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Electrical and Electronic Plastics Waste Co-Combustion with Municipal Solid Waste for Energy Recovery

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Juergen Vehlow
Forschungszentrum Karlsruhe

Frank E. Mark
DOW Europe

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Authors:
Juergen Vehlow
Forschungszentrum Karlsruhe
Frank E. Mark
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TABLE OF CONTENTS

SUMMARY

Co-combustion tests of E+E plastics waste with municipal solid waste (MSW) in a MSW combustion pilot plant (TAMARA) at the Forschungszentrum Karlsruhe (FZK) in Germany have clearly shown that this recovery route is environmentally sound. These tests have demonstrated that medium to high amounts (3-12 wt %) of plastics waste from end of life E+E equipment can be safely added to today's municipal solid waste to generate useful energy. The major conclusions of this test programme can be summarised as follows:

- *The high heat value of added plastics waste has a very beneficial effect on the required inert character of the grate ash residue. Higher burnout is caused by a more intensive combustion*
- *Clean gas emissions recorded for the PCDD/Fs comfortably achieved the lowest regulatory limits as required by the German BImSch V 17th*
- *Controlled MSW combustion has again confirmed that it is an effective "dioxin sink" with a destruction efficiency of > 90%*
- *Installed European municipal solid waste combustor (MSWC) capacity will allow energy recovery of significant amounts of specified E+E plastics waste without affecting investigated operational limits*
- *Higher levels of halogens in the raw gas will not cause higher emissions, as today's wet, dry or semi dry control systems are well capable of handling such levels*
- *E+E waste fractions should be treated for efficient metal separation prior to combustion.*

  Heavy metal amounts in the E+E plastics waste then conform to the range of typical municipal solid waste combusted today
- *Higher amounts of halogens: E+E waste containing bromine (Br) and chlorine (Cl) did not increase the presence of dioxins and furans. Increased Br content will only shift the Br/Cl homologue ratio for PXDD/Fs and not cause any catalytic effect*
- *A detailed analytical characterisation of the plastics waste has shown that the major portion of heavy metals in E+E waste is not due to the plastics, but comes from a poor level of metal separation.*

1. INTRODUCTION

The recovery or disposal of end-of-life electrical and electronic (E+E) equipment is receiving considerable attention from industry organisations such as APME in order to supply factual information which can be used in the development of a clear industry strategy(1,2,3). It is hoped that such information will persuade EU member states to define the best management practices for this waste stream.

One of the difficulties regarding the recovery or disposal of E+E waste is a lack of data regarding its behaviour when incinerated (4,5,6,7). This lack of data has led to unfounded conclusions by some parties that plastic wastes contain harmful halogenated species which are difficult to treat and remove, and when incinerated contribute to the emission of halogenated species and are responsible for the major portion of emissions.

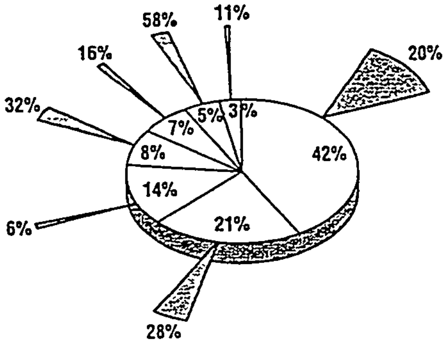
APME has a comprehensive testing programme investigating the impact of plastics on municipal solid waste (MSW) incineration. APME's previous work has demonstrated the positive, beneficial effects of mixed waste plastics in the MSW energy recovery process as well as studying halogen behaviour during the combustion of packaging plastics waste and construction foam from the building industry. The current study was designed to evaluate the incineration of MSW containing typical levels of electrical and electronic (E+E) plastic waste, as well as MSW containing E+E waste in amounts up to 12%. Parameters investigated included characterisation of the base MSW feedstock, different E+E waste streams and the incineration parameters related to the base feedstock containing 3, 6 or 12% added-E+E waste. The incineration parameters included combustion efficiency, halogen content and emissions from heavy metal content and emissions from trace levels of halogenated organics. In addition, the types and quantities of plastic waste materials used in today's E+E equipment were simulated in order to approximate the composition of future waste streams.

The materials investigated were representative samples from the major market sectors of consumer, commercial and industrial goods. They were of reasonable size (several hundred tonnes) and came from commercial operations in Germany, The Netherlands and Sweden. Today other countries do not have sufficient collection, dismantling and treatment capacities to provide large, representative samples.

2. E+E MARKET INFORMATION: CONSUMPTION

Typical E+E market information is available from a SOFRES study commissioned by APME (8). Plastics consumption in 1992 for this sector was estimated at 1.15 million tonnes in Europe, representing 16 % of the total E+E equipment by weight.The following sector share and the weight% of plastics in each sector is given as:

Figure 1:
TOTAL E+E SECTOR MARKET ANALYSIS Source: APME(8)



	Sector share %	plastics wt%
Large appliances	42	20
Brown goods	21	28
Electrical equipment materials	14	6
Small domestic appliances	8	32
Data processing	7	16
Telecommunications	5	58
Office equipment	3	11
	100	

For a better understanding, the E+E waste sector can be sub-divided into consumer, industrial and commercial goods. Within the consumer sector, a further division is commonly made into brown or white goods. The white goods sector contains refrigerators, freezers, washing machines etc. which are not part of this study. These are usually collected in schemes separate from other consumer equipment. Shredder or recycling operators do not commonly mix white goods shredder residues with those of brown goods (TVs, videos and audio equipment). For an accurate comparison of ESR (electrical shredder residue) compositions, a clear understanding of the source of the waste was needed.

The following examples are given to explain and illustrate the very different types of equipment which are considered:

Figure 2.
EXAMPLES OF MAJOR E+E MARKET SECTORS

Consumer	(1)	small appliances e.g. hairdryers, toasters, heaters, irons, toothbrushes
	(2)	medium sized appliances e.g. VCRs, coffee & kitchen machines, vacuum cleaners
	(3)	larger size units e.g. PCs, TVs, Hi-fi equipment
Commercial	(4)	electronics medium size parts e.g. PCs, fax machines
Industrial	(5)	electrical switch gear equipment
	(6)	electronic instrumentation and control systems.

3. ELECTRICAL + ELECTRONIC EQUIPMENT PLASTICS WASTE

3.1. E +E EQUIPMENT IN MSW

At the present time very little E+E equipment waste is combusted in MSW combustors (MSWC).

The increasing European MSWC capacity (34 MMt in 1992) designed for energy recovery and efficient flue gas cleaning is sufficient to combust certain fractions of special E+E equipment waste streams. If it is assumed that 5-10 wt% of the MSW feed comprised suitable E+E equipment waste then all of today's E+E plastics waste could be handled by existing MSWC capacity. This demonstrates the potential importance of MSWC as a recovery route.

Efforts by APME to define the E+E content in MSW in Germany resulted in a figure of about 1 wt% within the residual MSW (equivalent to 140 kg/year per person).

The recycling of plastics, paper, glass and metals reduces the commonly accepted value of 300 kg MSW/person/year to a figure of 140 kg of which around 1 kg/person/year can be attributed to E+E waste (9). As older equipment is replaced and taken out of stock this figure is likely to increase.

3.2 SOURCE SEPARATED E+E MATERIALS

Electronic and electrical equipment is sometimes collected by local authorities, but the information on E+E waste categories is rather scarce. Similarly the number of pilot projects to collect E+E waste in Europe is also limited (10, 11). Very little is known about the polymer composition in different types of equipment. Nevertheless the total amount of source separated E+E equipment is growing rapidly although as yet the waste amounts are still unclear. For these trials, it was therefore necessary to get E+E waste for TAMARA, the MSW combustion pilot plant of the FZK in Karlsruhe, from larger scale commercial operations. A very detailed identification and classification of the different E+E articles has been made for countries like Germany by the Zentralverband Elektrotechnik-und Elektronikindustrie e.V. (ZVEI) (12) and France by the Fédération des Industries Electriques et Electroniques (FIEE) (13), with reports on material stream identification by article from Institut für Umwelttechnologie und Umweltanalytik e.V. (IUTA) (14) and the company Schleswag (15).

Three medium sized suppliers of E+E plastics waste streams in Germany were asked to provide pretreated E&E waste. The pretreatment was not done specially for TAMARA, but was typical of commercial operations by the following companies:

IUTA	Consumer waste
(EGR) Elektro-Geräte Recycling GmbH	Commercial/small industrial waste
SCHLESWAG	Industrial (low, medium, high voltage) waste

4. E + E POLYMERIC MATERIALS USED FOR THE CO-COMBUSTION TESTS

4.1. WASTE MATERIALS FROM DIFFERENT MARKET SECTORS

IUTA: CONSUMER

The Institute for Environment Technology and Environmental Analysis (IUTA) has dismantled 1400 items of E+E equipment from the cities of Essen (20%) and Duisburg (80%) in Germany. All equipment was dismantled manually to get a better overview of the material streams. 15 % (210 t) of the input was plastics. Two thirds of these 210 tonnes were unidentified composites or polymer blends. From this unindentified amount of 140 tonnes, samples were taken according to the German specification guideline for shredder residue Länderarbeitsgemeinschaft (LAGA) specification PN 2/78.

The sampling was done over a period of two years in 1993/94 and resulted in 12 tonnes of E+E plastic waste. A 1000 kg sample for the TAMARA tests was collected from the 12 tonnes according to the same German guideline LAGA specification PN 2/78.

EGR: COMMERCIAL

The Electrical Equipment Recycling Company (EGR) collects E+E equipment from the Rhein-Ruhr area in Germany. EGR has an annual capacity of 2500 tonnes for E+E equipment waste treatment. Most of the industrial and commercial equipment is dismantled manually. From an amount of 144 tonnes which included TVs, audio equipment, radios, vacuum cleaners, and PCs (including housings, screens, printers and photocopiers), 15 % were plastics. A certain portion is suitable for mechanical recycling, and the remainder has to be disposed of by alternative means. Representative amounts of 100 tonnes E+E equipment were collected during 1992 and treated similarly to the shredder residue from IUTA. From the recovered 10 tonnes of plastics, 1 tonne was blended and shipped to TAMARA.

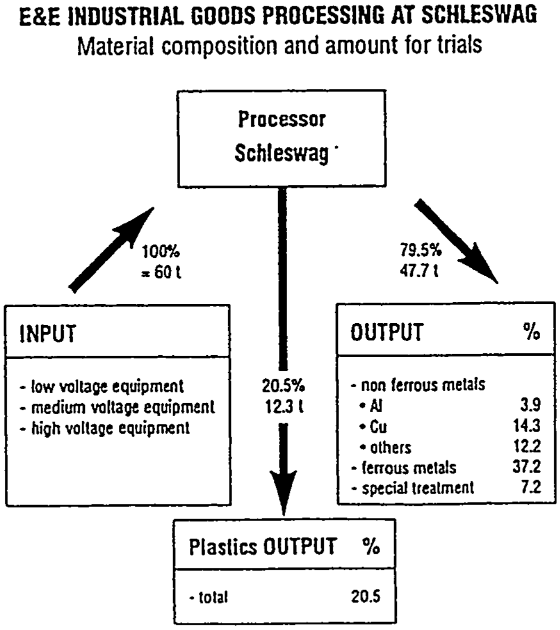
E + E POLYMERIC MATERIALS USED FOR THE CO-COMBUSTION TESTS

SCHLESWAG: INDUSTRIAL

The third source came from the company Schleswag Recycling GmbH in Brunsbüttel in the north of Germany. This operation consists of two stages. The first is dismantling and separation into the following fractions: metal housing, printed circuit boards, cables, plastic housing and screens. The second operation consists of a conventional shredding and separation phase with the following fractions being produced: iron, aluminum, plastics, thermoset plastics with fibres and metal granulate. Members of ZVEI supplied 60 tonnes of old E+E equipment resulting in 3.9 tonnes of materials to be specially treated, 26.7 tonnes of valuable metals and 29.7 tonnes (50 %) of a mixture which can only be thermally treated. The first coarse shredded fraction comprises about 25 wt% of plastics. This coarse material was shredded a second time on one of the four mechanical separation lines resulting in a fines fraction. This was the material evaluated at TAMARA.

This fraction of fines still contains high amounts of inert substances (>35 % wt) with very small metal parts barely observable to the naked eye. This amount of fillers and fibers is significant, contributing to high amounts of ash. The total mass balance data is very well described in (15).

