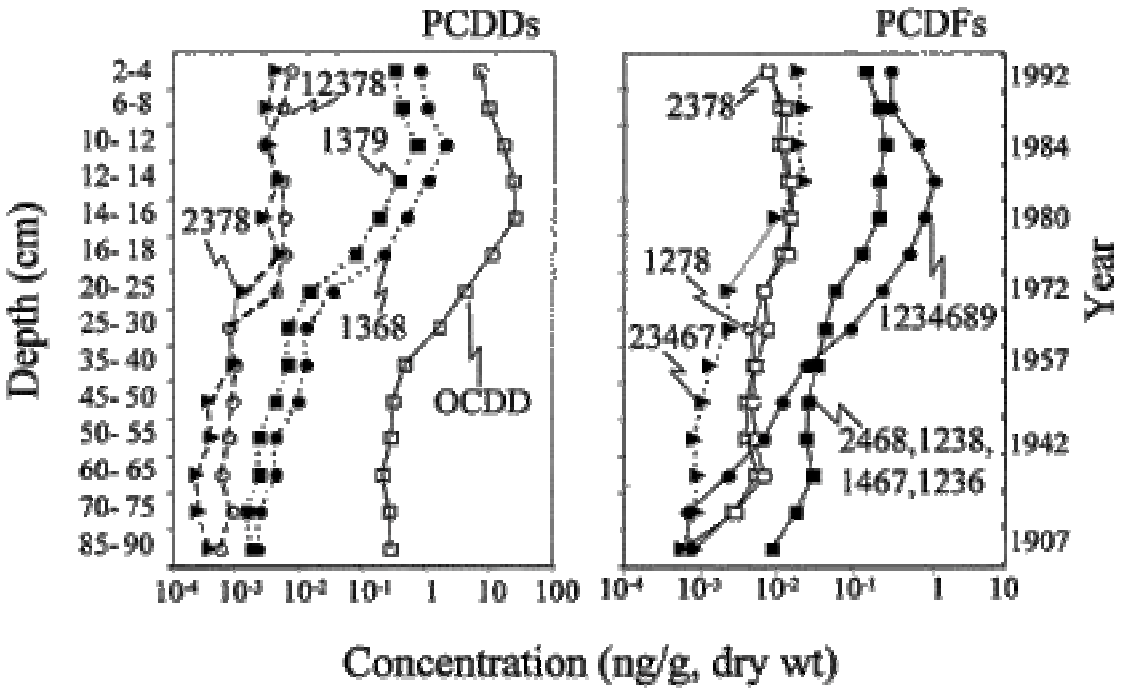
C. The Siskiwit Lake data have recently been revisited by Baker, J. I. and R. A. Hites. (2000. Siskiwit Lake revisited: time trends of polychlorinated dibenzo-p-dioxin and dibenzofuran deposition at Isle Royale, Michigan. Environ. Sci. Technol. 34(14):2887-2891.)
   1. They noted that the rise in dioxins began in the 1930's. The data do show a decline after reaching the highest levels in the 1970's.



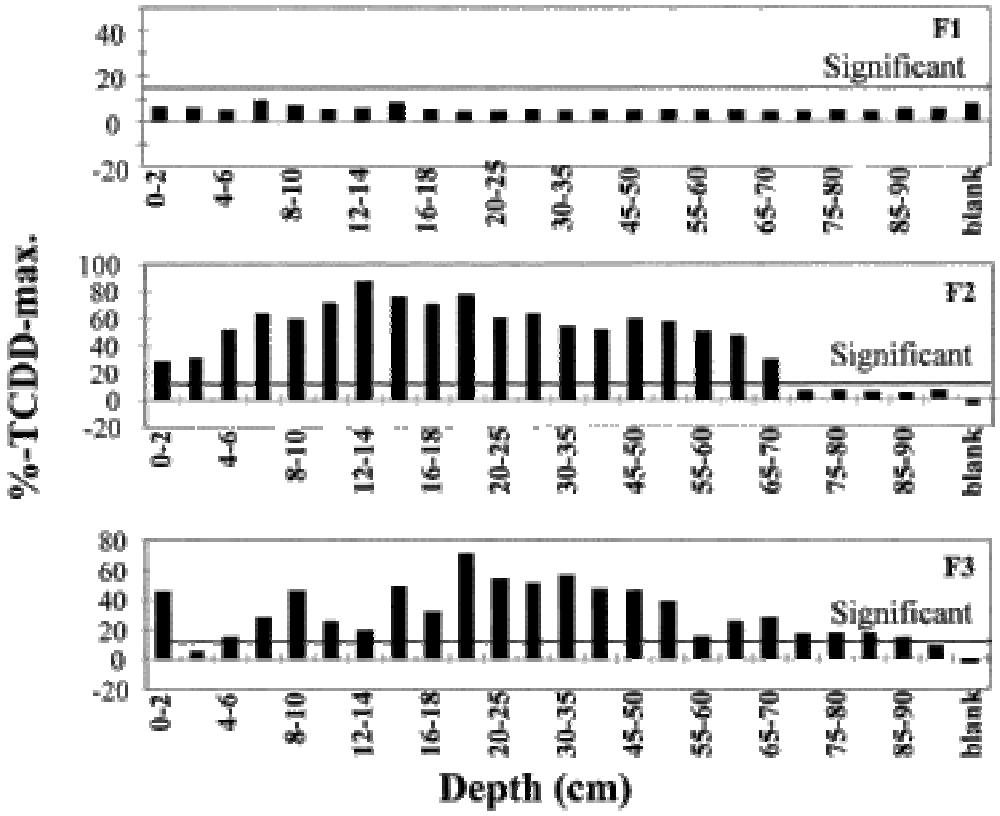
D. Studies from Japan concur with U.S. studies showing that dioxin congeners were present 100 years ago, but rose precipitously after the 1930s. (Yamashita, N. et al. 2000. Vertical profile of polychlorinated dibenzo-p-dioxins, dibenzofurans, naphthalenes, biphenyls, polycyclic aromatic hydrocarbons, and alkylphenols in a sediment core from Tokyo Bay, Japan. Environ. Sci. Technol. 34(17):3560-3567.)



