Dioxin Mass Balance for the City of Hamburg, Germany: Part 2: Flux of PCDD/PCDF with Liquid and Solid Wastes

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Abstract

As part of the dioxin mass balance of the natural and anthropogenic environment in the federal state and city of Hamburg, Germany, we present methods and results of an evaluation of the fluxes of polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/PCDF, "dioxins") connected with the waste management. We calculated that the disposal of liquid and solid wastes caused a flux of more than 34 g I-TEQ in the year 1992. Additionally, residues from waste incineration carried a load of almost 35 g I-TEQ, while separately collected waste and reusable residues contained about 4 g I-TEQ. Thus, only about 5 % of the total dioxin load from waste management was re-introduced into the environment and 95 % was disposed of in secured landfills.

1 INTRODUCTION

The supply of food, water, energy, household and industrial goods is followed by the generation of a certain amount of waste which has to be handled. The collection and management of liquid and solid wastes is a major challenge for any urban and industrialized region.

It is known that household and industrial wastes contain varying concentrations of PCDD/PCDF. This is due to the level of dioxins in *e.g.* foodstuffs, certain consumer goods, paper, and other materials, representing significant fractions of household waste. Thus, the waste management system is an essential part of a dioxin mass balance. Within the project "Dioxin Mass Balance for the City of Hamburg" the fluxes of polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/PCDF, "dioxins") in the natural environment (= biosphere) and in the man-made, technical environment (= technosphere) of the state of Hamburg was evaluated (Umweltbehörde Hamburg 1995). Concentrations and fluxes of PCDD/PCDF were reported and calculated as toxic equivalents (I-TEQ) according to the internationally acknowledged scheme of the NATO/CCMS (NATO/CCMS 1988).

There are three general options for the treatment of waste: incineration, landfill, and reuse or recycling of residues, respectively. The city of Hamburg uses all three strategies for its wastes.

Two municipal solid waste incinerators (MSWI) operated in 1992 and incinerated refuse from Hamburg. Additionally, there was one hazardous waste incinerator, which handled both waste from Hamburg and from other regions. It has to be mentioned that all three incinerator plants were modernized or rebuilt since the time of this evaluation (see Friesel et al. 1996). A minor part of the household waste was incinerated in an MSWI outside Hamburg.

As there is no actual landfill in the city of Hamburg, part of the household and hazardous wastes are disposed of in several landfills outside Hamburg. Only a small part of the sewage sludge from waste water treatment is used in agriculture and since there is no incineration of sewage sludge in Hamburg, these residues were landfilled together with household wastes. Table 1 summarizes the annual amount and treatment strategy of waste from Hamburg in the year 1992.

Table 1: Amount and treatment method for industrial and household wastes from Hamburg in the year 1992

Type of Waste	Landfill (t)	Incineration (t)	Total (t)
Household and Bulk Waste	308,900	220,000	528,900
Commercial Waste	233,600	166,200	399,800
Other Waste (Public, Trade)	32,400	23,000	55,400
Hazardous Waste	82,800	50,000	132,800
Sewage Sludge	46,100	--	46,100
MSWI Residues (fly ash, slag)	68,800	--	68,800
Total	**772,600**	**459,200**	**1,231,**

Residues which can be reused or recycled were partly treated in Hamburg partly transported to and used in other regions in Germany. This is shown in Table 2.

Table 2: Amount and treatment of reused or recycled residues from Hamburg in the year 1992

Type of Waste	Amount (t)	Treatment
Organic Waste, Household	8,850	Composting in Hamburg
Organic Waste, Industry and Trade	227,000	Agricultural Reuse and Export
Organic Waste, Public Sector	37,200	Composting in Hamburg
Sewage Sludge	1,500	Composting outside Hamburg
Industrial Waste	7,500	Industrial Reuse and Export
Slag from MSWI	120,000	Road Construction in Hamburg
Paper and Cardboard	368,000	Industrial Reuse and Export
Textiles	3,600	Industrial Reuse and Export
Total	**773,650**	

From Table 1 and Table 2 a total amount of 2,005,450 t of waste for the year 1992 was calculated. For the estimation of fluxes of PCDD/PCDF we also considered the import of waste for treatment in the city of Hamburg. Approximately 50,000 t of hazardous waste were brought to Hamburg for incineration and further 4,500 t of PCB-containing capacitor oils for the treatment (but not incineration) in Hamburg.

