

PCDD/PCDF RELEASES FROM VARIOUS WASTE MANAGEMENT STRATEGIES

G H Eduljee*, P Dyke+ and P W Cains■

* ERM, Eaton House, Wallbrook Court, North Hinksey Lane, Oxford OX2 0QS, UK.

+ ETSU, AEA Technology, B154, Harwell, Oxon OX11 0RA, UK.

■ Technical Products Division, AEA Technology, B404, Harwell, Oxon OX11 0RA, UK.

1. INTRODUCTION

The management of municipal solid waste (MSW) is increasingly based on an integrated approach, whereby individual components such as recycling, resource recovery, energy recovery and landfilling are combined into an overall waste management strategy that delivers the optimum balance between conservation of resources, beneficial use and ultimate disposal. However, when considering the environmental impacts of waste management activities, the most frequent approach has been to examine individual processes and not the combination of processes that make up the overall strategy. This is particularly the case with respect to the release of PCDDs and PCDFs to the environment: for example, incineration is often singled out as a "dirty" technology on the basis of releases of PCDD/Fs to atmosphere, and as a result rejected as a process to be considered along with other options in a balanced waste management strategy. In reality, the presence of PCDD/Fs in collected, untreated bulk refuse and in the various waste fractions^{1,2} will result in their transfer to downstream recycling and resource recovery options. PCDD/Fs have been measured in compost^{3,4}, landfill gas⁵ and leachate⁶, and in gases and residues from metals recycling operations⁷. An examination of PCDD/F releases to the environment from MSW incineration, landfilling, composting and metals recovery⁵ has highlighted the commonality of the PCDD/F issue between these waste management options. However, the study considered each option individually, not within the context of an integrated waste management strategy, and did not clearly differentiate between PCDD/F releases and environmental effects.

The environmental impact of an individual or a combination of waste management options is a function of the magnitude of the PCDD/F releases, the environmental media into which these releases are made, and the fate and transport of PCDD/Fs in these media. This paper presents a preliminary inventory of PCDD/F releases to the environment from the following example waste management strategies:

- **Strategy 1:** Landfilling of 100% of the MSW, coupled with recovery of energy from landfill gas.
- **Strategy 2:** Incineration of 100% of the MSW, followed by landfilling of the solid residues.
- **Strategy 3:** Separation of metals, glass and putrescibles from the MSW, followed by separate treatment of the waste fractions by thermal recovery (metals and glass) and composting respectively. The remaining fraction is incinerated.

The comparison between incineration and landfilling should ideally be made against a finite timescale (say, one year), since gas and leachate production during landfilling is a dynamic process with a far slower rate of generation than the near-instantaneous gas and residue generation rate during incineration. However, for the purposes of this preliminary assessment it is assumed that the maximum gas generation potential from landfilling can be compared against the quantity of gas generated during incineration. The difference in timescales over which gas is generated can be accounted for during the assessment of environmental effects.

A subsequent paper will examine the environmental effects of these releases.

2. DEVELOPMENT OF WASTE MANAGEMENT STRATEGIES

2.1. Waste Composition

The basis for the calculation of PCDD/F releases from the three waste management scenarios is the treatment of 1 tonne of collected, untreated MSW from households. Domestic waste is notoriously variable from one load to another, from one month to another, and between urban and rural regions. For the purpose of this study, the following general composition (in weight percent) is assumed, based on the UK's National Household Waste Analysis Programme⁸, from which samples are currently being analysed for PCDD/F and PCB contamination:

Paper and cardboard:	30%
Plastics (film and dense plastic):	10%
Textiles:	3%
Miscellaneous combustibles:	7%
Miscellaneous non-combustibles:	2%
Glass:	8%
Putrescibles:	27%
Metals (ferrous and non-ferrous):	7%
Miscellaneous (fines, etc):	6%

The assumptions on which each of the above waste management scenarios were constructed are described below.

2.2 Strategy 1

Strategy 1 involves the landfilling of 100% of a tonne of collected, untreated MSW. The following assumptions were made with respect to gas and leachate generation, energy recovery and PCDD/F emission factors:

- The maximum quantity of landfill gas generated is 120-240 m³ per tonne of MSW.
- 50% of the landfill gas leaves the landfill site as an uncontrolled fugitive emission.
- 50% of the landfill gas is collected for energy recovery in a gas engine. The generation of flue gas is 10 m³/m³ of raw gas (flue gas at 11% oxygen).
- Emission factors are 0.32-0.36 ng I-TEQ/m³ of fugitive gas, and 0.1-1 ng I-TEQ/m³ of flue gas⁵.

- As a first approximation, assuming a site porosity of 20-50%, the leachate generation rate is 200-500 l/tonne of MSW. Leachate generation is site-specific and depends on a number of climatological and compositional factors, together with the particular characteristics of the landfill.
- PCDD/F concentration in leachate is 0.05 ng I-TEQ/l⁶.