Figure 3
E+E INDUSTRIAL EQUIPMENT PROCESSING

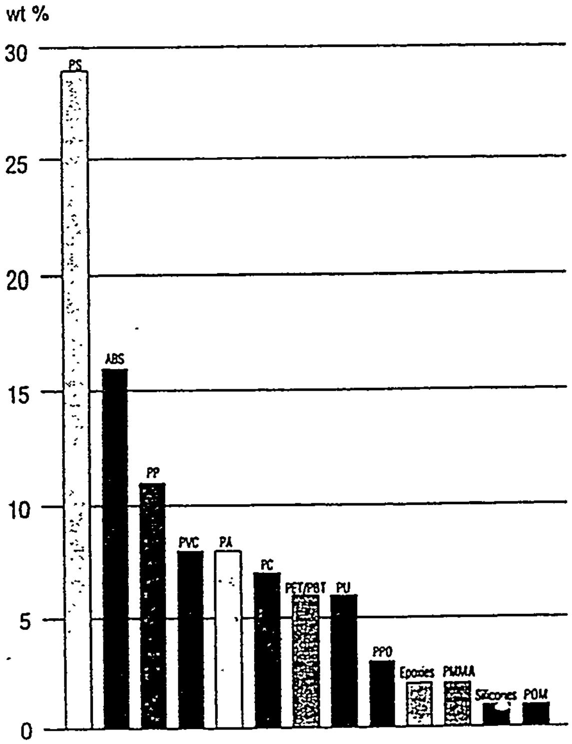


4.2. PLASTIC MATERIALS FROM TODAY'S E+E EQUIPMENT

A simulation of the types and quantities of plastics materials used in current E&E equipment was made to approximate the composition of future waste streams arising from the disposal of such equipment. The composition of an average E&E polymer mixture in Europe supplied by APME members was simulated by blending together materials typical of those sold in the market today. The materials can be separated into two categories by burning characteristics, horizontal burning or flame retarded. The ratio between these two classes is 66 % to 34 % respectively.

The overall composition assumed for today's European market agrees very closely with the SOFRES report (8) and is given as follows:

Figure 4:
POLYMER COMPOSITION FOR TODAY'S E+E EQUIPMENT.



The products requested from the APME member companies should be typical of normal commercial grades with respect to composition. 3 tonnes of these materials were blended at an outside commercial facility and then shipped to TAMARA.

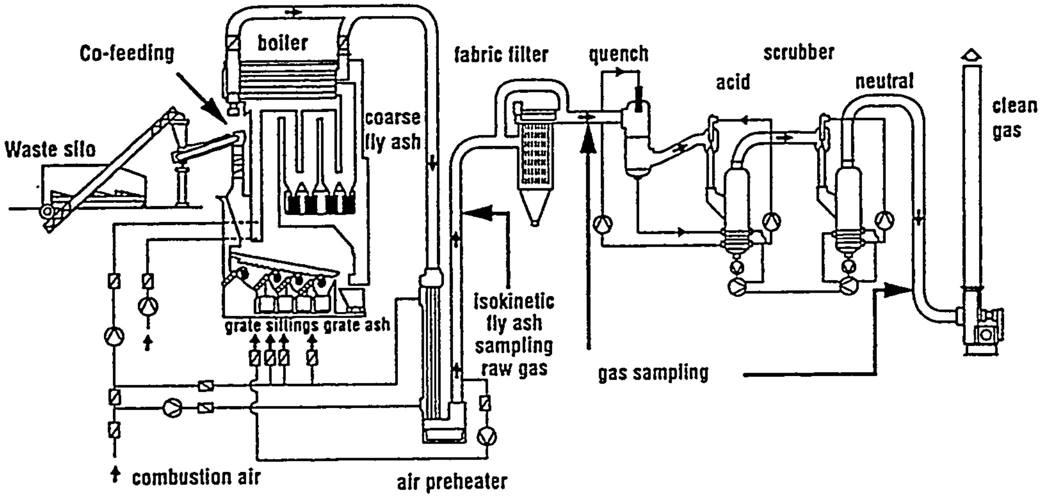
4.3. E+E MATERIALS PRETREATMENT

Thermal recovery of large E+E type equipment involves a thorough pretreatment process. The operational steps may vary from company to company although most use the following sequence: dismantling to remove hazardous compounds or parts, coarse shredding, ferrous and non-ferrous metal removal, followed by a second size reduction and air separation. For the TAMARA experiments shredding is necessary to get sufficiently homogenized good quality fuel but also to obtain sufficiently small pieces to be able to feed into the chute of the furnace.

All E+E streams tested went through some type of shredder. Hazardous components such as mercury and PCBs were removed after dismantling.

Figure 5

SCHEMATIC DRAWING OF THE KARLSRUHE TEST INCINERATOR TAMARA FOR MUNICIPAL SOLID WASTE



5. TEST INCINERATOR TAMARA

The Karlsruhe test incinerator TAMARA is a mass burner with a nominal throughput of 250 kg/h of preconditioned waste (16). The pilot plant has been described in detail in an earlier APME TEC report (17). A schematic drawing of this incinerator is given in Fig. 5. The design of the combustion chamber can be changed from the original counter current into one of parallel flow geometry by the installation of variable roof elements. The first test trials were conducted using the parallel flow design whereas during the second campaign only two roof elements were installed forming a middle flow configuration. In the first case the residence time of acid gases and alkaline fly ashes is extended and as a consequence the fly ashes will contain higher amounts of e.g. chlorides or bromides.

Dust removal is performed by means of a fabric filter consisting of PTFE fabric tubes coated with a GORETEX® membrane. This filter is operated at a temperature of approx. 200°C. For flue gas cleaning a two-stage wet scrubbing system is installed.

The impact of the E+E waste plastic materials on the scrubbing system is not covered here but in the original

FZK report or in (17). The majority of measurements have been done on the raw gas to understand the effect of E+E plastics waste on the combustion process. It is widely known that clean gas concentrations do not relate to the combustion conditions.They show the effect of the emission reduction system.

The basic fuel burnt in TAMARA is a shredded and sieved household waste which is enriched by 25 % of a pelletised RDF(Refuse Derived Fuel). The mean Cl and heavy metal content is slightly lower than that of typical Central European household waste.

The E+E materials were rather inhomogeneous, except the new E+E materials, and a thorough mixing in Karlsruhe of the large amounts proved to be impossible. As an alternative, representative samples of the feed during each of the co-combustion tests were taken, homogenised, subsampled and analysed. Figures 7, 8 and 9 give the concentrations of some important elements for the basic fuel and for the E+E materials averaged per test campaign. Typical standard deviations of the data are in the order of ±10 %. For low concentrations even higher values have to be considered. It must be mentioned that the first test campaign was performed in the summer whereas the second one took place in winter. This explains some minor changes in the composition of the basic feed.

6. FUEL COMPOSITION

6.1. Standard Fuel Analysis

For reference comparative reasons, analysis of the various E+E plastic waste was carried out by both FZK and GfA, Gesellschaft für Arbeitsplatz - und Umweltanalytik mbH (Munster). Some key items of standard fuel characterisation: heat value, ash, etc. are shown in Figure 6. A more detailed fuel analysis overview is shown in Figures 7 and 8. Aspects more important for E+E plastics waste, such as the analysis for metals and for dioxin and furan content, are covered later.

Special importance was given to the elemental analysis of bromine and chlorine contents. Bromine analysis was performed by four different parties all experienced in this field. The ratio of antimony to bromine is a very good indicator of the accuracy of bromine content analysis.

The range of bromine content covered was quite large, from a very low level of around 0.4 wt% up to 4 wt%. The consumer type equipment had a low level of about 0.4 wt%. The commercial material could be assumed to be more representative for the commercial/industrial E+E plastics as there is more flame retardant product used. The ratio of bromine to antimony on a weight for weight basis ranged from about 2 to 7. This is in line with the experience of formulating flame retardant products by addition of bromine plus antimony to gain beneficial synergistic effects.

Figure 6
E+E WASTE PLASTICS FUEL ANALYSIS
(Test series)

	Source of E+E waste					
	Consumer	Commercial		Industrial		Today's polymer market mix
Test series	(1)	(1)	(2)	(1)	(2)	
Heat Value, Hu, GJ/t	35	32		25.5		35
Ash, wt%	3-5	3-5		35-40		6.5
Bromine, wt%	0.4	4.1	1.5	1.3	0.6	0.9
Chlorine, wt%	0.4	2.3	1.1	0.7	0.2	3.5
Antimony, wt%	0.2	1.3	0.2	0.35	0.2	0.3

A comparative fuel analysis is shown in the following table where all elements in the E+E plastics waste are compared to the basic fuel of the TAMARA runs. The results of the analysis are from FZK and may differ slightly from earlier data measured by GfA.

Figure 7

CONCENTRATIONS OF SELECTED ELEMENTS IN THE BASIC FEED AND IN THE DIFFERENT E+E MATERIALS

(data in mg/kg)

material	basic fuel	basic fuel	consumer	Today's polymer market mix
test series	1	2	1	2
Cl	5800 ± 230	6150 ± 300	3895	38550 ± 2000
K	9500 ± 500	7100 ± 800	1050	2150 ± 400
Ca	34000 ± 2500	32000 ± 5000	1200	7000 ± 1500
Ti	1120 ± 140	1420 ± 240	1730	4550 ± 620
V	46 ± 18	47 ± 12	36	900 ± 15
Cr	109 ± 12	150 ± 30	63	53 ± 8
Fe	5800 ± 900	6400 ± 650	1700	287 ± 36
Ni	69 ± 13	56 ± 13	88	30 ± 1
Cu	109 ± 22	112 ± 36	1900	137 ± 55
Zn	470 ± 30	430 ± 70	620	292 ± 18
As	17 ± 4	25 ± 11	9	47 ± 2
Br	62 ± 13	34 ± 10	4290	8600 ± 1000
Rb	22 ± 3	17 ± 2	30	20 ± 3
Sr	130 ± 19	108 ± 17	18	79 ± 17
Mo	7 ± 2	7 ± 1	2	4 ± 1
Cd	10 ± 3	9 ± 3	240	41 ± 6
Sn	26 ± 4	24 ± 5	85	18 ± 15
Sb	31 ± 8	26 ± 4	2000	2630 ± 110
Ba	410 ± 75	660 ± 320	250	•
Pb	410 ± 40	600 ± 350	146	1890 ± 50
P	1880	2080	250	1200

Figure 8

CONCENTRATIONS OF SELECTED ELEMENTS IN THE BASIC FEED AND IN THE DIFFERENT E+E MATERIALS

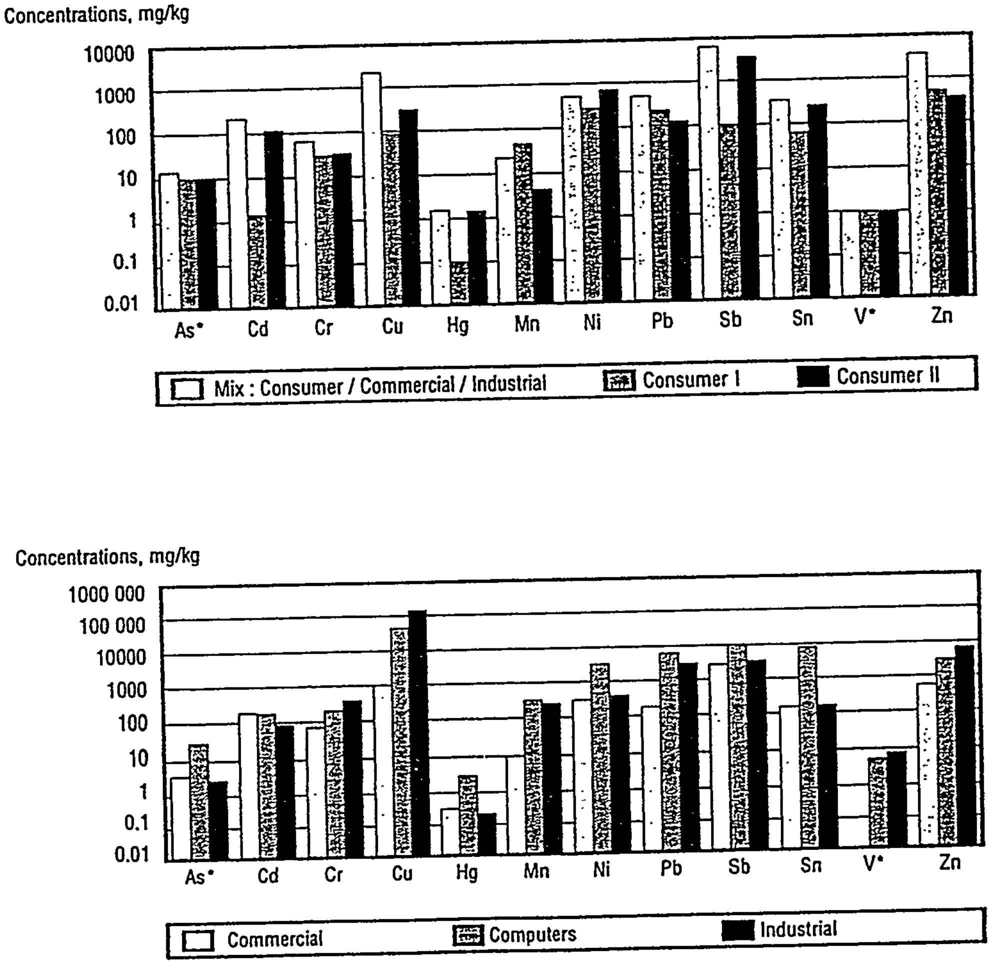
(data in mg/kg)

material	commercial		industrial	
test series	1	2	1	2
Cl	22970	10990 ± 1400	7435 ± 10	1865 ± 30
K	1500	3080 ± 230	1350 ± 100	2700 ± 170
Ca	2500	2550 ± 750	50000 ± 300	73900 ± 1100
Ti	18350	15200 ± 300	3350 ± 120	1500 ± 180
V	155	880 ± 30	149 ± 11	900 ± 15
Cr	164	250 ± 25	384 ± 1	140 ± 50
Fe	950	440 ± 120	3250 ± 300	2830 ± 260
Ni	780	550 ± 90	170 ± 50	200 ± 40
Cu	1140	82 ± 32	105000 ± 5000	77500 ± 6500
Zn	3350	1540 ± 320	5100 ± 800	4720 ± 70
As	38	29 ± 3	46 ± 1	45 ± 1
Br	41100	15000 ± 900	12550 ± 250	5750 ± 300
Rb	51	55 ± 30	21 ± 7	51 ± 9
Sr	36	22 ± 5	215 ± 8	222 ± 23
Mo	36	13 ± 4	35 ± 4	15 ± 8
Cd	124	123 ± 44	94 ± 7	29 ± 4
Sn	880	63 ± 39	2130 ± 10	1230 ± 230
Sb	13200	1950 ± 430	3500 ± 400	2200 ± 300
Ba	590	n.m.*	580 ± 15	571 ± 13
Pb	152	96 ± 19	2050 ± 320	1890 ± 50
	•	2600	n.m.*	8150

6.2 METAL ANALYSIS OF USED PLASTICS FROM VARIOUS E+E SECTORS

The broad range of metals of E+E plastics waste can be seen in Figure 9. The range is rather wide and could vary by more than several orders of magnitude.

