DIOXIN EMISSIONS FROM MUNICIPAL SOLID WASTE INCINERATORS AND THE POTENTIAL FOR HUMAN EXPOSURE

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INTRODUCTION

Although sanitary landfills are currently the primary method of municipal solid waste (MSW) management, the U.S. Environmental Protection Agency (US EPA, 1987a) estimates that half of all municipalities will lack adequate landfill space within 10 years. Consequently, numerous cities and counties are considering MSW incineration as an alternative waste management option (Petty and Rodgers, 1985). Because combustion is widely recognized as a source of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), including the highly toxic 2,3,7,8,-tetrachlorodibenzo-p-dioxin (TCDD, commonly referred to as dioxin) (Rappe *et al.*, 1987a), considerable local and national opposition to MSW incineration has arisen. Many people living near MSW incinerators fear that they will be exposed to high levels of PCDDs and PCDFs and subsequently develop cancer.

As the controversy surrounding MSW incineration intensifies, government agencies, public officials, and the public question whether municipal waste combustion is a feasible waste management alternative. In this atmosphere of intense political debate, decision makers are presented with massive amounts of information and pressured to address public skepticism and concern about the safety of these facilities. It has become a formidable challenge for any individual to critically evaluate the myriad of information available. Given the sensitivity and importance of this issue, however, we have attempted such an evaluation. This paper is not intended to resolve the incineration debate but to examine the following issues concerning human exposure to facility-emitted dioxins and furans: (1) Are environmental concentrations of PCDDs and PCDFs around MSW incinerators elevated? (2) Are MSW incinerators the

major source of human exposure to PCDDs and PCDFs? and (3) Are incinerators the major source of PCDD/PCDF input into the environment?

II. ENVIRONMENTAL CONCENTRATIONS

To determine if environmental PCDD/PCDF concentrations around operating MSW incinerators are elevated, they must be evaluated in the context of background environmental concentrations to which individuals are continuously exposed. Measured data on the concentration of PCDDs and PCDFs in air, soil, and animal tissues obtained from sites near operating MSW incinerators are scarce. The existing data, however, provide little evidence that PCDD/PCDF concentrations around these facilities are substantially elevated relative to background levels.

A. Ambient Air

The incremental change in air concentration (expressed in TCDD-toxic equivalents) predicted by air quality models to occur at the point of maximum individual exposure near a typical, modern MSW incinerator is 11 fg/m^3 (Table 1). Background concentrations of PCDDs and PCDFs (expressed in TCDD-toxic equivalents) measured in urban air in the U.S. (Indiana, New York, California, and Ohio), West Germany, and New Zealand range from 11 to 345 fg/m^3 with a geometric mean concentration of 55 fg/m^3 (Table 2). [The relative toxicity of measured background dioxin and furan urban air concentrations was calculated according to the International Toxic Equivalent Factor (I-TEF) weighing scheme (Kutz *et al.*, 1989) assuming a perfect isomeric distribution if values for 2,3,7,8-substituted congeners were not reported.] Thus, the maximum

incremental air concentration of dioxins and furans estimated to occur around a typical, modern MSW incinerator (11 femtograms (fg)/m^3) is about five times lower than mean background levels of PCDDs and PCDFs measured in urban air (55 fg/m^3).

Measurements of atmospheric levels of PCDDs and PCDFs (in toxic equivalents) near operating MSW incinerators are scarce. Rappe *et al.* (1988) reported that the mean concentration of PCDDs and PCDFs measured 1.5 kilometers (km) downwind from an MSW incinerator near Hamburg, West Germany, was 100 fg/m^3. Olie *et al.* (1983) found that the concentration of PCDDs and PCDFs in air two km from an MSW incinerator near Amsterdam was 164 fg/m^3. Edgerton *et al.* (1989) reported that the concentration of PCDDs and PCDFs in air two km downwind from an MSW incinerator in an urban area of Ohio was 78 fg/m^3. These data are difficult to interpret, since background measurements were not taken silmutaneously. Three studies that do report background levels along with measured air concentrations around an operating facility (Edgerton *et al.*, 1989; Rappe *et al.*, 1988; Tiernan *et al.*, 1989) show that levels near the MSW incinerators (78, 100, and 12 fg/m^3, respectively) are virtually identical to measured background urban air concentrations (48, 83, and 11 fg/m^3, respectively). Furthermore, the geometric mean measured air concentration around operating MSW incinerators (63 fg/m^3) appears to be comparable to the mean background urban air concentration of PCDDs and PCDFs (87 fg/m^3) (Table 2). These data suggest that PCDD/PCDF levels two km away from MSW incinerators should be indistinguishable from background urban air levels.