2 DATA EVALUATION AND RESULTS

2.1 Evaluation of a Mass Balance

Based on a mass balance of the waste management system of Hamburg we calculated the flux of PCDD/PCDF by multplying the amount of waste with corresponding dioxin concentrations. PCDD/PCDF levels were reported from dioxin analyses done by the Environmental Agency of the State of Hamburg (Umweltbehörde Hamburg) or retrieved from published scientific literature. Data concerning the amount of waste were obtained from authorities in Hamburg and from statistical reports (Statistisches Landesamt 1992-1995). A comparable method of establishing a mass balance for the heavy metals lead and cadmium has recently be published by Daxbeck et al. (1996) for the city of Vienna, Austria. While dioxin mass balances of different waste treatment methods can be found in the literature (*e.g.* Lahl *et al.* 1990) there is no publication demonstrating the flux of PCDD/PCDF within the waste management system of a whole geographical region as it is represented by the state and city of Hamburg.

2.2 Household and Commercial Waste

Detailed data on the amount and composition of household waste were available in Hamburg (Umweltbehörde Hamburg 1994), but no PCDD/PCDF analyses were performed on wastes from Hamburg. Greiner *et al.* (1991) and other authors (Wilken *et al.* 1992) found high seasonal and regional variations of PCDD/PCDF in household waste. Therefore we used a value of 50 ng I-TEQ/kg which is reported in the literature as a representative value for household waste (Fiedler 1993). This corresponds to a total PCDD/PCDF flux of 49,180 mg I-TEQ in the year 1992 for the sum of waste from trade, commerce, public sector, and households. The input to incinerators in Hamburg was 318,200 t or 15,910 mg I-TEQ and 91,000 t or 4,550 mg I-TEQ to incineration plants outside Hamburg. A dioxin load of 28,720 mg I-TEQ was disposed of in landfills in other regions of Germany.

2.3 Hazardous Waste

As shown in Table 1, hazardous waste was incinerated in Hamburg or disposed of in hazardous waste landfills in other parts of Germany. Dioxin analyses of hazardous wastes were not available, but are probably highly variable due to their origin. For a rough estimation, we used the same PCDD/PCDF content as for household waste (50 ng I-TEQ/kg). So, landfilling 82,800 t of hazardous waste resulted in a PCDD/PCDF flux of 4,140 mg I-TEQ in 1992. The total input into the hazardous waste incinerator was calculated to 5,000 mg I-TEQ, half caused by import of waste from other regions. The PCDD/PCDF load of the PCB-containing wastes treated in Hamburg was calculated to be 4,150 mg I-TEQ, of which at least 2,000 mg I-TEQ were from imported waste.

2.4 Sewage Sludge

Sewage sludge is collected in the central waste water treatment plant of Hamburg. The city of Hamburg regularly analysed sewage sludge for PCDD/PCDF. Dioxin levels in 1991 and 1992 were around 30 ng I-TEQ/kg dry weight (Umweltbehörde Hamburg 1994) which gave a total amount of 1,440 mg I-TEQ. Using a comprehensive investigation by Horstmann (1994) on the origin of PCDD/PCDF in sewage sludge we could attribute about 420 mg I-TEQ to household waste water. Here, the main source is the washing of textiles which contributes to more than

70 % of the total load from household waste water. The dioxin load with faeces and toilette paper causes another 20 %, other sources like water from personal hygiene and cleaning are only of minor importance.

A further 60 mg I-TEQ present in the sewage sludge might be caused by urban run-off water from roads and buildings.

The remaining dioxin load of about 960 mg I-TEQ in 1992 was attributed to not identified sources in Hamburg, *e.g.* industrial waste water. Due to insufficient data on the PCDD/PCDF level of waste waters it was not possible to make more precise assumptions.

2.5 Organic Waste

Organic residues were differentiated according to their origin (industry/trade/commerce, public, household). Wastes from food industry represent the major fraction, but were assumed to contain only low levels of PCDD/PCDF (0.015-0.3 ng I-TEQ/kg) because of their low fat content. Timber and other wood residues contributed 545 mg I-TEQ to the total flux of 555 mg I-TEQ in organic waste from industry, trade, and commerce. It was assumed that all residues were used outside Hamburg.

The grass and other plant residues from the maintenance of cemetries and public gardens were brought to various composting sites. Compost analyses were done frequently by the authorities of the state Hamburg (Umweltbehörde Hamburg 1994). We calculated a total load of 244 mg I-TEQ in the year 1992 which was applied to soils in Hamburg.