2.3 Strategy 2

Strategy 2 involves the incineration of 100% of a tonne of collected, untreated MSW in a modern incinerator equipped with an electrostatic precipitator and a two stage wet scrubber⁹. Gas and residue generation rates and emission factors were assumed to be as follows:

- Gas generation rate is 5,140 Nm³/tonne of MSW.
- It is assumed that the incinerator operates within a PCDD/F emission concentration range of 0.1-1 ng I-TEQ/Nm³ of flue gas.
- Bottom ash, boiler ash and flyash/scrubber residue generation is 300, 5 and 32 kg/tonne of MSW respectively⁹. All of the solid residue is landfilled.
- The concentration of PCDD/Fs in the solid residues is 0.02, 0.05 and 0.3 µg I-TEQ/kg of bottom ash, boiler ash and flyash respectively⁹.
- Leachate generation resulting from the landfilling of the residues is assumed to be 200-500 l/tonne, arising from infiltration of rainfall. PCDD/F concentration in the leachate is 0.05 ng I-TEQ/l.

2.4 Strategy 3

Strategy 3 involves the separation of metals, glass and putrescibles from the collected MSW, followed by thermal processing for recovery of metals, composting of the putrescibles and incineration of the remaining fraction. The assumptions for calculation of PCDD/F releases are as follows:

- 27% (270 kg) of putrescibles is separated from the MSW and composted. It is assumed that a 50% weight reduction is achieved during composting, resulting in the production of 135 kg of compost with a moisture content of 35%. The PCDD/F concentration in compost is assumed to be between 5 ng I-TEQ/kg³ and 38 ng I-TEQ/kg¹⁰ dry matter.
- 7% (70 kg) of metals is separated from the MSW and dispatched for thermal processing. A common emission factor range of 5-35 µg I-TEQ/tonne is assumed for all thermal operations involving metals¹¹. PCDD/Fs have been identified in filter dust from secondary smelting works^{12,13} but for the purpose of this study it is assumed that all flue dust is recycled back into the smelting process.
- 8% (80 kg) of glass is separated from the MSW and dispatched for thermal processing. An emission factor range of 0.002-0.005 µg I-TEQ/tonne of product is assumed¹⁴.
- The remaining 58% (580 kg) of MSW is incinerated, and the solid residues landfilled. The gas generation rate of the remaining MSW fraction is assumed to be 4,300 Nm³, discounting the

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contribution from the putrescible fraction. Bottom ash generation is adjusted to 123 kg, by subtracting the contribution from glass (80 kg) metals (70 kg) and ash from putrescibles (27 kg).

Several simplifying assumptions have been made. For example, it has been postulated that PCDD/F levels (in terms of I-TEQ) increase during composting, owing to the formation of 2,3,7,8-positional congeners from biochemical reactions involving chlorinated precursors³. When data on PCDD/F levels in the putrescible fraction of MSW becomes available, this can be used to develop a more refined calculation of PCDD/F levels in the resulting compost. Some data is presented from Germany^{2,15} but the ranges are very wide.

3. RESULTS

Total PCDD/F concentrations in untreated MSW have been reported for German waste^{1,2}. An average concentration of 50 µg I-TEQ/tonne (wet) has been reported², with a range of 8-180 µg I-TEQ/tonne¹, assuming a moisture content of 35%. For the purpose of estimating the input of PCDD/Fs to land of untreated MSW and to assess the releases to the environment relative to the quantity in the untreated MSW, a value of 50 µg I-TEQ/tonne has been assumed.

PCDD/F releases to air, water and land from the three waste management strategies are summarised below in Table 1. For landfilling of untreated MSW and of residues, mobilisation of PCDD/Fs through leaching and/or landfill gas will gradually effect a reduction in the quantity employed in the landfill. However, since the quantities mobilised are small relative to the initial quantity landfilled, at least over relatively short timescales, this effect has not been taken into account.

Table 1: PCDD/F released per tonne of MSW (ng I-TEQ)

	Air	Water	Land
Strategy 1			
• Fugitive emissions	19-43		
• Combustion emissions	60-1200		
• Landfill and leachate		10-25	50,000
Strategy 2			
• Gas emissions	514-5140		
• Landfill and leachate		3-8	15,850
Strategy 3			
• Metals recovery	350-2450		
• Glass recycling	0.2-0.4		
• Incineration of MSW residue	430-4300		
• Landfill and leachate		2-5	12,310
• Compost			440-3344

Releases to Land

Landfilling of untreated MSW introduces the greatest quantity of PCDD/Fs to land, with the low PCDD/F content relative to the concentration in ash residues offset by the greater volume of waste

emplaced in the landfill. However, as with the ash residue, PCDD/F mobility is believed to be very low, and hence the release of these chemicals to other environmental media will be slow. Implementation of Strategies 2 and 3 results in a 3-fold and 4-fold reduction in PCDD/F introduction into the landfill relative to direct emplacement of untreated MSW.

Compost introduces lower quantities of PCDD/Fs to land relative to ash residue and untreated MSW, but its application on land utilised for the cultivation of food products could result in the mobilisation of PCDD/Fs through the foodchain, whereas operating landfills are never used for this purpose, and the cover on completed landfills is unlikely to contain PCDD/Fs equivalent to the concentration in compost.