Rappe *et al.* (1988) measured ambient PCDD and PCDF levels in an industrial area 100 m from a motorway and 600 m from a copper smelter. Mean

PCDD/PCDF levels (in toxic equivalents) were 608 fg/m^3, which is about 11 times higher than the global mean concentration measured around operating incinerators. Similarly, Christmann *et al.* (1989) found that mean PCDD/PCDF levels in air 300 m from a copper smelter in Austria were 1200 fg/m^3, which is 19 times higher than the mean global air concentration measured around operating MSW incinerators (Table 2). These data indicate that sources other than MSW incinerators can contribute to elevated levels of PCDDs and PCDFs in urban air.

B. Soil

PCDDs and PCDFs have also been detected in soil samples worldwide. PCDD/PCDF levels measured in background urban soil and in soil around MSW incinerators are presented in Table 3. Nestrick *et al.* (1986) measured PCDDs and PCDFs in surface soil samples at 15 urban sites in the midwest. These samples contained mostly HCDDs and OCDDs, a pattern which is similar to that observed in other media samples taken from sites with no known direct source of contamination (US EPA, 1988b). Total PCDD/PCDF concentration in suburban and rural samples ranged from 0.47 to 9.1 ng/g, with a geometric mean concentration of 1.0 ng/g, which is about two times higher than the mean world concentration of PCDDs and PCDFs around incinerators.

Yasuhara *et al.* (1987) measured PCDD/PCDF levels in soil near four MSW incinerators in Japan. (Incinerator type, age, and distance from the incinerator at which samples were taken were not specified). The geometric mean concentration near these incinerators (5.3 ng/g) is about 18 times higher than the mean world background concentration but only about four times greater than the US/Canada mean concentration (1.3 ng/g). Since background

concentrations of PCDDs/PCDFs in Japanese soil were not reported, it is impossible to determine if soil concentrations near these incinerators were elevated relative to background levels in that country.

McLaughlin and Pearson (1985) measured soil concentrations of PCDDs and PCDFs at 11 sites 0.1 to 2.1 km away from the SWARU MSW incinerator, which has been operating in Hamilton, Ontario, Canada, since 1973, and at three control sites (two suburban sites 4.5 and 5.6 km away and one remote site 22 km away). The geometric mean concentration for the 11 test sites near the incinerator (0.4 ng/g) was about five times lower than the geometric mean concentration for the two suburban sites (1.8 ng/g) and about two times lower than the remote site concentration (0.8 ng/g).

Berlincioni and di Domenico (1987) assayed soil samples collected at five sites within a 1 km radius of an MSW incinerator that has been operating in Florence, Italy, since 1973. Background levels were determined at two sites eight kilometers from the incinerator. The geometric mean PCDD/PCDF soil concentration near the incinerator (0.25 ng/g) is 25 times higher than Italian background levels (0.01 ng/g) but virtually identical to mean world background levels (0.35 ng/g).

Nielsen and Lokke (1987) examined soil samples from three "relatively unpolluted sites" 0.1 to 0.5 kilometers away from a small MSW incinerator and found that PCDD/PCDF concentrations near that facility were not elevated relative to background concentrations. Depending on release point and plume characteristics, however, maximum soil concentrations may have occurred further away from the incinerator.

Finally, Creaser *et al.* (1989) sampled 77 sites across the United Kingdom to quantify typical environmental levels of PCDDs and PCDFs in British

soil. Total PCDD/PCDF levels ranged from <0.05 ng/g to 2.3 ng/g with a mean concentration of 0.45 ng/g. U.K. soil levels appear to be about half as high as U.S. levels but virtually identical to mean levels near MSW incinerators (0.57 ng/g).