Figure 9
COMPARISON OF E+E WASTE METAL CONTENT
*Detection limits : As = 10 mg/kg, V = 1mg/kg



All samples were analysed for metal content by the same laboratory using the same test procedure. Prior to the polymer milling and grinding to reach a sufficiently small particle size for elemental analysis, the different materials (ferrous and non-ferrous metals, glass, polymer > 2 mm and rest < 2 mm) were removed. This preseparation step made sure that residual metal content related only to the polymer. Analytical techniques have been described in earlier APME reports (18).

The samples representative for the computer sector came from Sweden, and represent today's personal computer (PC) market quality for all 4 equipment units: monitors, processing units, printers and keyboards.

The average data are representative of a broad market mix. The second sample from the consumer sector is representative of a small section of the market, mainly TVs and audio-visual equipment. Prior to analysis, the elemental metallic parts were removed as far as possible by hand. Differences in results between the two laboratories for elements primarily found in the polymer were acceptable. Larger differences are seen for e.g. copper, which is influenced mainly by separation of the metal. The high level of metallic content originates from wire.

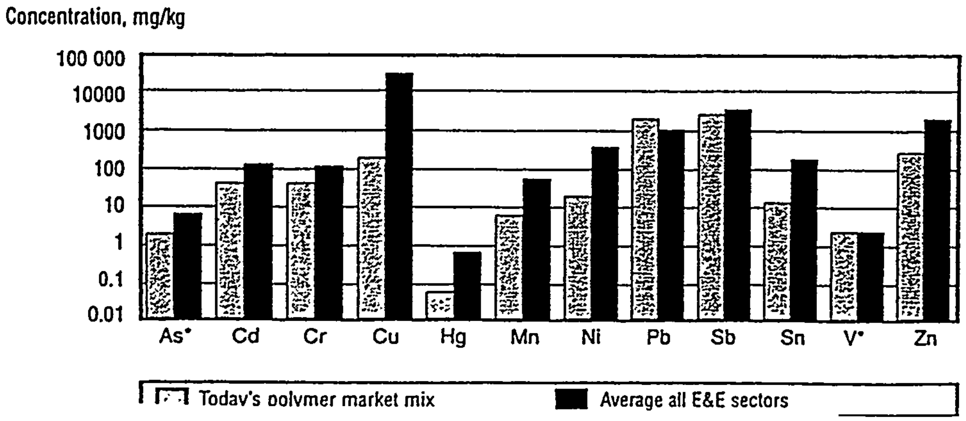
The type and quality of pretreatment of the E+E plastics waste have a major influence on the amounts of metals left in the polymer/metal mixture. Low levels of elemental metals are achieved by a well run magnetic or eddy current separation. High levels of metal content are the result of a poor physical separation. Earlier results in the literature (1) claiming very high contents of metals in the polymer phase may have resulted from poor separation techniques to remove ferrous and non-ferrous metals.

6.3. PLASTIC MATERIALS FROM TODAY'S E+E EQUIPMENT

The plastics studied above were from current E&E waste, i.e. from 'old' E&E equipment. They do not represent the materials used in E&E equipment being sold today. There have been many changes in materials, colorants and additives, and it is important to understand the composition of today's materials, which will make up the E&E waste of the future.

The new plastic materials were sampled and analysed in a similar way to the previous samples from commercial operations. It is interesting to compare the new and older materials from the point of view of levels of metallic elements, as well as the numbers and types of metal found. The total amount of heavy metals was significantly less with a maximum of 0.4 wt%. There were only two major metal elements, lead and antimony, found in today's plastic materials mix; with roughly equal concentration levels of 0.2 wt%. Other heavy metals such as arsenic, cadmium, cobalt, mercury, nickel, titanium, vanadium and tin are at very low concentrations compared to the levels previously found in the commercial waste samples. It is reasonable to conclude that recovered plastics in the future will not be the source of high levels of metals. The fact that these metal elements are found in the commercial samples was due to incomplete recovery during the metal separation processes.

Figure 10
METALS COMPOSITION COMPARISON OF OLDER VS. CURRENT POLYMERIC MATERIALS



6.4. FLAME RETARDANT ANALYSIS

The range of different flame retardant materials in today's E+E market sector is quite broad and cannot be covered here. Major elemental components like aluminum (Al), bromine (Br), chlorine (Cl), magnesium (Mg) and phosphorous (P) have been looked at in more detail. Each flame retardant class gives rise to specific questions in the context of combustion. The more volatile elements were examined with respect to air and water emissions, whereas the less volatile elements should be judged on their behavior in the solid residue (grate ash). Results from leaching tests are still not subject of a common regulatory understanding (19) and have therefore been omitted.

In order to judge the destruction efficiency of the TAMARA facility, the levels of brominated flame retardant compounds in the polymer matrix were determined in a similar way to the levels of brominated dioxins and furans. It is important that waste management routes for E+E equipment should particularly address this aspect of complete destruction of all organo-halogen compounds.

Chemical analysis of the flame retardant content of mixtures of E+E waste polymers is not standardised today by any European or national standardisation body.

Analysis of typical flame retardant compounds such as polybrominated diphenylethers (PBDPEs), tetra-bromo-bisphenol A (TBBA) and polybrominated biphenyls (PBBs) has been accurately demonstrated only in single polymers or known constant polymer mixtures. Therefore an inter-laboratory comparison between two well known certified German laboratories GfA and ITU (Ingenieurgemeinschaft Technischer Umweltschutz) was initiated.

In most samples the levels of PBBs were below the detection limit. Only in the industrial sample was a significant level of PBBs (50 mg/kg) found. PBDPEs were detected in all three samples with levels ranging from 0.01 to 2.0 wt%. The amount of TBBA found in all samples ranged from 0.01 to 0.60 wt%.

The accuracy of these results is satisfactory considering the fact that both laboratories had different methods of sample pretreatment, e.g. solvent extraction techniques. Calibration was done with solutions of available native congeners of the compound classes to be analysed.

Comparing the validated bromine content from four laboratories with the bromine content of the three flame retardant compounds, the following conclusions can be drawn: in addition to PBB, PBDPE and TBBA, all polymer samples contained significant levels of other brominated flame retardant compounds in the polymer matrix and the levels of the three flame retardants which could be identified ranged from 5% to 50% in the various samples.

6.5. CONCLUSIONS

A detailed analytical characterisation of the plastics waste has shown that :

- Analysis of halogen levels found that the level of bromine ranged from as low as 0.4 wt % for the consumer sector, to as high as 4 % by weight for industrial high voltage applications. Ratios of Br to antimony (Sb) were between 2 and 7, which is in agreement with typical industry formulations for flame retardancy. The chlorine level ranged very widely from as low as 0,2 % to several % by weight

- The bromine level is directly linked to the amount of flame retardant. Analytical work was carried out to determine the level of flame retardant for three commercial compounds sold today namely, PBB, PBDPE and TBBA. In practice, the two latter compounds contribute the majority market share, with PBB being a relatively small contributor and other Brominated Flame Retardants (Fr-Br) from older products

- The amounts of micro-organic species such as halogenated dibenzo-para-dioxins and furans (PXDD/F) were analysed, and compared with the limits of the German ordinances. Although the range of levels found was quite large, the average content value met the German regulations

- These levels of halogenated dioxins and furans in existing (old) end of life E+E equipment suggests that mechanical recycling of plastics waste as an option for these articles should be considered carefully. In such cases, combustion or chemical treatment of these older articles which ensures total and safe destruction of dioxins and furans are proven options.

7.TEST PROGRAMME

The TAMARA test programme lasted about two weeks. Two test runs were conducted per day, each lasting four hours. On the first and on the last day of each week, two reference tests were performed which burnt only the basic fuel. The test programme is detailed in Figure 11. During the first week of tests, the combustion chamber was in a parallel flow geometry and in the second week, a middle flow system was installed. The combustion temperature was kept at approx. 900°C in the first and approx. 930°C in the second week.

Figure 11
E+E MATERIAL ADDITIONS DURING THE TEST PROGRAMME

code	test series	E+E material	addition in wt%
ref. 1.1	1	-	0
ref. 1.2	1	-	0
E+E. 1.1	1	consumer	3
E+E. 2.1	1	commercial	3
E+E. 3.1	1	industrial	3
E+E. 3.2	1	industrial	6
ref. 2.1	1	-	0
ref. 2.2	1	-	0
ref. 3.1	2	-	0
ref 3.2	2	-	0
E+E. 4.1	2	today's polymer market mix	6
E+E. 4.2	2	today's polymer market mix	12
E+E. 2.2	2	commercial	6
E+E. 2.3	2	commercial	12
E+E. 3.3	2	industrial	12
ref. 4.1	2	-	0

8. SAMPLING AND ANALYSIS

During all test trials, the raw gas was permanently monitored for the concentrations of O_2, CO_2, CO, HCl, SO_2, NO, H_2O, and NH_3. Isokinetic gas sampling was performed by FZK in the raw gas upstream of the fabric filter. The fly ashes sampled here were used for all sorts of analyses. All other solid streams, the input as well as the residue streams were sampled taking care to obtain representative sampling, subsampling and sample pretreatment by following the recommendations of the International Ash Working Group (19).

Close to the position of the FZK isokinetic sampling train, the German certified analytical laboratory GfA had installed their own isokinetic probe for sampling of halogenated dibenzo-p-dioxins and dibenzofurans.

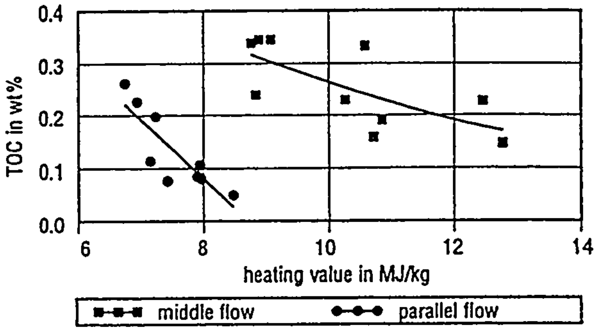
FZK conducted most of the inorganic analysis by applying total digestion to all solid samples for metal analysis. The organic samples were digested by pyrolysis followed by combustion in pure oxygen. For metal analysis, Total Reflecting X-Ray Fluorescence Analysis (TXRF) was used anions were analysed by means of ion chromatography. In addition, selected samples were analysed for special elements by GfA, IUTA, and other industry laboratories for comparison. In all cases different digestion and analysis methods were applied.

The clean up and the analysis of halogenated organic compounds was done by GfA following their own protocols (20). PCDD/F were analysed for comparative purposes by FZK.

9.COMBUSTION CONDITIONS

The combustion quality was not negatively influenced by the addition of the E+E plastic materials. As already experienced from the co-combustion of mixed post-consumer plastics waste (21), the increased heating value of the plastics improved the burnout in all residue streams. As can be seen in Fig. 12, these experiments revealed a significant reduction in the TOC of the bottom ashes. This effect is more pronounced in the parallel flow geometry of the combustion chamber due to the higher temperature at the back end of the grate.

Figure 12
TOC IN THE BOTTOM ASHES VS.
HEATING VALUE OF THE FEED



The burnout in the raw gas was extremely low during all test runs (CO< 5 mg/m^3 and TOC in the fly ashes < 700 ppm). A major difference could not be detected between the two configurations.

9.1. Residues

An efficient metal separation prior to combustion in a MSWC plant is strongly recommended. If metal separation prior to combustion is inadequate, a substantial amount of metallic species such as Cu and Pb can be found in the grate siftings and to a minor extent in the bottom ashes. These metals are not totally oxidized inside the combustion chamber. They tend to melt down and seep through between the grate bars. This behavior may endanger the operational function of the grate. On the other hand metallic species deteriorate the bottom ash quality. Hence an efficient metal separation prior to combustion in a MSWC plant is strongly recommended. In one preliminary test run, not included in this report, a deterioration of the grate ash characteristics for a high metal content in the feed could be confirmed.

10. THE ROLE OF VOLATILE ELEMENTS IN MSW COMBUSTION

10.1. Halogens in Municipal Solid Waste

In previous investigations (21) at TAMARA with packaging plastics and construction foam from the building industry, halogen (Cl, Br, F) behavior has been documented.