   1. The dominant congener was OCCD and either the hepta or octachlorodibenzofuran.



2. Extraction and subsequent biological testing of limnological core material did indicate dioxin-like biological activity. (Kannan, K. et al. 2000. Vertical profiles of dioxin-like and estrogenic activities associated with a sediment core from Tokyo Bay, Japan. Environ. Sci. Technol. 34(17):3568-3573.)



E. Given the physicochemical properties of PCDD/Fs and the slow elimination half-lives from the whole body, bioconcentration factors will be extremely high, and thus we expect long term accumulation of residues in aquatic organisms, especially fish. However, trends in fish tissues indicate some decline, as would be predicted if water concentrations are declining. (Graph clipped from Alcock & Jones (1996) Dioxins in the Environment: Review of trend data. Environ. Sci. Technol. 30:3133-3143)

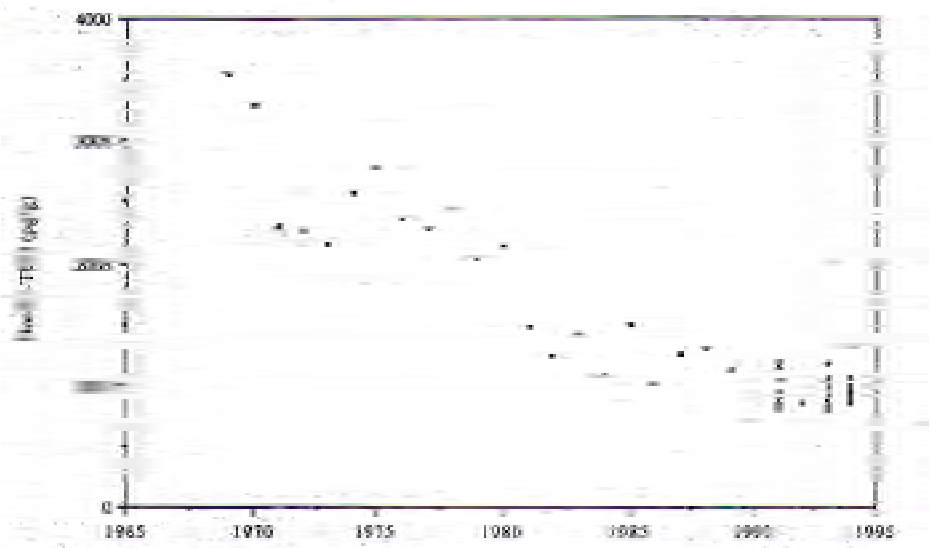


FIGURE 6. Nordic-TEQ trends (1969–1994) in guillemots from Stora Karlsö, Sweden.