These data are not sufficient to make definitive statements about whether the concentration of PCDDs and PCDFs around operating MSW incinerators are substantially elevated. For example, if the Japanese data are included in the geometric mean, levels of PCDDs and PCDFs in soil around MSW incinerators appear to be about two times higher than background concentrations. Conversely, if the Japanese data are not included in the geometric mean, PCDD/PCDF levels near MSW incinerators (0.27 ng/g) are virtually identical to background urban levels (0.35 ng/g).

C. Cow Milk

Although analyses of PCDDs and PCDFs in commercial milk samples are limited, existing measurements indicate global contamination of dairy products. PCDD/PCDF levels measured in commercial milk samples and samples obtained from cows grazing on farmland near operating MSW incinerators are presented in Table 4.

Rappe *et al.* (1987b) analyzed single milk samples from cows that grazed on farmland located: (1) 16 km from a small MSW incinerator and 20 km from a large MSW incinerator; (2) 0.2 to 1 km from a "typical medium-sized MSW incinerator;" (3) 0.3 to 1 km from the same incinerator in (2); and (4) one km from a production site for chlorinated products. Two commercial milk samples represented background samples. PCDD/PCDF concentrations (expressed in toxic equivalents on a whole milk basis) for the three incinerator samples had a

geometric mean concentration of 289 picograms (pg)/kg. Mean PCDD/PCDF concentrations for the two control samples was 71 pg/kg. The concentration of PCDDs and PCDFs in the sample collected from cows grazing near the chlorinated products production site was 212 pg/kg, which is similar to levels in milk from cows grazing near MSW incinerators and about three times higher than background levels. These data indicate that other processes (not just MSW incineration) are capable of contributing to elevated levels of PCDDs and PCDFs in cow milk.

Beck *et al.* (1987) analyzed eight cow milk samples collected from different dairies in West Germany not located near MSW incinerators and found that the mean concentration of PCDDs and PCDFs was 62 pg/kg. The Ontario Ministry of the Environment (OME, 1988) analyzed concentrated extracts of composite milk samples pooled from four regions in Ontario and found that PCDD/PCDF levels in whole milk were 30 ng/kg. Fürst *et al.* (1989) tested 10 West German cow milk samples for the presence of dioxins and furans and found that mean PCDD/PCDF levels of 144 pg/kg. Finally Startin *et al.* (1989) collected milk samples from seven farms located in rural areas of England and Wales and found mean PCDD/PCDF levels of 43 pg/kg.

Thus, the single measured concentration of PCDDs and PCDFs in milk samples from cows grazing near MSW incinerators (289 pg/kg) is about five times higher than mean measured world background concentrations (61 pg/kg). Data on PCDD/PCDF levels in commercial milk samples and samples from cows near operating MSW incinerators, however, are not sufficient to make definitive statements. Given that dairy products are a major pathway of human exposure to dioxin (Travis and Hattemer-Frey, 1990) and that milk cartons may also be a source (Mathar *et al.*, 1989), it is essential that more measurements be taken

around operating facilities.

III. BACKGROUND EXPOSURE TO PCDDs AND PCDFs

PCDDs and PCDFs, including the toxic TCDD, have been measured in practically all media, including air, soil, meat, milk, fish, vegetation, and human biological samples (Beck *et al.*, 1987, 1989; Creaser *et al.*, 1989; Czuczwa *et al.*, 1984; Eitzer and Hites, 1989; Nestrick *et al.*, 1986; OME, 1988; Patterson *et al.*, 1986; Rappe and Kjeller, 1987; Smith *et al.*, 1989; US EPA, 1987b). Because dioxins and furans tend to bioaccumulate in the food chain, even the small concentrations found in vegetation, fish, beef, and dairy products result in human exposure. For example, Travis and Hattemer-Frey (1990) showed that the food chain, especially beef and dairy products, accounts for 99% of human exposure to background levels of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). Inhalation and ingestion of contaminated water are not major pathways of human exposure to TCDD.