The levels of Br investigated here extend the experience to even higher Br concentrations.

The level of bromine in municipal solid waste and the chemical form in which it is introduced into the MSW is not well understood. Only very few investigations (22,23) concerning MSW composition have concentrated on this aspect. Older estimates in the literature range from 6 to 90 mg Br/kg MSW. The TAMARA feed has averaged around 200 mg/kg. APME's bromine balancing measurements calculate a feed concentration of about 30 to 60 mg Br/kg MSW (24). The contributions of bromine entering the waste can be natural bromine sources, bromine from flame retarded polymers and other bromine containing materials such as textiles.

Higher bromine levels in the feed to the combustor may influence the emission and residue disposal characteristics. The following aspects were examined during the trial:

I. What was the bromine path through the main units : furnace and scrubber of a typical MSWC?

II. Where did the bromine leave the MSWC: grate ash, liquid effluent and/or gaseous emission?

III. What gaseous bromine containing compounds were formed ?

IV. How, and to what extent, did bromine act as a promoter to increase the concentration of certain chloro-bromo-organic species in the gaseous phase, as had already been proposed (25).

ELEMENT PARTITIONING: Cl

Earlier investigations had shown the distribution of Cl in the various streams for a very broad range from as low as 0.6 wt % to 3 wt %. Due to the importance of chlorine in the discussion of the formation of dioxins and furans the results from these tests are shown.

The Cl load in the feed varies between approx. 0.6 and 1,2 wt% based on output and input analysis. The comparison of the input numbers to the outputs analysed in the different compartments is shown as a percent partitioning in Fig. 13.

The Cl data show a substantial scattering and the averaged output is approx. 10 - 20 % higher than the input. This indicates errors caused during sampling, sample preparation, digestion or analysis. It is very likely that the digestion of the high volatile organic components causes most of the differences.

But taking into account the relative homogeneity of some of the feed materials and the analytical error of all different analyses this result can be deemed satisfactory. It is well known, from full scale incineration plants, that

Figure 13
PERCENT PARTITIONING OF Cl

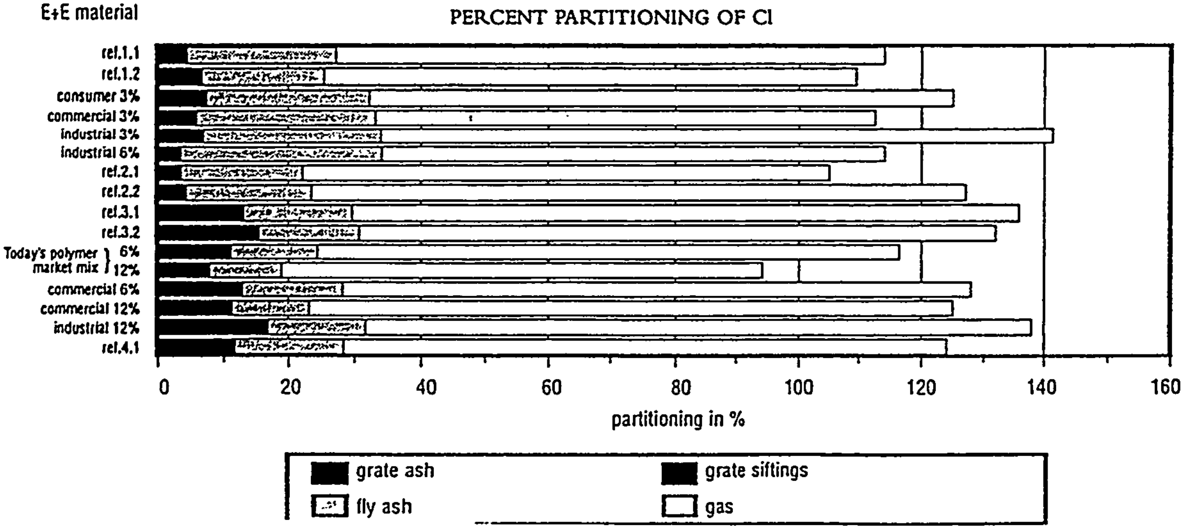
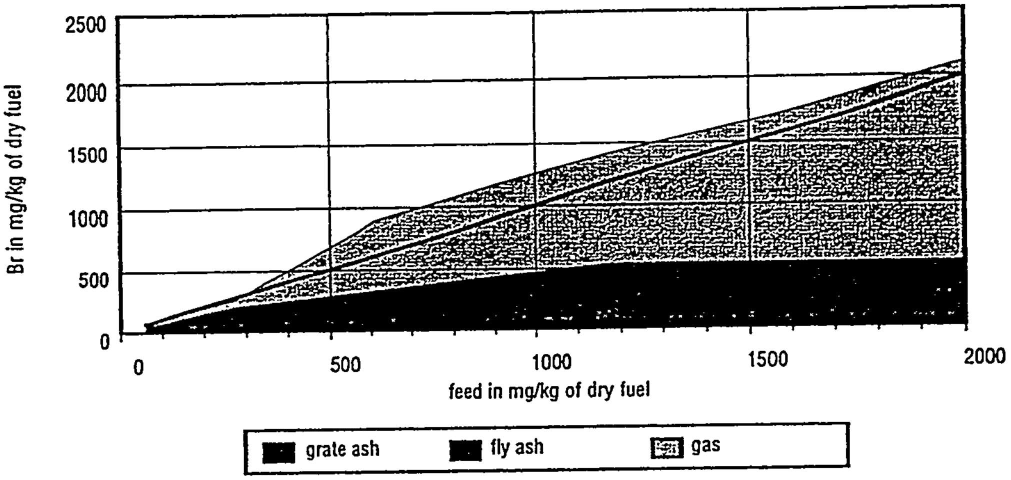


Figure 14

PARTITIONING OF Br IN THE PARALLEL FLOW COMBUSTION CONFIGURATION



about 70 - 80 % of the total Cl inventory is found in the gas phase. This was confirmed by the tests for high Cl and very high Br concentrations.

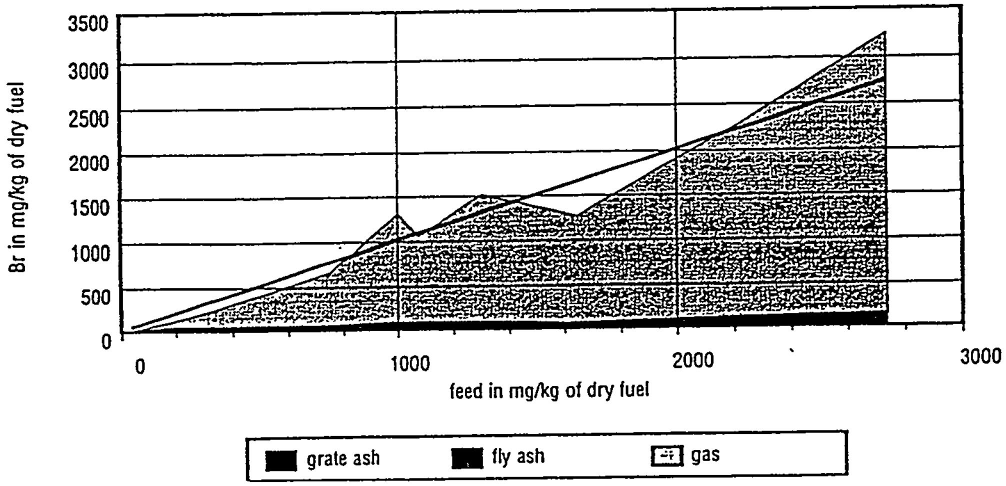
A more detailed investigation revealed a significant difference of the partitioning depending upon the geometry of the combustion chamber. During the first test campaign the fly ashes carried a significantly higher fraction of the Cl inventory than they did in the second campaign. The probable reason was the higher residence time of the acid HCl and the alkaline fly ashes at high temperatures in the parallel flow configuration.

ELEMENT PARTITIONING: Br

The geometrical effect was more easily seen for the Br behaviour (Figs 14 and 15). Fig. 14 shows the sum of analysed output streams plotted against the sum of analysed input. Dry fuel is in this case the total feed, basic fuel and E+E materials without water. Again the output data were to some extent exceeding the inputs. The potential errors should be the same as those already discussed for Cl. In general the agreement of both Br balances can be deemed satisfactory. Figure 14 also indicates an increasing incorporation of Br into the fly ashes with increasing Br input. At very high input the curve seems to level off.

Figure 15

PARTITIONING OF Br IN THE MIDDLE FLOW COMBUSTION CONFIGURATION



This might be caused by the exhausted alkalinity of the fly ashes. In almost all cases the pH of the fly ashes was in the order of 6.5 - 7, which is common in most modern large scale operations.

In the second test campaign (Fig 15) when TAMARA was operated in a middle flow combustion chamber design and even higher amounts of Br were added along with the E+E material, only smaller fractions of Br were found incorporated in the fly ashes.

The differences between the total fly ash concentrations, however, are difficult to explain purely on the basis of changes in combustion geometry.

10.2. METALS IN MUNICIPAL SOLID WASTE

Two different types of metal species can be differentiated by their volatility behaviour.

Lithophilic elements stay mostly in the grate ash and do not volatilise. In this case it is the residue characteristics that are important. The others are subject to volatilisation and could cause emissions if not properly equipped.

The degree to which metals from plastics could be released to the environment through the stack depends on the levels of metals in the raw gas after the boiler. This amount is related to the following factors: metal volatility, fuel bed temperature Tb, raw gas temperature Tg in the combustion chamber, solid matter concentration Xs in the raw gas and air velocity v.

$$\text{Volatility} = F\ (\text{Tb}, \text{Tg}, \text{Xs}, \text{v}...).$$

Due to experimental difficulties of sampling hot and high solid concentration gases, reported raw gas solid content values Xs relate mostly to the boiler exit. The air velocity v in the combustion chamber directly influences Xs. The bed temperature Tb, of a MSWC, depends on the type of grate design. Tg covers the range of 850°C to 950°C. Raw gas dust concentrations are comparatively low due to low gas velocities; typically 4 m/sec in the furnace. [illegible] from 1.5 to 3 g/m^3 in MSWC

Al and Mg are typical lithophilic elements and stay completely in the grate ash (17). The oxides and silicates of Al and Mg have very high boiling points and show no volatility. The concentration ranges of the MSW typically found are 0.2 to 1.0 wt % of Mg and 2 to 4 % of Al. Due to the high base load concentration in the MSW, relative small additions through the E+E plastics do not change the total concentration in the grate ash.

10.3. FATE OF HEAVY METALS IN COMBUSTION

Heavy metals were examined in more detail because of the environmental concern from both the public and authorities. Heavy metals may be present in the following phases in the combustion system:

GAS PHASE:

1. volatilised gas
2. as an aerosol in the gas phase

SOLID PHASE:

3. bound to fly ash particles
4. in the solids (ash and slag)

Specific heavy metals are classified mainly by the two or three official emission classes of the waste incineration or combustion Directives. Potential critical elements from plastics are cadmium from class I, lead, antimony and zinc from class II and nickel and cobalt from class III. Heavy metal balances around MSWC have been done (26,27,28) to establish volatility numbers. Some volatility data are shown below:

Figure 16
TYPICAL VOLATILITY NUMBERS FOR METALS

Cd	85 to 90	wt%	high volatile heavy metal
Zn, Sb, Pb	30 to 50	wt%	medium volatile heavy metal
Ni, Cu	1 to 10	wt%	low volatile heavy metal

It can be seen from Figure 16 that most of the metals in E+E type plastics waste do not show a high volatility. The most critical heavy metals from an emission directive viewpoint are Cd followed by Pb, Sb and Zn.

ELEMENT PARTITIONING: Sb

The element antimony (Sb) is quite frequently added to improve the flame retardant behavior of E+E plastic materials. A relation of 3 - 4 to 1 is typical in flame retarded plastics for Br and Sb. This approximate value was also found in the E+E waste materials used here. Fig. 17 details the percent balances for Sb found during all of the test trials. In most cases the balances match nicely to 100 %. In two tests, during the addition of 6 and 12 wt. % of the commercial material, extremely high output numbers were found. The resultant discrepancy is most likely due to an underestimation of the input. The graph demonstrates the well known influence of increased Cl levels upon the volatilisation of Sb (21).

Estimates of the partitioning of other elements confirmed the findings of former experiments for the volatilisation of heavy metals such as Zn, As or Sb.