F. Air concentrations appear to be declining. Considering atmospheric deposition is the main source of dioxin exposure in the environment, declines in air concentrations also signal further declines in other environmental compartments. (Graph clipped from Alcock & Jones [1996])

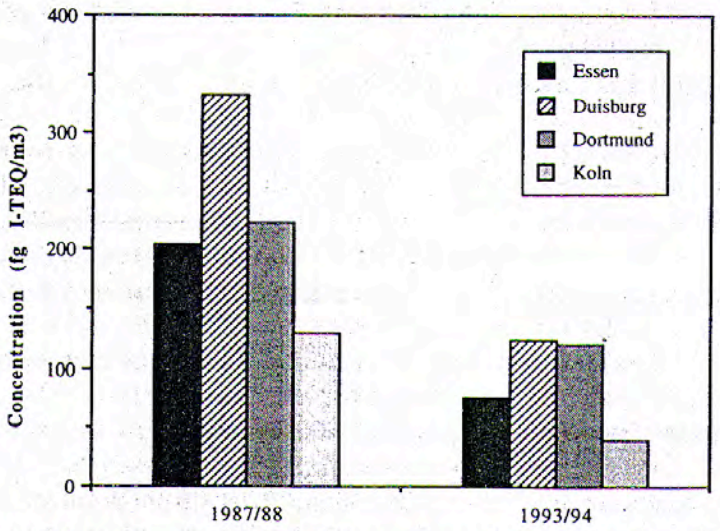


FIGURE 2. Reduction of ∑PCDD/F concentrations in the ambient air of four cities in North-Rhine-Westfalia, Germany.

G. Concentrations in vegetation samples (according to measurements in the U.K.) seem to be declining from historically high levels. (Graph clipped from Alcock & Jones [1996])

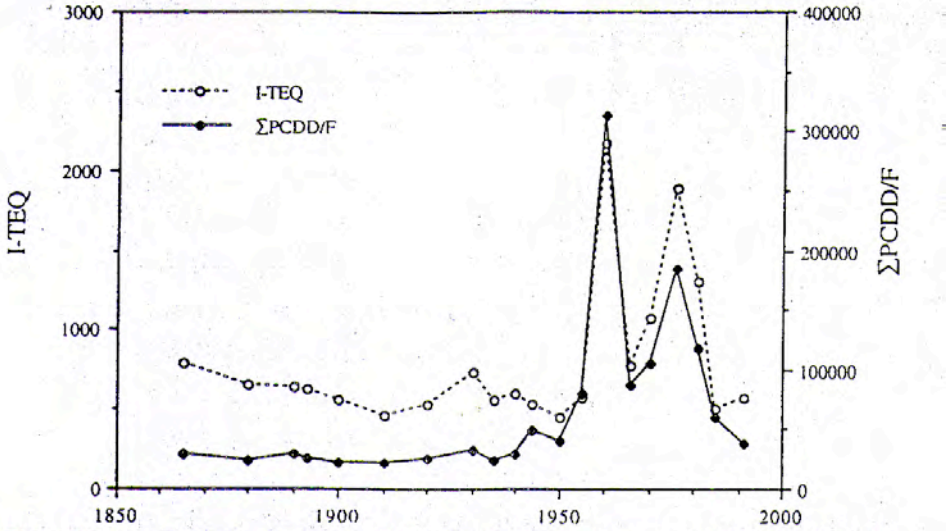


FIGURE 3. Trends in both ∑PCDD/F (ng/kg) and I-TEQ (ng/kg) in archived Park Grass herbage.

H. The declines in vegetation samples should eventually translate to a decline in human intake through declines in concentrations in meat and milk. (Graph clipped from Alcock & Jones [1996])

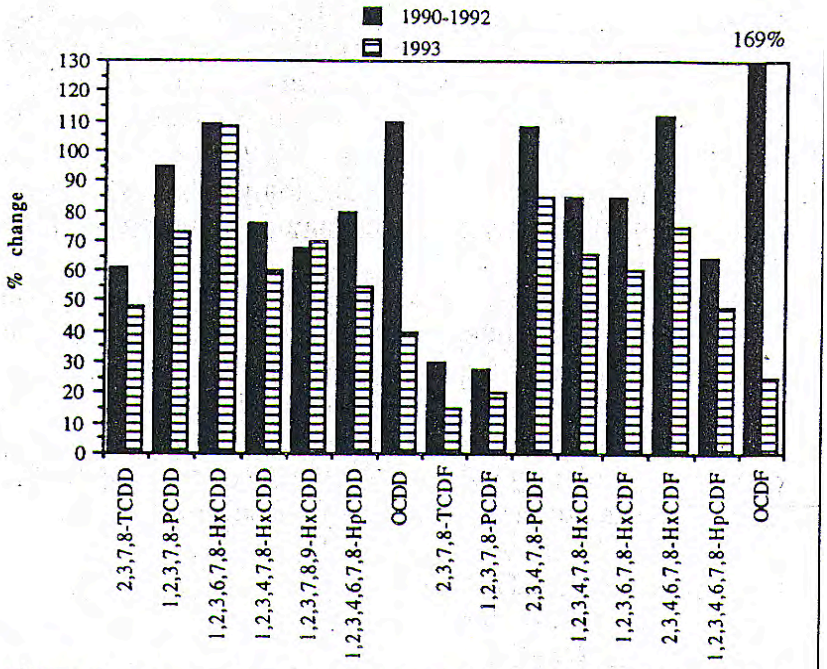


FIGURE 7. Change in mean concentrations of PCDD/Fs (in pg/g of fat) in Dutch human milk between 1988, 1990–1992, and 1993. The figures show mean concentrations in 1990–1992 (*74*) and 1993 (*73*) expressed as a percentage of the concentrations found in 1988.