Beck *et al.* (1989), Ono *et al.* (1987), OME (1988), and Fürst *et al.* (1989) analyzed randomly collected food samples of the human diet and estimated the average, background daily intake of PCDDs and PCDFs (in TCDD-toxic equivalents) by the general population to be 90, 60, 92, and 89 picograms (pg) per day, respectively. The Japanese and Canadian intake estimates, however, reflect the dietary consumption of an individual weighing 50 kg and 60 kg, respectively. If these estimates are adjusted for an individual weighing 70 kg, then the average daily intake of PCDDs and PCDFs is 84 and 107 pg/day, respectively. Hence, market basket studies show that the mean background dietary intake of PCDDs and PCDFs (expressed in toxic

equivalents) in industrialized countries is about 93 pg/day (for an individual weighing 70 kg), with meat and dairy products accounting for the majority of daily intake.

Table 5 shows that human exposure to PCDDs and PCDFs emitted from a state-of-the-art MSW incinerator is dominated by background environmental contamination. One might question why, if measured environmental concentrations of PCDDs and PCDFs in air around operating MSW incinerators are similar to background levels, is the total daily intake of PCDDs and PCDFs by the maximally-exposed individual living near a typical, modern facility estimated to be so small? One reason is that risk assessments prepared for proposed MSW incinerators generally assume that only a small percentage of food is locally produced and consumed. For example, only about 5% of meat (except poultry), 21% of vegetables, and 8% of fruits consumed by all households nationwide are home grown (USDA, 1966). Those percentages are even lower for individuals living in urban areas. Since the food chain is the primary pathway of human exposure to a large class of organics including DDT, TCDD, and most pesticides (Hattemer-Frey and Travis, 1989; Lioy *et al.*, 1988; Travis and Hattemer-Frey, 1990; Stevens and Gerbec, 1988; Travis and Arms, 1987), this assumption can substantially reduce exposure estimates. In areas of high agricultural production, the 0.7 pg daily intake estimate for combustors could be low.

IV. ESTIMATING THE MAGNITUDE OF TCDD EMISSIONS INTO THE U.S. ENVIRONMENT

There is a general perception that dioxin contamination is a localized problem and that control of a few, specific sources (such as MSW incinerators)

will reduce human exposure to tolerable levels. The reality is that dioxin is everywhere and virtually every man, woman, and child is exposed to dioxin daily (Travis *et al.*, 1989). Given that the global population is being continuously exposed to small amounts of TCDD, the question arises as to the magnitude of TCDD emissions into the environment and the relative contribution of various sources to total input.

The Fugacity Food Chain (FFC) model, a multimedia environmental partitioning model, was used to determine the rate of input necessary to maintain measured background levels of TCDD in air and soil assuming continuous input. The model can be applied to a hypothetical, evaluative environment (a 1 km^2 area) or can be scaled to depict an actual region (Mackay and Paterson, 1990). The regional and evaluative models differ only in compartment volumes and advective flow rates. Hence, these parameters were modified to represent the contiguous U.S. (Hattemer-Frey and Travis, 1990a). Our best estimate of TCDD emissions into the contiguous U.S. is 80 kg/yr with a range of 25 to 120 kg/yr as the assumed half-life of TCDD in soil varies from infinity to 20 years.

To validate this source term estimate for TCDD, we used the modified (U.S. scale) model to estimate the magnitude of emissions into the contiguous U.S. for pentachlorophenol (PCP), polychlorinated biphenyls (PCBs as Araclor 1254), hexachlorobenzene (HCB), trichloroethylene (TCE), and benzene. Table 6 shows that total emissions predicted by the model agree relatively well with reported emissions or production data for these compounds. Nevertheless, our TCDD source term estimate should be not be viewed as definitive but as a <u>preliminary</u> attempt to estimate the magnitude of TCDD input into the environment.

V. CONTRIBUTION OF SOME DIOXIN SOURCES TO TOTAL ENVIRONMENTAL INPUT

While investigators have estimated or measured TCDD emissions from various sources, data on the relative contribution of these sources to the total TCDD load are missing. Having estimated the magnitude of TCDD emissions into the environment, the next step is to determine the relative contribution of known and suspected sources to total TCDD input.