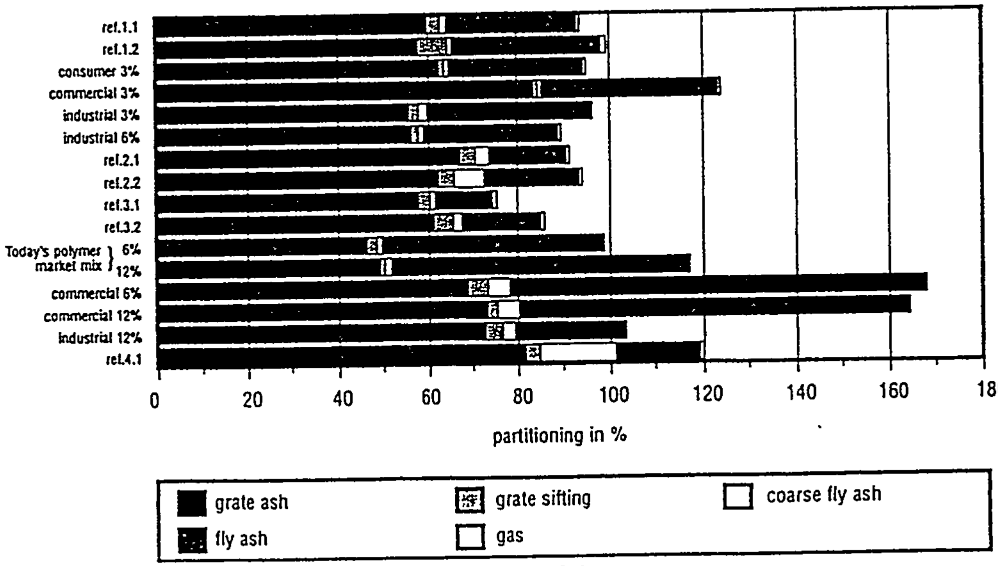
11.HALOGENATED MICRO-ORGANICS

Because of their persistancy in the environment, halogenated micro-organics are seen as a very specific class of dangerous substances. As a consequence of the sensitive nature of this subject, specific emphasis was given to all three following aspects: their content in E+E waste, potential emissions and their degree of destruction.

11.1. DIOXIN AND FURAN CONTENT IN E+E WASTE

Two ordinances exist in Germany regulating the transport and handling of hazardous materials: "The German Regulations for Hazardous Materials", and a second regulating materials brought to the market in "The German Chemicals Restriction Ordinance" enacted July 16,1994. The same 17 poly-chlorinated (PCDD/F) and 8 poly-brominated (PBDD/F) dioxins and furans are mentioned in both ordinances. Limit values are given for single congeners like the 2,3,7,8 PCDD/F as well as for groups of dioxin and furan compounds. Limits for mixed halogenated (PXDD/F) are not specified. The feed materials for the TAMARA campaigns as well as for the broad range of specific market samples were analysed.

Figure 17
PERCENT PARTITIONING OF Sb



It is known from the literature that TV housings made out of polystyrene and containing deca-bromo-diphenyloxide as fire retardants may contain certain amounts of brominated furans/dioxins (29).

Within APME's programme to gather analytical data of polymers used in the E+E area, additional samples were analysed from typical E+E waste. In summary it was found that PXDD/F content is very broad, ranging from <1 ppb to several hundred ppb. The average value is around 20 ppb (micrograms per kg) and meets the German regulations. It can be further concluded that the amount of brominated dioxins/furans belonging to the group of 8 selected 2,3,7,8-PBDD/Fs is larger than the equivalent chlorinated group with 17 PCDD/Fs.

The level of total PXDD/Fs in old end-of-life E+E equipment still in circulation suggests that material recycling of plastics from these articles should be looked at with great care.

Disposal of these articles through methods like combustion or feedstock recycling, ensuring total and safe PXDD/F destruction, is to be preferred.

11.2. Halogenated Dioxins and Furans PXDD/F in the Raw Gas

11.2.1. PCDD/F in the Raw Gas

A moderate increase of Cl input in the combustion chamber should not significantly influence the formation of PCDD/F. Former experiments in TAMARA did not show an effect even if the Cl load was elevated by a factor of 5 (21).This has been supported by similar tests in a German full scale MSW incinerator (24).

Two recently published studies on the relationship of PVC and PCDD/F in waste combustion also gave no indication of a significant correlation (26,27).

There is one paper claiming an increase in PCDD/F when electronic waste flame retarded by polybrominated diphenylethers is co-combusted in a MSWC plant (25).

Although the effect seems statistically insignificant such potential influences also had to be considered in our experiments. More recent investigations in Dutch incineration plants have not confirmed a correlation between Br and the total dioxin formation (28). A recently published study on the role of Br in the de novo synthesis in a model fly ash system has also not confirmed the promoting effect of Br (30).

Figure 18
PCDD LEVELS IN THE RAW GAS

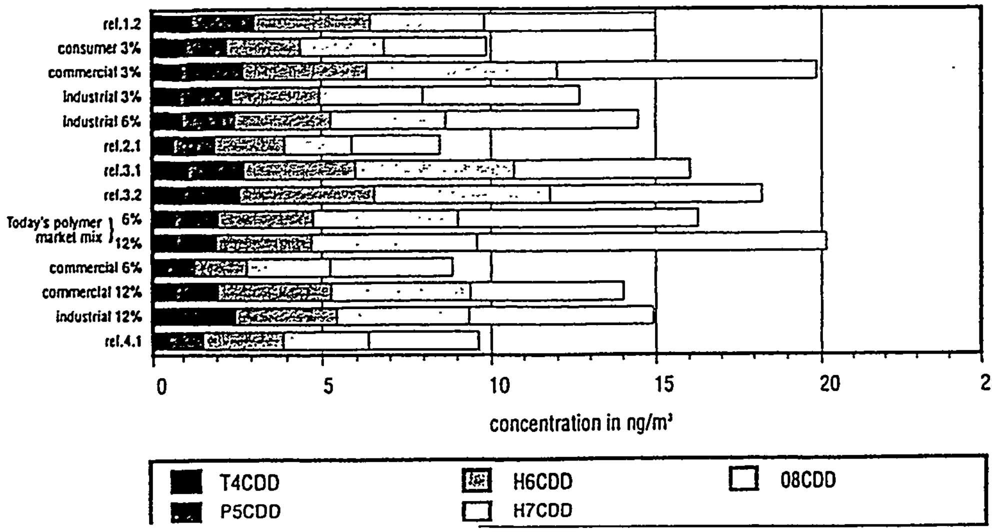
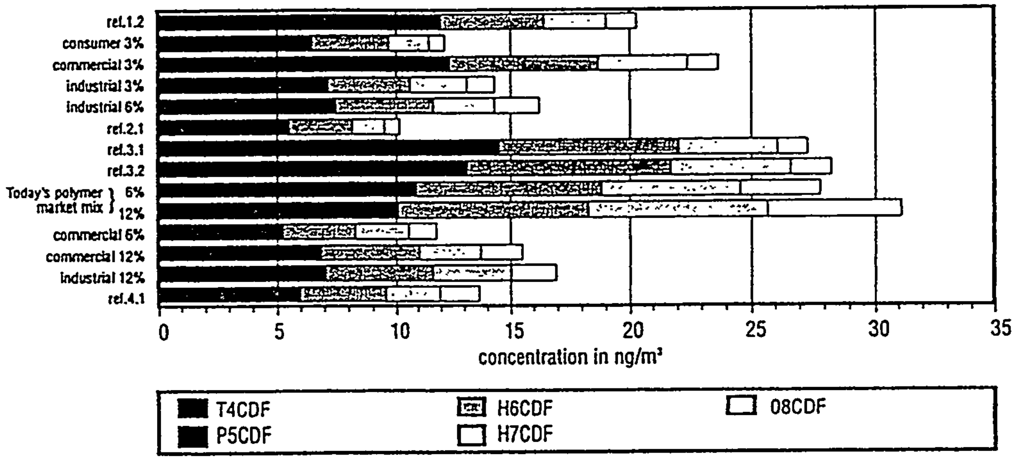


Figure 19
PCDF LEVELS IN THE RAW GAS



The levels of PCDD and PCDF in the raw gas of TAMARA have a tendency to decrease with increasing time of operation. This has already been extensively documented and can be compared with the time behavior of large scale boilers due to dust accumulation. Hence the actual reference level of PCDD/F for certain co-combustion tests is somewhere between the initial and the final reference test results.

The PCDD and PCDF concentrations analysed by FZK and two outside laboratories were in most cases very close to each other. Figs. 18 and Fig. 19 detail the sum of homologues obtained for PCDD and PCDF in the raw gas of TAMARA. The data show typical scattering. A significant increase caused by the co-combustion of the flame retarded E+E materials is not apparent. This was valid for the PCDD as well as for the PCDF, especially when the experiments with high additions of E+E materials were taken into consideration.

The homologue pattern of both classes of compounds stayed about constant. There was no influence of the elevated Cl or Br load to be seen as documented for construction foam from PUR and XPS nor was there an observed influence of the changed combustion chamber configuration.

11.2.2 Br CONTAINING DIOXINS AND FURANS IN THE RAW GAS

Data for PCDD and for PCDF did not show a significant influence of the elevated Br input. The situation changes as far as bromine containing dioxin and furan is concerned. According to the literature (23), brominated and mixed halogenated compounds add only a small percentage to the PCDD/F levels in MSWC. This was also confirmed by the co-combustion of XPS and PUR foams in TAMARA (17).

The analysis of brominated and mixed halogenated dibenzo-p-dioxins and dibenzofurans was also performed by GfA and ITU. Figure 20 shows the respective Br containing homologues analysed in the raw gas of TAMARA. Again previous results were confirmed:

I. the formation of furans exceeded that of dioxins

II. there were only very low levels of brominated homologues found

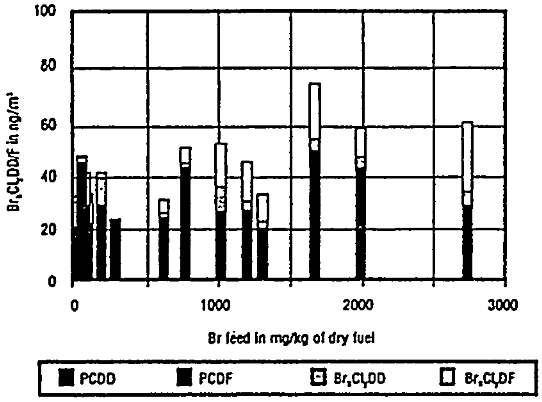
III. the prevailing homologues were those containing one Br atom

IV. homologues containing two Br atoms were only detected if very high amounts of E+E waste material (which means Br) were added

V. homologues containing more than two Br atoms were not found.

Figure 20

SUM OF HALOGENATED DIBENZO-P-DIOXINS AND DIBENZOFURANS



The foam tests cited above showed that the formation of Br containing dioxins and furans was limited and was responsible for approx. 20 - 30 % of the total dioxin and furan level in the raw gas if high amounts of Br were added to the feed stream. In Fig. 20 all of the analysed chlorinated and Br containing homologues are summed up for all test runs.

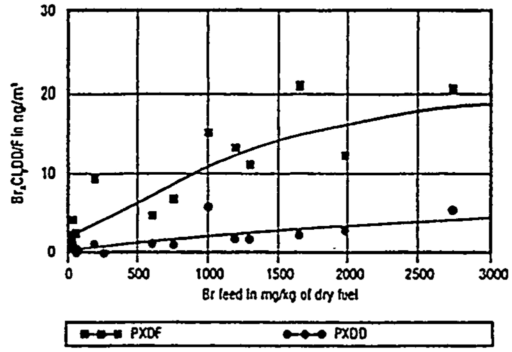
Fig. 20 also demonstrates that the mixed Cl/Br containing furans in these tests sometimes reached the same order of magnitude as the purely chlorinated ones. This was observed in the two tests when 12 wt. % of commercial or industrial E+E material was co-combusted. The dioxins were always lower in concentration by a factor of 3 - 4 than the furans and did not add substantially to the total sum of the halogenated compounds in question.

In all tests the total dioxin/furan load in the raw gas did not exceed the typical operation window of TAMARA which is in the range of 20-120 ng/m^3. This means that the contribution of brominated species is of no concern for MSW emissions from incineration plants fitted with modern air pollution control systems.

The level of mixed halogenated dioxins and furans is correlated to the bromine concentration in the fly ash in Fig. 21. The saturation effect observed to produce PBCDD/Fs in earlier test campaigns (17) is also shown here. It can therefore be concluded that the chemical form of the Br input is of no significance.

Figure 21

INFLUENCE OF Br CONTENT IN FLY ASH ON PBCDD/Fs



11.3. DESTRUCTION EFFICIENCY

The destruction efficiency of the TAMARA pilot plant for the halogenated dioxins and furans has been calculated to support this waste management route. A realistic scenario case has been chosen for this evaluation. The total halogenated dioxin and furan input stream from the E+E plastics waste can be estimated from the measured concentrations (see chapter 6.4). The range was very broad as indicated and a value of 2 micro g PXDD/F /kg E+E plastics waste was chosen. This concentration times the mass stream of E+E plastics waste of 15 kg/h leads to the total PXDD/F input from the plastics. For the total amount of PXDD/F, all 25 compounds from the German Dioxin Ordinance were taken into account. This resulted in a figure of about 0.030 mg PXDD/Fs per hour.

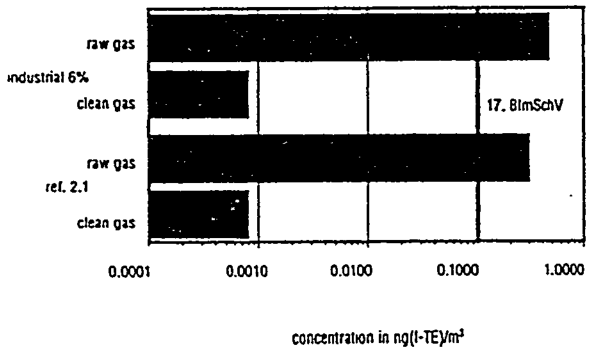
The PXDD/F mass contribution of the MSW can be estimated from literature data. The PCDD/F content in MSW ranges are very wide and a good average is 5 micro g/kg MSW. The total input for the most realistic case is then 0.5 mg PCDD/F per hour taking a medium value for the PCDD/F concentration. The grand total input of E+E waste and MSW is around 0.6 mg PXDD/F per hour.