At the time of our evaluation, organic waste from households was collected separately just in some suburbs of the city of Hamburg. Thus, only about 8,850 t of residues were processed at two composting sites and produced a dioxin flux of 25 mg I-TEQ. An estimated flux of further 140 mg I-TEQ is caused by private composting in home gardens. All compost was applied to gardens in Hamburg.

2.6 Paper, Textiles, and Industrial Residues

A total amount 368,000 t of paper was collected in 1992 in Hamburg. No dioxin analyses of this fraction were undertaken but levels in paper were reported in the literature to be in the range of 0.1 to 11.5 ng I-TEQ/kg (Santl 1993). Using an average amount of 1 ng I-TEQ/kg the flux of PCDD/PCDF was 368 mg I-TEQ in 1992.

Different textiles were analysed for PCDD/PCDF by Horstmann (1994). Although he found some higher contaminated textiles (probably due to the preservation of cotton with pentachlorophenol contaminated with PCDD/PCDF), it was reasonable to assume a general dioxin amount of only 1 ng I-TEQ/kg for less than 4,000 t of separately collected clothes. The load did not exceed 4 mg I-TEQ.

About 7,900 t of industrial residues from metallurgic processes containing 460 mg I-TEQ were used in other industrial processes outside Hamburg.

2.7 Residues from MSWI

Slag from the municipal solid waste incineration was used after treatment in road construction in Hamburg as a gravel substitute. Approx. 120,000 t of MSWI slag (Table 2) with an average value of 19 ng I-TEQ/kg were used in 1992, causing a dioxin flux of approx. 2,300 mg I-TEQ.

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Fly ash from MSWI as well as slag and fly ash from the hazardous waste incinerator were disposed of on hazardous waste landfills in Northern Germany (Table 1). Analyses of PCDD/PCDF in fly ash showed levels up to 1,150 ng I-TEQ/kg. The total flux of dioxins was calculated to 32,390 mg I-TEQ in the year 1992.

3 DISCUSSION

The fluxes of PCDD/PCDF connected with different processes of the waste collection and treatment in Hamburg can be summarized as shown in Figure 1.

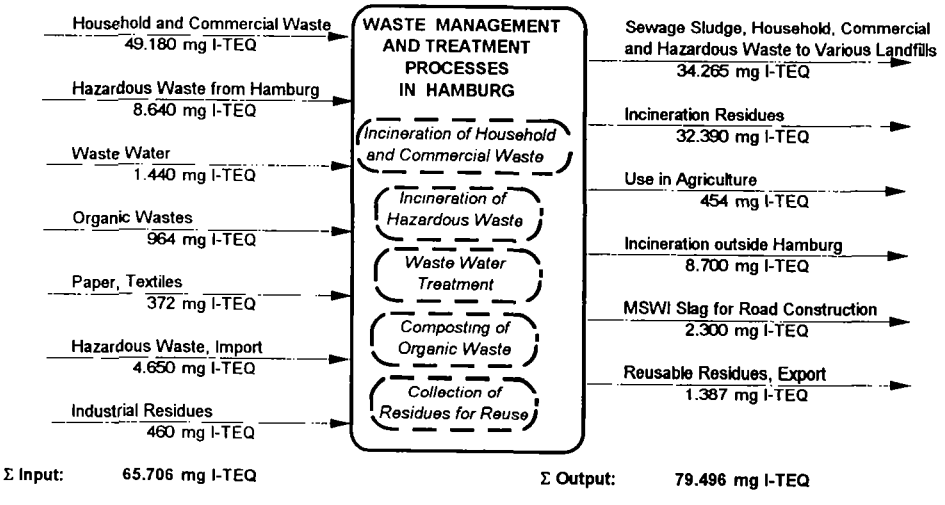

Figure 1: Input and Output of PCDD/PCDF in the waste management system of Hamburg

The output of dioxins from all technical process of the waste management and treatment in Hamburg was higher than the input. This was due to the fly ash from waste incineration where high levels of dioxins could be found. It has to be taken in account that waste management concentrates the flux of PCDD/PCDF in inert matrices (fly ash, slag from hazardous waste incinerator) which is disposed of in hazardous waste landfills without contact to the environment or exposure to man.

In this investigation we could evaluate which fluxes of dioxins were induced by the waste production, treatment, and management of the state and city of Hamburg in the year 1992. Any changes in the waste management system, e.g. promotion of composting organic material or

increasing incinerator capacity can easily be implemented and may also show the impact of different waste management strategies on the distribution of PCDD/PCDF in the technical and natural environment.

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