A. Municipal Solid Waste (MSW) Incinerators

Fig. 1 shows that the range of TCDD emissions in grams per second (g/sec) at 12% oxygen from existing U.S. MSW incinerators (US EPA, 1987a) are lognormally distributed with a geometric mean (50th percentile value) of 2.4×10^{-8} g/sec. Assuming that there are 130 MSW incinerators currently operating in the U.S. (IRR, 1989), total emissions from MSW incinerators are approximately 0.1 kg/year or less than 1% of total TCDD environmental input. Adopting a worst-case scenario (i.e., assuming that all operating MSW incinerators in the U.S. emit TCDD at the maximum rate measured for any facility, 7×10^{-7} g/sec) reveals that TCDD emissions would approximate 2.9 kg/year, which would account for about 4% of total TCDD input.

The US EPA (1987a) estimates that 300 MSW incinerators will be operating in the U.S. by the year 2000. If all projected MSW incinerators emitted TCDD at the maximum rate (7×10^{-7} g/sec), total emissions would reach 6.7 kg/year, which would account for about 8% of total input assuming that annual TCDD emissions into the U.S. environment remained constant over time. These data suggest that MSW incinerators are not a major source of environmental dioxin.

B. Motor Vehicles

Direct and indirect evidence indicates that motor vehicles are a prominent source of environmental dioxin (Ballschmiter *et al.*, 1986; Marklund *et al.*, 1987; Rappe *et al.*, 1988). Although direct measurements of TCDD emissions from motor vehicles are scarce, Marklund *et al.* (1987) reported that cars using leaded gasoline in Sweden emitted <2.0 to 12 ng TCDD per mile driven. TCDD emissions from cars run on unleaded gasoline were nondetectable. Assuming 42 million cars in the U.S. in 1985 used leaded gasoline and that the typical car was driven 7900 miles per year (USDC, 1989), emissions of TCDD from vehicles that use leaded gasoline range from <0.7 to 4.0 kg/yr, which would account for up to 5% of total TCDD input. Past emissions could have been higher, since more vehicles used leaded fuel.

In 1969, the 87 million passenger vehicles that use leaded gasoline in the U.S. averaged 9650 miles per year (USDC, 1975). TCDD emissions from U.S. automobiles in the past can thus be estimated to have been <1.7 to 10.1 kg/yr, which could account for up to 13% of TCDD input into the environment. These data indicate that motor vehicle emissions may have been a significant source of environmental dioxin in the past, although modifications to gasoline products instituted in the early 1970's have notably reduced dioxin emissions from automobiles.

C. Hospital Waste Incinerators

The California Air Resources Board (CARB) tested pollutant emissions from hospital waste incinerators in California. TCDD emissions from two incinerators in California ranged from <0.02 to 0.5 ng/sec and <0.11 to 0.24 ng/sec (Jenkins *et al.*, 1987, 1988). Assuming that 6185 U.S. hospitals have

an incinerator on-site (US EPA, 1988a), total TCDD emissions from hospital incinerators in the U.S. appear to account for <1% of total TCDD input.

D. Residential Wood Burning

Residential wood burning has been shown to be a significant source of environmental pollution (Cooper, 1980). Nestrick and Lamparski (1982) surveyed residential wood combustion (RWC) units and found TCDD emissions ranged from nondetectable (<0.0.7 ng/kg) to 20 ng TCDD/kg wood burned. Assuming that in 1980-81 U.S. households burned 42 million cords of wood and that 0.677 cords equals one ton (Skog and Watterson, 1983), total TCDD emissions from RWC units are approximately <0.06 to 1.1 kg/yr or about 1% of total TCDD input. Thus residential wood burning appears to contribute more TCDD than hospital refuse incinerators but less than motor vehicles and MSW incinerators.