Taking the solid and the gas phase concentration into account, the outgoing stream is estimated on the basis of the raw gas analysis. The total chlorinated and halogenated dioxins and furans were measured at maximum to about 45 ng PCDD/F /m^3 and 23 ng PBCDD/F /m^3 respectively leading to an out flowing flux of 0. 061 mg PXDD/F / h with 900 m^3/h flue gas volume. The total degree of dioxin and furan destruction is therefore greater than 90 % (24).

11.4. PCDD/F IN THE CLEAN GAS

The clean gas emissions were measured for two cases ref 2.1 and the addition of 6% industrial type E+E materials in the Tamara pilot plant. This is not normally done and was only to demonstrate the effectiveness of active carbon addition to reduce the amounts of PCDD/F in the clean gas. The level of less than 0.001 ng (I-TE)/m^3 is typical for this safe emission control technology. The required 0.1 ng (I-TE)/m^3 limit from the German BImSchV 17th is easily met. Actual emissions are less than 5% of the required limit in Fig. 22.

Figure 22
E&E CO-COMBUSTION - PXDD/PXDF IN RAW AND PCDD/PCDF IN CLEAN GAS



12. RECOMMENDATIONS

On the basis of all of the results presented in this report, we are lead to the following conclusions:

The tests supported MSW combustion as an environmentaly and economically sound recovery route for limited amounts of specific E+E waste plastics. The metal content, however, should be reduced in order to minimize the amount of metallic species in the grate siftings.

CONTRIBUTIONS:

During this project a number of people have cooperated from different companies: Elf Atochem: A. Jean, Bayer: M. Rohr, Dow Europe: F.E. Mark, Du Pont de Nemours: J.M. Falguière and representing the organisations involved: APME: R. Martin, EBFRIP/BFRIP/EFRA: M. De Poortere, FZK: J. Vehlow, B. Bergfeld, T. Wanke, ZVEI: W. Pauli (ABB). Their dedication and efforts are appreciated.

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Co–Combustion of E+E Waste Plastics in the TAMARA Test Plant

Jürgen Vehlow
Thomas Wanke, Britta Bergfeldt, Frank E. Mark*
Forschungszentrum Karlsruhe GmbH
Institut für Technische Chemie, Bereich Thermische Abfallbehandlung
Weberstr. 5
D–76133 Karlsruhe, Germany
*Dow Europe S.A.
Bachtobelstr. 3
CH–8810 Horgen, Switzerland

ABSTRACT

The co–combustion of different amounts of various plastic fractions of electrical and electronic (E+E) waste together with municipal solid waste has been tested in the Karlsruhe test incinerator TAMARA. The tests revealed no negative influences upon the combustion process. In general the increased heating value of the fuel causes an improved burnout in all residue streams. The halogens Cl and Br added with the plastics are mainly transferred as HCl or HBr into the flue gas. An influence upon the formation of chlorinated dioxins and furans could not be observed. With increasing Br feed bromine containing homologues were detected in the raw gas. The furans formed easier than the dioxins and those homologues carrying one Br atom were by far prevailing. Even at high Br input the total amount of mixed halogenated species was limited to approximately 30 % of the total load of such compounds which did not leave the typical operation window for PCDD/PCDF in TAMARA. The co–combustion tests demonstrated that MSW combustion is an ecologically acceptable and economically sound disposal route for limited amounts of specific E+E waste.

INTRODUCTION

The plastic fraction of electrical and electronic (E+E) waste is a material the disposal of which is in discussion at various forums. Different waste management routes including material recycling, chemical recycling and energy recovery are under evaluation. Municipal solid waste combustion (MSWC) as a means for recovery of the energy stored in the plastics seems to be a promising option. Existing research of various groups[1, 2], however, has mostly focused on assumed negative effects of heavy metals like Cd, Cu, Pb and Sb and the halogens bromine and chlorine. The effect flame retardancy related compounds or elements may have upon the formation of organic micropollutants such as chlorinated, brominated or mixed halogenated dibenzo–p–dioxins (PCDD) and dibenzofurans (PCDF) is controversially discussed, too.

Due to the lack of documented operational experience and to the limited awareness about bromine containing materials a research program for co–combustion experiments in a test incinerator was launched by the Forschungszentrum Karlsruhe (FZK) and a project group under the umbrella of APME (Association of Plastics Manufacturers in Europe). The goals of the project were to study the effects of

- higher E+E waste concentrations in order to simulate real life worst case conditions,
- higher concentrations of volatile heavy metals in the feed due to E+E products,
- flame retardancy related organic compounds like polybrominated diphenylethers (PBDPE), biphenyls (PBB), and tetra–bromo–bisphenol A (TBBA) as well as the active elements like bromine, phosphorous or chlorine.

The major results of the tests carried out in two test campaigns are compiled in this paper.

THE TEST INCINERATOR TAMARA

The Karlsruhe test incinerator TAMARA[3] is a mass burner with a throughput of 250 kg/h of preconditioned, mainly shredded waste. TAMARA has installed a reciprocating grate and the design of the combustion chamber can be changed from the original counter current configuration into a parallel flow geometry by the installation of variable roof elements.

The dedusting is performed by means of a fabric filter which is operated at approx. 200 °C. For flue gas cleaning a two–stage wet scrubbing system is implemented. The E+E material was added by a separate feeding system directly into the feeding chute. An isokinetic sampling train is installed upstream of the fabric filter in order to get representative samples of the gas phase as well as of the particulate matter in the raw gas. All other solid streams were sampled caring for a representative sampling, subsampling and sample pretreatment. The sampling and analysis of chlorinated dioxins and furans was done by FZK and simultaneously by two German commercial analytical laboratories, GfA (Münster) and ITU (Berlin).

TAMARA is equipped with a variety of monitoring systems to document all mass streams, temperatures, pressures etc. The major gas components in the raw gas are monitored on line, e.g. O_2 by an ZrO_2 electrode, CO_2, CO, HCl, SO_2, NO, N_2O, H_2O by means of spectroscopic or electrochemical methods.

MATERIALS AND TEST PROGRAM

Material Categories. Since the information on E+E waste categories is rather scarce and very little is known about the article type and the respective amounts of waste the E+E waste sourcing was from larger scale commercial operations to get representative testing materials. The pretreatment was part of the commercial operation today practiced by the following companies:

IUTA	consumer type (small appliances, kitchen machines, PC, TV, ...)
EGR	commercial / small industrial type (medium size parts, PC, fax machines, ...)
Schleswag	industrial (electrical housings, switches, main frames, ...)

The composition of the actual European average polymer mixture has been simulated by blending materials today sold on the market. Members of the APME have supplied these market typical qualities. The overall composition assumed for today's and future European market agrees very closely with the SOFRES report[4] (PS 29%, ABS 16%, PP 11%, PA 8%, PVC 8%, PC 7%, PET/PBT 6%, PU 6%, PPO 3%, PMMA 2%, Epoxies 2%, POM 1%, Silicones 1%).

Inorganic Composition. Table 1 compiles the concentrations of some elements in the different feed streams which are characterized by a substantial additional input during the co–combustion tests. An increase in load has in particular been expected for the flame retardancy related elements Cl, Br and Sb. Especially for the industrial material a high amount of metallic species, e.g. Cu and Pb had been anticipated and were indeed found.

Organic Composition. To analyse for the organic compounds used for flame retardancy in the E+E materials is a difficult task since there is only limited information about the types of used for that purpose in plastics for the E+E market and there is no standardized method for the isolation and analytical procedure in mixed plastics. Furthermore some of the originally used materials are polymerized during the blending procedure and hence there is no way to analyze for them in the finished product.

Therefore an interlaboratory comparison of the analysis of the consumer, commercial and industrial material was initiated between two well known certified German laboratories, GfA and ITU. The analytical review was limited to three classes of compounds, that is PBB, PBDPE and TBBA.

The accuracy of these quantitative results is satisfactory considering the fact that both laboratories had different methods for sample pretreatment, e.g. solvent extraction techniques. The calibration was done with solutions of available native congeners of the compound classes to be analyzed. The PBB levels were below detection limits in all samples but in the industrial material. Here a typical concentration of

50 mg/kg was found.. PBDPE were detected in all three samples with levels ranging from 100 to 20 000 mg/kg. The amount of TBBA found in all samples ranged from 100 to 6 000 mg/kg.

The analysed flame retardants contributed only 5 – 50 % to the directly analysed Br content in the various E+E plastics. One explanation is that other compounds have been used for flame retardancy, too, the other one is that some flame retardants have been compounded into the plastic matrix and cannot be recovered any more.

Another class of organic micropollutants regulated in German ordinances for the transport and handling (German Regulations for Hazardous Materials) and for the marketing of materials (German Chemicals Banning Ordinance) are chlorinated and brominated dioxins and furans. Both ordinances set limits for single isomers like the 2,3,7,8–TCDD and for the sum of 17 chlorinated and 8 brominated isomers. Limits for mixed halogenated congeners are not specified.

In a special program APME organised the analysis not only of the TAMARA samples but of a large number of market products. In summary the concentration of halogenated dioxins and furans varies substantially ranging from < 1 to several hundred µg/kg. The average value is around 20 µg/kg and meets the German regulations. Another finding of the program was that the amount of brominated congeners belonging to the group of 8 selected PBDD/PBDF is larger than the equivalent group of 17 chlorinated congeners.

The total level of halogenated dioxins and furans in existing end of life E+E equipment suggests that material recycling of plastics from these articles should be looked at with great care. Disposal by other methods such as combustion, gasification, or thermolysis which guarantee a total destruction of these compounds is to be preferred.

Test Program. The test program comprised about two weeks of TAMARA operation. Two test runs were conducted per day, each lasting four hours. On the first and on the last day of a week two reference tests were performed burning the basic fuel only. During the tests in the first week the combustion chamber was in a parallel flow geometry, in the second week a middle flow was adjusted. The combustion temperature was kept at approx. 900 °C in the first and approx. 930 °C in the second week. The co–feeding was 3, 6 and 12 wt % in the case of the commercial and the industrial material, 6 and 12 wt % for the new and 3 wt % for the consumer material.

DISCUSSION OF RESULTS

Combustion Efficiency

Some important data for the evaluation of the experiments are compiled in Table 2. The data show the increase in heating value of the feed stream with increasing addition of E+E waste plastics. The combustion temperatures, the CO levels and the raw gas cocentrations of HCl and HBr are given, too.

The combustion quality was not negatively influenced by the addition of the E+E materials. All parameters and raw gas concentrations showed rather constant numbers during the different trials. As had already experienced from the co–combustion of mixed post–consumer plastic waste the increased heating value of the plastics improved the burnout in all residue streams[5], especially in the grate ashes as can be seen in Fig. 1. Due to the higher temperature on the back end of the grate the effect is more pronounced in the parallel flow tests. The burnout in the raw gas was extremely low in all test runs (CO < 5 mg/m3 and TOC in the fly ashes < 700 ppm) and a major difference could not be detected between the two configurations.

No traces of the brominated flame retardants analysed in the E+E materials could be detected in raw gas samples. In view of the well known high destruction potential of waste combustion[6] this result had been expected. Similar statements can be made for the brominated dioxins and furans. Only trace amounts of furans were detected in the raw gas of one single reference test and during the addition of 3 wt. % of commercial material. Due to the low input numbers and the high analytical error no quantitative destruction yields were calculated. The same stays for the PCDD/PCDF since the major fraction found in the raw gas has been originated in the boiler and a distinction between compounds having survived the combustion process and those having been synthesized post combustion cannot be made.

During the co–combustion of the industrial material which contained visible amounts of Cu fibres and metallic residues from the circuit boards, pure metals were found in the grate siftings. To avoid his unwanted effect a thorough metal removal of the E+E waste material is recommended.

Element Partitioning

The addition of E+E waste caused – depending upon the material – a more or less substantial increase of the halogens Cl and Br as well as of some heavy metal inventories (Sb, Cu, Pb) in the feed stream. Out of the total number the flame retardancy born elements Cl, Br and Sb will be discussed in short terms.

The analysed Cl varied between approx. 6 000 and 12 000 ppm. The comparison of this input numbers to the outputs analysed in the different compartments is shown as a percent partitioning in Fig. 2. The Cl data show a substantial scattering and the averaged output is 10 – 20 % higher than the input which is a satisfactory result for this kind of balancing. About 70 – 80 % of the total Cl inventory is found in the gas phase. The respective HCl concentrations in the raw gas cover the range of 670 to 1 000 mg/m^3 (compare Table 2). A more scrutine investigation reveals a significant difference of the partitioning depending upon the geometry of the combustion chamber. During the first test campaign the fly ashes carry a significantly higher fraction of the Cl inventory than they do in the second campaign. The reason is the higher residence time of the acid HCl and the alkaline fly ashes at high temperatures in the parallel flow configuration.

This effect is more easily seen in the behaviour of Br. Fig. 3 and Fig. 4 show the sum of Br in the analysed output streams plotted against the respective number of the analysed input. Again the match of both of the Br balances can be called satisfactory. The graphs indicate an increasing incorporation of Br into the fly ashes with increasing Br input in the parallel flow co–combustion tests. At high input the curve seems to level off. In the middle flow tests when even higher amounts of Br were added along with the E+E waste only smaller fractions of Br were found in the fly ashes. This distinction is hard to be explained by the change in combustion geometry only. The analysed K and Ca concentrations suggest a higher alkalinity of the fly ashes in the first campaign.