Releases to Water

The three scenarios considered here release PCDD/Fs to water through landfilling of untreated MSW and of ash residues. The quantities released appear very small, and owing to the very low mobility of PCDD/Fs in these matrices, releases will be over long timescales.

Releases to Air

Total emissions to air are 79-1243 ng I-TEQ for Strategy 1, 514-5140 ng I-TEQ for Strategy 2, and 770-6750 ng I-TEQ for Strategy 3, based on the assumptions listed in Section 2. The strategy with the highest degree of recycling appears to release the highest overall quantity of PCDD/Fs to air, principally due to the addition of a thermal metallurgical recycling process. At a localised level, the environmental impact of the releases from Strategy 2 and Strategy 3 will differ, since the MSW incinerator and the metals smelter will generally not be located in the same vicinity. The releases to air differ in other important respects. For example, the release from the landfill is over a long timescale, and from a ground level source, whereas the releases from the MSW incinerator and metals smelter are from an elevated source and over a near-instantaneous timescale. The environmental impacts resulting from the three strategies will therefore be different.

4. CONCLUSIONS

It appears that waste management strategies with a greater level of recycling could be larger overall emitters of these chemicals to atmosphere, the environmental medium in which PCDD/Fs have the greatest mobility. However, the range of emissions for all three strategies overlap to the extent that, if the varying timescales of PCDD/F release to atmosphere are discounted, landfilling of untreated MSW does not necessarily result in the lowest atmospheric burden, especially if MSW incinerators operated to an emission limit of 0.1 ng I-TEQ/Nm³. Depending on the medium into which PCDD/Fs are released, their mobility and potential for transfer into biological media, and hence for human exposure, will differ. Releases from Strategy 3 present an interesting environmental analysis in that metals recovery and composting, two waste management components representing resource recovery and beneficial use, increase the burden of PCDD/Fs in air and introduce PCDD/Fs to land in a form that is potentially more transferable to the foodchain.

5. REFERENCES

1. Johnke B and Stelzner E (1992). Results of the German dioxin measurement programme at MSW incinerators. *Waste Manage & Res*, 10: 345-355.

2. Wilken M, Cornelsen B, Zeschmar-Lahl B and Jager J (1992). Distribution of PCDD/PCDF and other organochlorine compounds in different municipal solid waste fractions. *Chemosphere*, **25**: 1517-1523.
3. Schafer K, McLachlan M S, Reissinger M and Hutzinger O (1993). An investigation of PCDD/F in a composting operation. *Organohalogen Compounds*, **11**: 425-428.
4. Öberg L G, Wagman N, Koch M and Rappe C (1994). Polychlorinated dibenzo-p-dioxins, dibenzofurans and non-ortho PCBs in household organic waste compost and mature garden waste compost. *Organohalogen Compounds*, **20**: 245-250.
5. Lahl U, Wilken M, Keschmer-Lahl B and Jager J (1991). PCDD/PCDF balance of different municipal waste management methods. *Chemosphere*, **23**: 1481-1489.
6. Hiraoka M, Tanaka M, Matsuzawa Y, Miyaji K, Kawanishi T, Matumoto S, Horii Y and Ihara H (1993). Concentrations of PCDD/PCDF in leachates from disposal sites and their removal characteristics during leachate treatment. *Organohalogen Compounds*, **11**: 409-412.
7. Bröker G, Bruckmann P and Gliwa H (1993). Systematic monitoring of PCDD and PCDF emissions of industrial installations. *Organohalogen Compounds*, **11**: 303-306.
8. *The Technical Aspects of Controlled Waste Management*, Report NO. CWM 082/94, UK Department of the Environment, 1994.
9. International Ash Working Group (1995). An International Perspective on Characterisation and Management of residues from Municipal Solid Waste Incineration.
10. Fiedler H (1993). Formation and sources of PCDD/PCDF. *Organohalogen Compounds*, **11**: 221-228.
11. Bremmer H J, Troost L M, Kuipers G, de Koning J and Sein A A (1994). Emissions of Dioxins in the Netherlands. Report No. 770501018, RIVM, Bilthoven, Netherlands.
12. Laue G, Herrmann D, Möder M and Herzshuh R (1993). Analysis of filter dusts from aluminium recycling processes and interpretation of the results by multivariate data analysis (MVDA). *Organohalogen Compounds*, **11**: 351-354.
13. Kuykendal W B, Lamason W H, Miles A J and Keating M H (1989). Ash data from combustion sources: results of Tier 4 of the national dioxin study. *Chemosphere*, **18**: 1227-1234.
14. ERM, unpublished data.
15. Krauß Th, Krauß P and Hagenmaier H (1994). Formation of PCDD/PCDF during composting ? *Chemosphere*, **28**: 155-158.

ACKNOWLEDGEMENT: The authors are grateful to the UK Department of Trade and Industry for funding this work. The views expressed in this paper are those of the authors and do not necessarily represent those of ETSU or the Department of Trade and Industry.