E. Pulp and Paper Mill Effluent

Pulp and paper mill liquid effluents were tested at five bleached kraft mills in the U.S. as part of the EPA/Paper Industry Dioxin Screening Survey (Amendola *et al.*, 1989). Mean TCDD levels ranged from 0.02 to 1.1 ng/L. Assuming that $1x10^{12}$ gallons of effluent are released annually from U.S. mills (Gelman, 1989) and that all effluents are contaminated at the mean level (0.15 ng/L), TCDD emissions from pulp and paper mills in the U.S. are estimated to be about 0.6 kg/yr, which would account for less than 1% of total TCDD input into the environment. These data indicate that bleached kraft pulp and paper mills appear to contribute less TCDD than residential wood burning and motor vehicles but are comparable to mean MSW incinerator emissions and hospital

waste incinerators.

F. Isomeric Pattern

Rappe *et al.* (1987a) reported that the isomeric pattern of dioxins and furans observed in air, sediment, and soil samples is virtually identical to the pattern established for several incineration sources, including MSW incinerators, hazardous waste incinerators, steel mills, copper smelting plants, and motor vehicle exhausts. These data imply that environmental concentrations cannot be linked to any one combustion source.

Conversely, most biological samples, including cow milk, human breast milk, and human adipose tissue, tend to exhibit a different isomeric pattern than that observed for combustion sources (Rappe *et al.*, 1987a). Biological samples contain primarily the more toxic 2,3,7,8-substituted congeners. A possible explanation of this finding is variations in the bioaccumulation and/or biodegradation rates associated with the different PCDD/PCDF congeners (Rappe *et al.*, 1987a). Öberg *et al.* (1989) also noted that 2,3,7,8-substituted congeners are produced endogenously in the human body.

G. Recommendations

The fact that the five dioxin sources characterized above, some of which were suspected to be major emitters, together account for a maximum of 11% of total annual TCDD input into the U.S. environment is surprising and indicates that: (1) our source term estimate for TCDD may be high; (2) some unidentified major source(s) of dioxin contamination exist; or (3) there are multiple environmental sources of dioxin, and no one source dominates total input. Other potential sources of TCDD input include: (1) forest fires

(Sheffield, 1985); (2) discharges from metal processing and treatment plants and copper smelting plants (Rappe *et al.*, 1987a); (3) chemical/industrial incineration (Ballschmiter *et al.*, 1986; Marklund *et al.*, 1987; Rappe *et al.*, 1988); and (4) the widespread, trace-level contamination of industrial products. Given the omnipresence of dioxin in the environment, it is imperative that the major sources of TCDD be determined and controlled, so that background environmental concentrations are not further elevated.

VI. CONCLUSIONS

MSW incineration has been widely perceived to be a major source of human exposure to dioxin. Considerable local and national opposition to MSW incineration has arisen because people living near these facilities fear that they will be exposed to high levels of dioxin and subsequently develop cancer. We have shown, however, that emissions from MSW incinerators on the national level account for, at most, 4% of total current TCDD input into the environment.

On the local level, human exposure to PCDDs and PCDFs emitted from MSW incineration is small relative to exposure to background environmental contamination (Travis and Hattemer-Frey, 1989a). The incremental air concentration (expressed in TCDD-toxic equivalents) predicted to occur at the point of maximum individual exposure near a typical, modern MSW incinerator is 11 fg/m^3 (express in TCDD-toxic equivalents) (Hattemer-Frey and Travis, 1990b; Travis and Hattemer-Frey, 1989b), which is about five times lower than mean background levels of PCDDs and PCDFs measured in urban air (55 fg/m^3) (Tables 1 and 2). Recent measurements near an operating MSW incinerator confirm this

estimate. For example, Edgerton *et al.* (1989) measured background levels and the concentration of PCDDs and PCDFs in air two km downwind from an MSW incinerator in an urban area of Ohio. Their data show that levels near the MSW incinerator (78 fg/m^3 in toxic equivalents) are virtually identical to background concentrations (48 fg/m^3) (Edgerton *et al.*, 1989). Thus, both theoretical predictions and empirical measurements indicate that PCDD/PCDF concentrations in air around operating MSW incinerators is not substantially elevated relative to mean background urban air levels.