As an example for the typical results of heavy metal balancing the percent partitioning of Zn is shown in Fig. 5. Although the variability of the data is higher than found in the case of the halogens the match of this balance can be called satisfactory, too. The scattering is more distinct for metals like Cu and Pb which are often found as pure metals in the E+E waste.

An important element involved in the flame retardancy of E+E materials is Sb. Fig. 6 compiles the percent balances for Sb as found during all of the test trials. Except for two tests, where the input was most likely underestimated, the balances close very well.

PCDD / PCDF in the Raw Gas

Former experiments in TAMARA did not show an effect even if the Cl load was elevated by a factor of five[5]. This has been supported by similar tests in a German full scale MSW incinerator[7] and by two recently published studies upon the relationship of PVC and PCDD/F in waste combustion[8]. There is one paper claiming an increase in PCDD/F if electronic waste flame retarded by polybrominated diphenylethers is co–combusted in a MSWC plant[9]. This could not be confirmed by TAMARA tests on the co–combustion of flame retarded XPS and PUR foams[10].

The levels of PCDD and PCDF in the raw gas of TAMARA tend to decrease with increasing time of operation. Hence the matching reference level of PCDD/F for a certain co–combustion test is somewhere between the respective initial and final reference test results. The PCDD and PCDF concentrations analysed by FZK, GfA and ITU were in most cases very close to each other. The raw gas concentrations of PCDD and PCDF are compiled in Table 3.. Fig. 7 depicts the sum of homologues as a function of the Br level in the feed stream. The data show the typical scattering. A significant increase or homologue change caused by the co–combustion of the flame retarded E+E materials is not revealed.

Br Containing Dioxins and Furans in the Raw Gas

This situation changes as far as bromine containing homologues are concerned. According to literature and to the above cited TAMARA tests brominated and mixed halogenated compounds add only a small percentage to the PCDD/PCDF levels in MSWC[10, 11, 12]. The sum concentrations of bromine containing dioxins and furans are compiled in Table 3 which also contains the Br input data. Fig. 8 and Fig. 9 show the sum of Br containing homologues analysed in the raw gas of TAMARA. There were next to none purely brominated homologues found. The prevailing homologues analysed were those containing one Br atom. Homologues containing two Br atoms were only detected if very high amounts of Br were added and those containing more than two Br atoms could not be detected. The formation of bromine containing furans exceeded that of dioxins.

The formation of bromine containing furans increases with increasing Br input and seems to level off at high Br loads (compare Fig. 10). The effect is less pronounced for the dioxins the concentrations of which, however, are very low. These findings confirm the results of the above cited foam co–combustion tests.

The graph in Fig. 11 demonstrates that the Br containing furans in these tests sometimes reached the same order of magnitude than the purely chlorinated ones. This has been observed in the two tests when 12 wt. % of commercial or industrial E+E material were co–combusted. The dioxins were always lower in concentration by a factor of 3 – 4 than the furans and did not add substantially to the total sum of the halogenated compounds in question.

In all tests the total dioxin/furan load in the raw did not exceed the typical operation window of TAMARA which is shown in the background of Fig. 11 and covers the range of 20 – 120 ng/m^3. Samples taken after the flue gas had passed a charcoal filter resulted in residual PCDD/F concentrations of <0.001 ng/m^3. Bromine containing homologues could not be detected. This means that the contribution of brominated species is of no concern for the emission of MSW incineration plants as far as a modern air pollution control system is installed.

CONCLUSIONS

Co–combustion tests of different types E+E waste and MSW in the Karlsruhe test incinerator TAMARA were performed looking for real effects in a modern MSW combustor. Up to 12 wt. % of E+E material was added to the basic fuel. The following most important results were obtained:

- The combustion process was not negatively influenced even if high amounts (up to 12 wt. %) of E+E material were added to the basic fuel.
- The increase in heating value improved the burnout of the bottom ashes.
- Residual organic compounds indicating unburnt flame retardants could not be detected in the flue gas.
- The levels of Cl in the feed were moderately, those of the flame retardancy related elements Br and Sb as well as those of a number of heavy metals were substantially increased by the addition of the E+E wastes. Some metals, especially Cu and Pb may be present in the metallic state and tend to sift through the grate. Hence a thorough metal separation from the E+E plastic waste prior to combustion is strongly recommended.
- The increased Cl and Br levels caused no significant increase of the concentrations of PCDD or

PCDF in the raw gas.

- The formation of limited amounts of brominated and chlorinated dioxins and furans was observed with the furans exceeding the dioxins by a factor of 3 – 4. For both classes of compounds mainly homologues carrying one Br atom were detected.
- At high input of E+E waste Br containing homologues added up to 50 % to the total load of dioxins and furans. The data obtained did not leave the typical operation window of TAMARA.
- Air emission sampling during some co–combustion tests resulted in PCDD/PCDF concentrations of <0.001 ng/m^3 showing that activated carbon is effectively removing the moderate to low PXDD/PXDF concentrations in the raw gas to almost zero levels.

The co–combustion experiments did not show severe influences upon the quality of waste incineration. The expected promoting effect upon the production of Br containing dibenzo–p–dioxins and dibenzofurans stayed moderate even if high amounts of E+E material were added. In full scale incineration plants the co–feeding of high calorific waste fractions will be limited to 3 – 5 wt % as a worst case. In those cases the increase in dioxin and furan levels will stay within the window of the PCDD/F levels typically found in such incineration plants.

On the basis of the results presented here it seems a fair statement:

- MSW combustion is an ecologically acceptable and economically sound disposal route for limited amounts of specific E+E waste. The metal content, however, should be reduced as is done today in most recycling operations in order to reduce the maintenance of the grate and to minimise the amount of metallic species in the grate siftings.

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Table 1 Concentrations of selected elements in the materials of the 2nd campaign (data in mg/kg, consumer data of 1st campaign)

	basic fuel	consumer	commercial	industrial	new material
P	2080	250	2600	8100	1200
Cl	6150	3895	10990	1865	38550
Cu	112	1900	82	77500	137
Zn	430	620	1540	4720	292
Br	34	4290	15000	5750	8600
Cd	9	240	123	29	41
Sn	24	85	63	1230	18
Sb	26	2000	1950	2200	2630
Pb	600	146	96	1890	1890

Table 2 Lower heating value of feed, temperature in the combustion chamber, oxygen, HCl and HBr in the raw gas for all test trials

	H_l kJ/kg	T °C	O_2 vol %	CO mg/m^3	HCl mg/m^3	HBr mg/m^3
ref.1.2	6960	894	9.7	1.2	730	3
cons.3%	7950	900	9.9	1.7	680	9
comm.3%	7910	912	9.9	2.1	900	204
ind.3%	7960	901	10.0	1.7	840	72
ind.6%	8480	893	10.4	3.6	850	131
ref.2.1	7440	892	9.9	1.2	750	3
ref.3.1	8880	930	10.0	0.0	790	4
ref.3.2	8770	912	10.3	0.1	760	3
n.mat.6%	10580	923	10.5	1.8	870	63
n.mat.12%	12440	949	10.5	0.0	1010	119
comm.6%	10260	926	10.5	0.1	860	157
comm.12%	12760	937	10.9	0.2	940	292
ind.12%	10840	932	10.6	0.3	800	141
ref.4.1	8840	939	9.9	0.3	670	4

Table 3 Br input and raw gas concentrations of chlorinated and mixed halogenated dioxins and furans

test	Br input mg/kg	PCDD ng/m^3	PCDF ng/m^3	Br_xCl_yDD ng/m^3	Br_xCl_yDF ng/m^3
ref.1.2	67	15.0	20.2	0	0
cons.3%	270	9.8	12.1	0	0
comm.3%	1979	19.8	23.6	3.13	12.4
ind.3%	606	12.6	14.2	1.2	5.0
ind.6%	1193	14.4	16.2	2.0	13.5
ref.2.1	68	8.4	10.1	0	0
ref.3.1	57	16.0	27.2	0.5	2.5
ref.3.2	45	18.2	28,2	0.5	2.5
n.mat.6%	757	16.3	27.8	1.1	7.1
n.mat.12%	1650	20.1	31.0	2.5	20.9
comm.6%	1297	8.8	11.7	1.9	11.4
comm.12%	2735	14.0	15.5	5.8	20.6
ind.12%	1000	14.9	16.9	6.1	15.6
ref.4.1	38	9.6	13.6	1.2	4.3