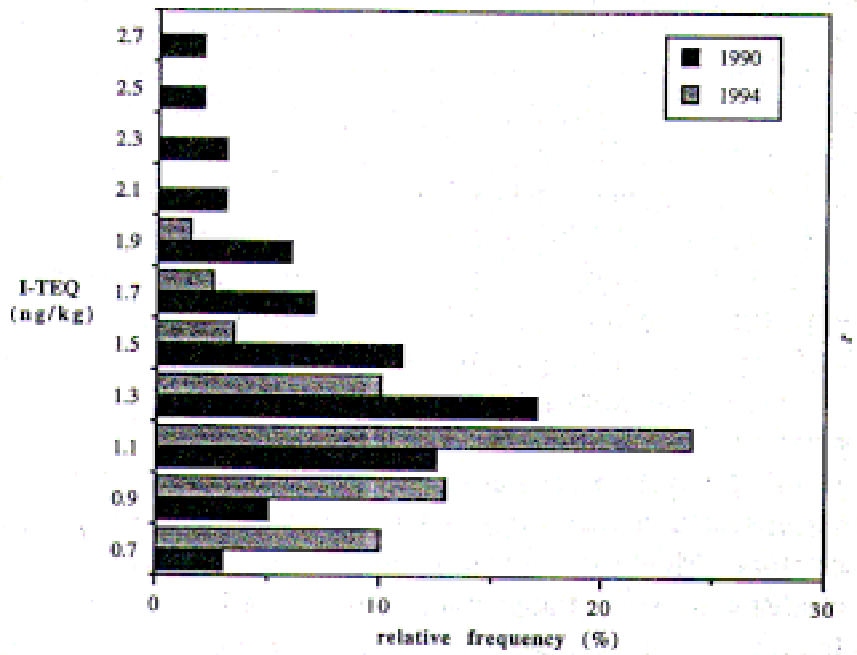


FIGURE 5. Declining relative frequency of I-TEQ concentrations in German cows milk from 1990 to 1994.

1. A decline in PCDD/F intake in milk may be occurring. (Graph clipped from Alcock & Jones [1996])

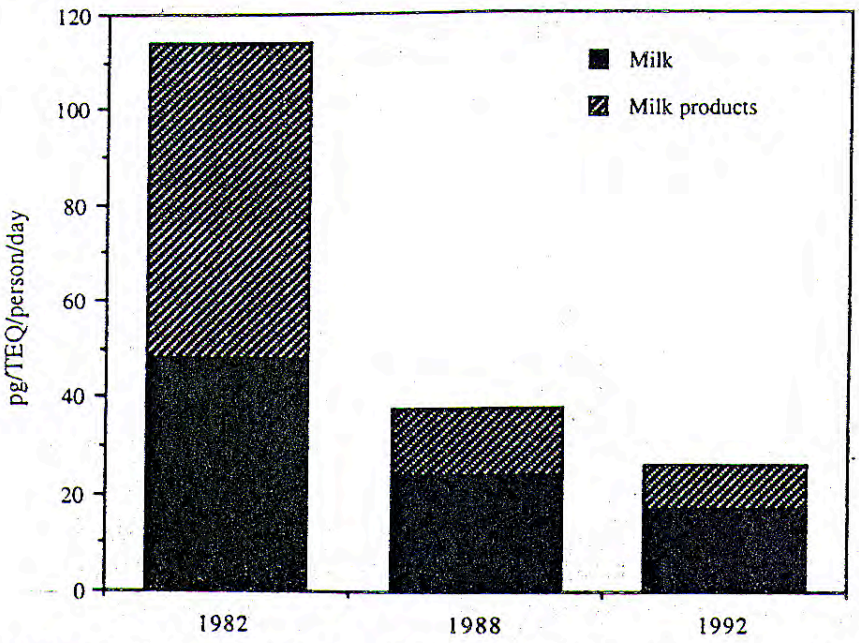


FIGURE 4. Estimated dietary intakes of dioxins by average U.K. consumers of milk and milk products (calculated using U.K. National Food Survey consumption data).