The predicted daily intake of PCDDs and PCDFs by the maximally-exposed individual living near a typical, modern MSW incinerator (0.7 pg/day) was calculated by taking the geometric mean of the total daily intake estimates reported in risk assessments prepared for 12 proposed incinerators (Hattemer-Frey and Travis, 1990b). Table 4 shows that the predicted daily intake of PCDDs and PCDFs (expressed in TCDD-toxic equivalents) by the maximally-exposed individual is 130 times less than exposure to background contamination. These data indicate that human exposure to PCDDs and PCDFs emitted from a typical, modern MSW incinerator is not excessive relative to exposure to background levels. Furthermore, the individual lifetime cancer risk associated with exposure to facility-emitted PCDDs and PCDFs ($2x10^{-6}$) is two orders magnitude lower than the cancer risk associated with exposure to background environmental TCDD contamination ($2x10^{-4}$).

We do not conclude from this analysis that the risks associated with facility-emitted dioxins and furans are negligible or that MSW incinerators are safe. We are not advocating nor criticizing MSW combustion as a waste management tool. Furthermore, this paper evaluates only the risks associated with exposure to dioxins and furans. Many other health-related issues

concerning combustion of MSW remain unresolved. Current scientific data, however, indicate that modern, well-operated MSW incinerators are not a major source of human exposure to PCDDs and PCDFs relative to background levels of dioxins and furans.

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Table 1

PREDICTED MAXIMUM EMISSION RATES, AIR CONCENTRATIONS, AND DEPOSITION VELOCITIES OF PCDDs AND PCDFs (EXPRESSED IN TOXIC EQUIVALENTS) FOR TWELVE PROPOSED MUNICIPAL SOLID WASTE INCINERATORSS

Facility	Maximum annual average emission rate (ng/sec)[a]	Maximum air concentration (fg/m^3)[b]	Maximum deposition rate ($ng/m^2/yr$)[c]
1. Irwindale	640	2.1	1.32
2. San Diego	1700	48.0	9.84
3. Los Angeles	19	2.4	0.18
4. Philadelphia	390	17.0	0.70
5. Brooklyn	638	20.3	8.93
6. Stanislaus	1700	44.0	2.77
7. N. Hempstead	130	8.1	0.31
8. Milliken	160	6.1	0.31
9. Boston	470	15.0	1.98
10. Bloomington	80	20.0	3.72
11. Pomona	110	40.0	4.28
12. Montgomery	367	1.3	0.60
Typical Facility[d]	284	10.9	1.43

[a] Nanograms per second. [b] Femtograms per cubic meter. [c] Nanograms per square meter per year. [d] Geometric mean of the 12 facilities evaluated.

TABLE 2

PCDD/PCDF LEVELS IN BACKGROUND URBAN AIR AND IN AIR NEAR MSW INCINERATORS

Location	Background levels in urban air[a] (fg/m^3)[b]	Levels near MSW incinerator[a] (fg/m^3)	Reference
California	345	NA	CARB, 1988
West Germany	176	NA	Christmann *et al.*, 1989
West Germany	96	NA	Buck and Kirschmer, 1986
West Germany	83	172	Rappe *et al.*, 1988
New Zealand	56	NA	Bingham *et al.*, 1989
Ohio	48	78	Edgerton *et al.*, 1989
Berlin	41	NA	Christmann *et al.*, 1989
New York	35	NA	Smith *et al.*, 1989
Indiana	13	NA	Eitzer and Hites, 1989
Ohio	11	12	Tiernan *et al.*, 1989
Netherlands	NA	164	Olie *et al.*, 1983
GEOMETRIC MEAN	55	63	

[a] Concentrations are expressed in TCDD-toxic equivalents using the International Toxic Equivalency Factor (I-TEF) weighing scheme and assuming a perfect isomeric distribution if values for 2,3,7,8-substituted congeners were not reported.

[b] Femtograms per cubic meter.

Table 3

PCDD/PCDF CONCENTRATIONS IN BACKGROUND URBAN SOIL AND IN SOIL NEAR MSW INCINERATORS NANOGRAMS PER GRAM OF SOIL)

Location	Background levels in urban soil	Levels near MSW incinerators	Reference
U.S. (urban)	0.96	NA[a]	Nestrick *et al.*, 1986
Canada (urban)	1.82	0.38	McLauglin and Pearson, 1985
Canada (remote)	0.81	NA	McLauglin and Pearson, 1985
Italy	0.01	0.25	Berlincioni & di Domenico, 1987
Denmark	0.29	0.21	Nielsen and Lokke, 1987
United Kingdom	0.45	NA	Creaser *et al.*, 1989
Geometric mean	0.35	0.57	

[a] Measurement not available.

Table 4

PCDD/PCDF CONCENTRATIONS IN COMMERCIAL MILK SAMPLES AND SAMPLES FROM COWS GRAZING NEAR MSW INCINERATORS

PICOGRAMS PER KILOGRAM WHOLE MILK BASIS

Location	Levels[a] in commercial samples	Levels[a] in samples near MSW incinerators	Reference
Switzerland	71	289	Rappe *et al.*, 1987b
West Germany	62	NA[b]	Beck *et al.*, 1987
Canada	30	NA	OME, 1988
West Germany	144	NA	Fürst *et al.*, 1989
United Kingdom	43	NA	Creaser *et al.*, 1989
Geometric mean	61		

[a] Concentrations are expressed in TCDD-toxic equivalents using the International Toxic Equivalency Factor (I-TEF) weighing scheme and assuming a perfect isomeric distribution if values for 2,3,7,8-substituted congeners were not reported.

[b] Measurement not available.

Table 5

TOTAL DAILY INTAKE OF PCDDs AND PCDFs (EXPRESSED IN TOXIC EQUIVALENTS) BY THE MAXIMALLY-EXPOSED INDIVIDUAL LIVING NEAR A TYPICAL, MODERN MUNICIPAL SOLID WASTE INCINERATOR

Source	Daily intake (pg/day)[a]	Percentage of total daily intake	Reference
Background	92.1[b]	99.2	Beck *et al.*, 1989 Ono *et al.*, 1987 OME, 1988 Fürst *et al.*, 1989
Incinerators	0.7	0.8	Hattemer-Frey and Travis, 1990b
Total	92.8	100	

[a] Picograms per day.

[b] Geometric mean of daily intake estimates reported by Beck *et al.* (1989), Ono *et al.* (1987), OME (1988), and Fürst *et al.* (1989).

TABLE 6

ESTIMATED MAGNITUDE OF EMISSIONS INTO THE U.S. ENVIRONMENT FOR SELECTED ORGANIC COMPOUNDS (KG/YEAR)

Chemical	Range of model-predicted emissions values (kg/year)	Best estimate of emissions (kg/year)	Reported emissions or production (kg/year)
TCDD	25 -- 120	80	---
PCB (Araclor 1254)	1.1×10^6 -- 1.5×10^7	8.5×10^6	3.9×10^6 (a)
			2.8×10^6 (b)
Pentachlorophenol (PCP)	4.5×10^6 -- 2.2×10^8	6.3×10^7	2.3×10^7 (c)
Hexachlorobenzene (HCB)	2.5×10^5 -- 6.4×10^6	7.2×10^5	2.2×10^6 (d)
			2.7×10^6 (e)
Trichloroethylene (TCE)	4.8×10^8 -- 1.4×10^9	4.9×10^8	2.8×10^8 (f)
			1.5×10^8 (g)
Benzene	5.8×10^9 -- 3.3×10^{10}	8.3×10^9	8.5×10^9 (e)

(a) Estimated emissions into U.S., 1972-1977 (Holton et al., 1985).

(b) Total U.S. sales of Araclor 1254, 1974 (IARC, 1978).

(c) Annual U.S. production (Cirelli, 1978).

(d) Estimated U.S. peak production, 1979 (US EPA, 1980).

(e) Total input from fungicidal and industrial production (Courtney, 1979).

(f) Total input from industrial production, 1972 (US EPA, 1985b).

(g) Total U.S. production, 1987 (SRI International, 1988).