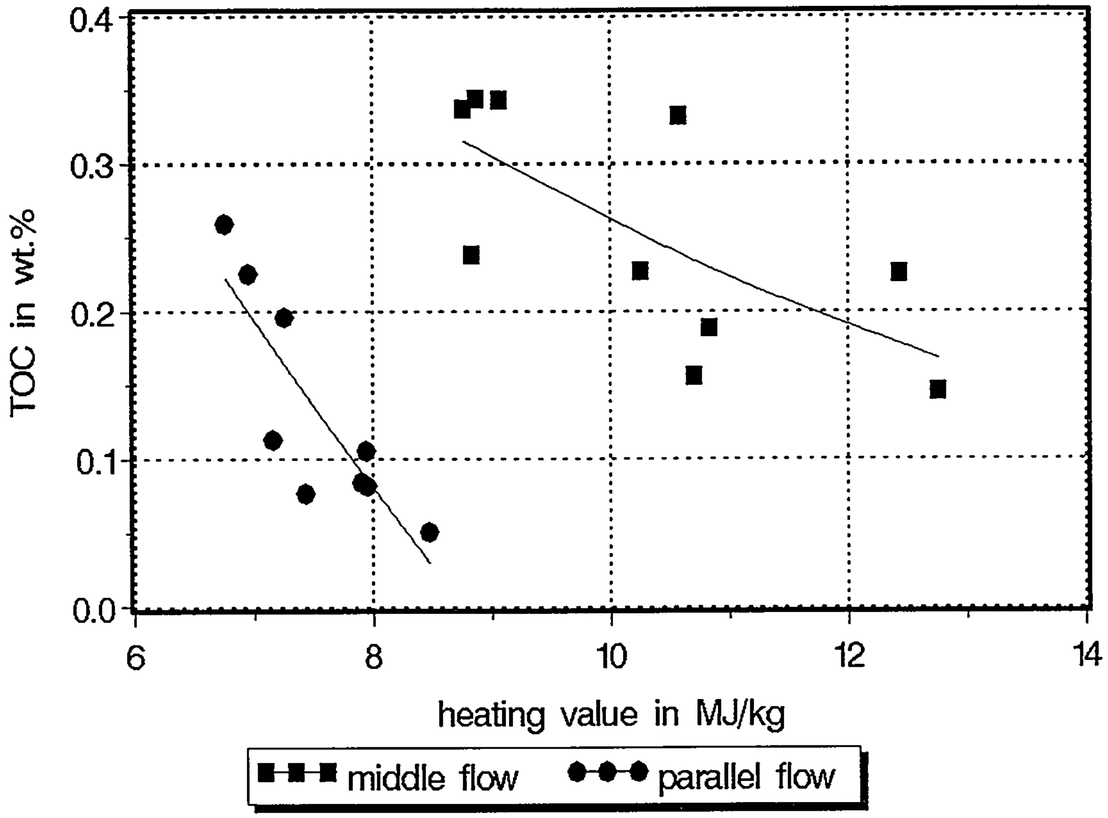

Fig. 1: TOC in the grate ashes vs. heating value of the feed

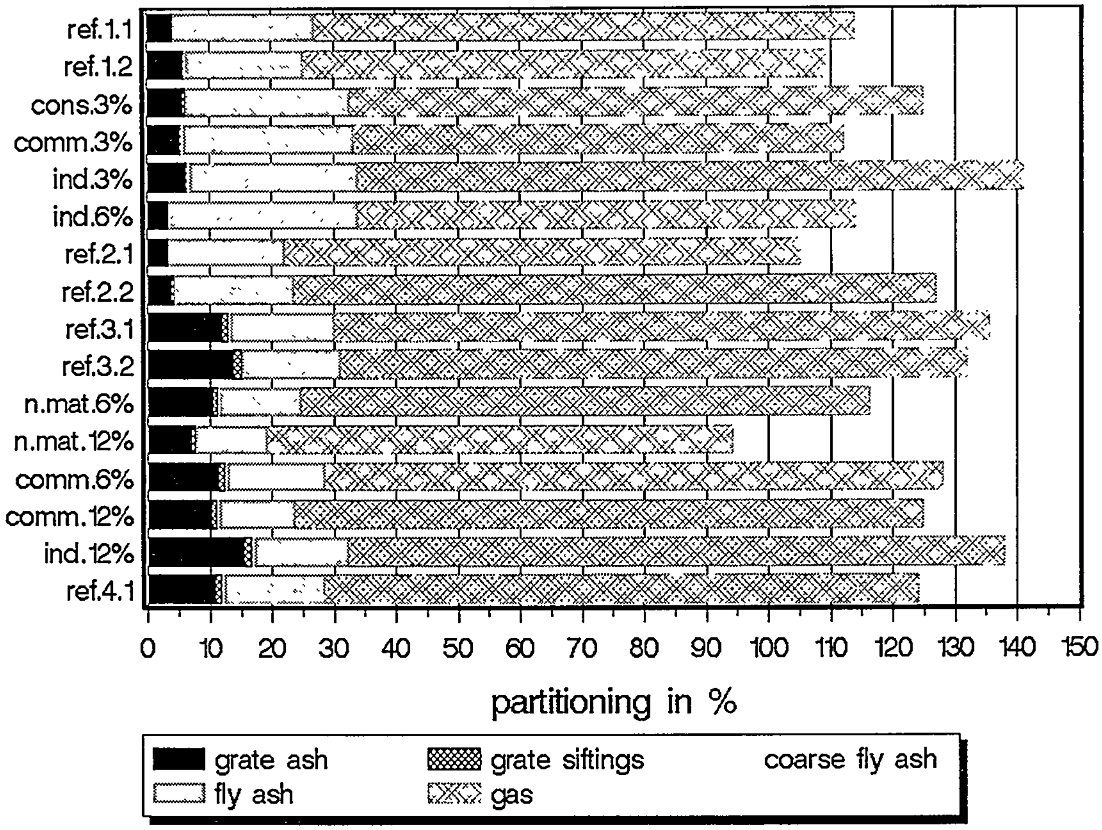

Fig. 2: Percent partitioning of Cl

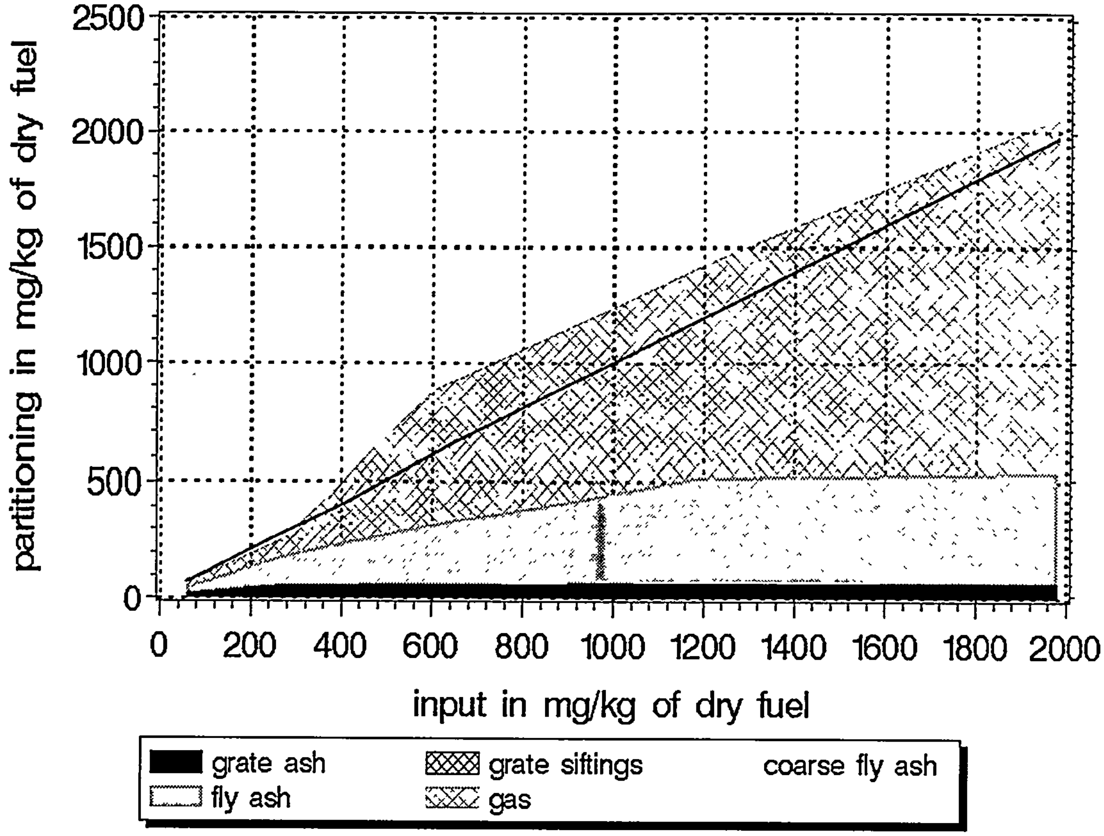

Fig. 3: Partitioning of Br in the parallel flow combustion geometry

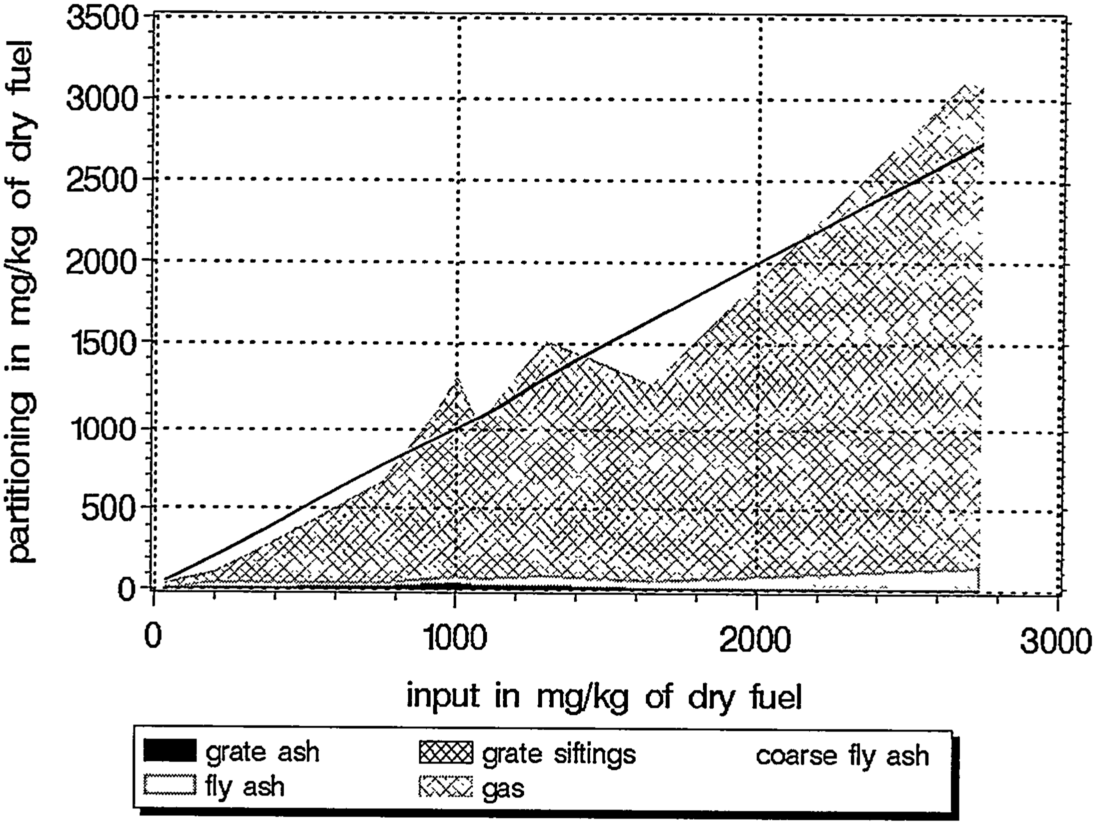

Fig. 4: Partitioning of Br in the middle flow combustion geometry

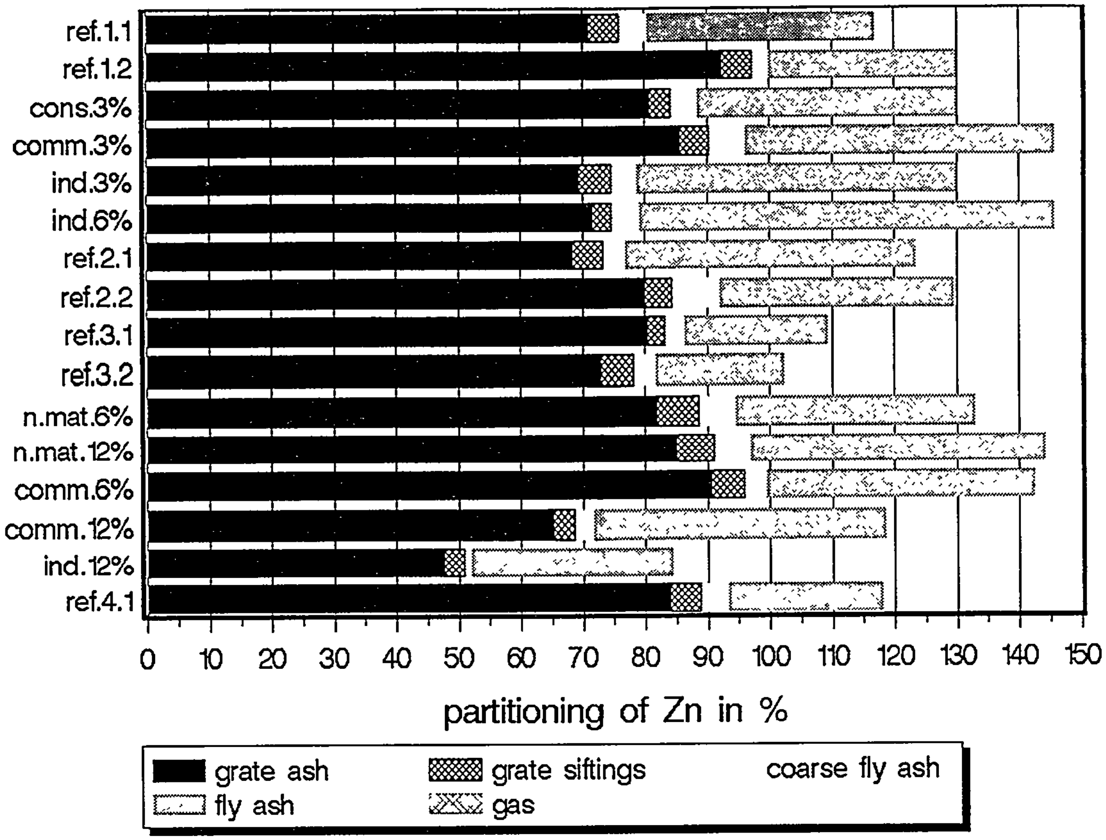

Fig. 5: Percent partitioning of Zn

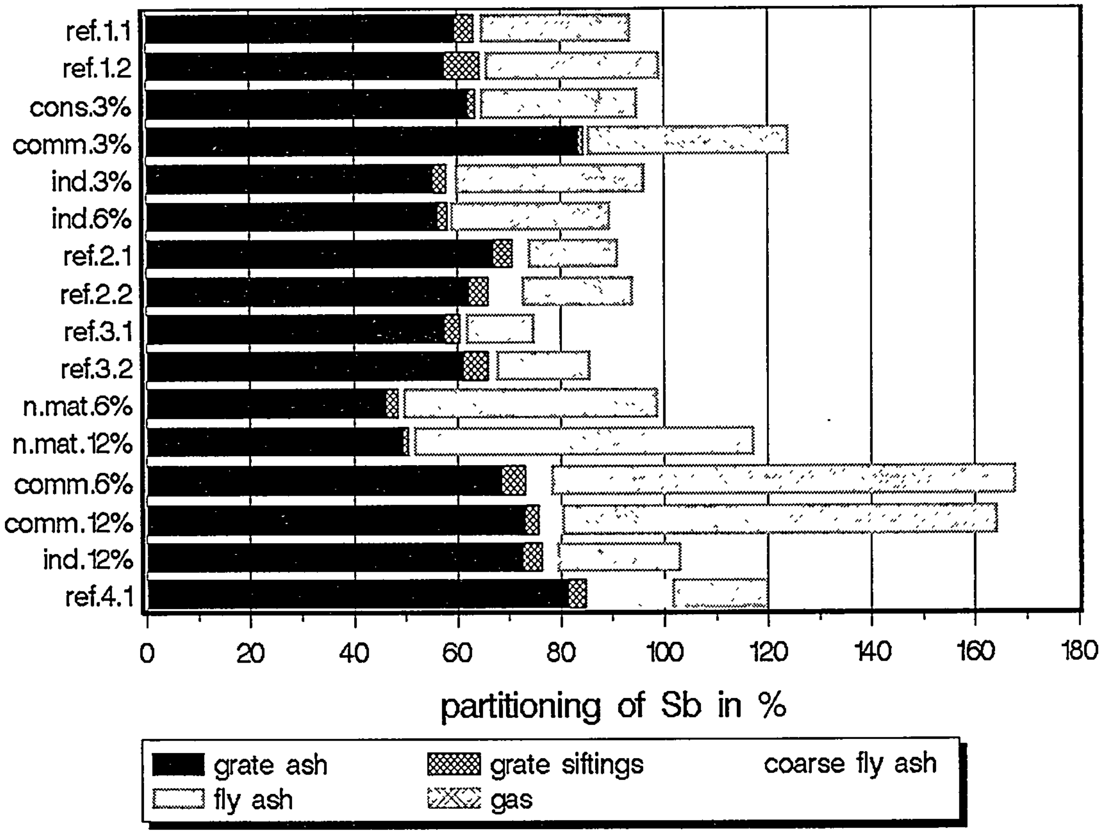

Fig. 6: Percent partitioning of Sb

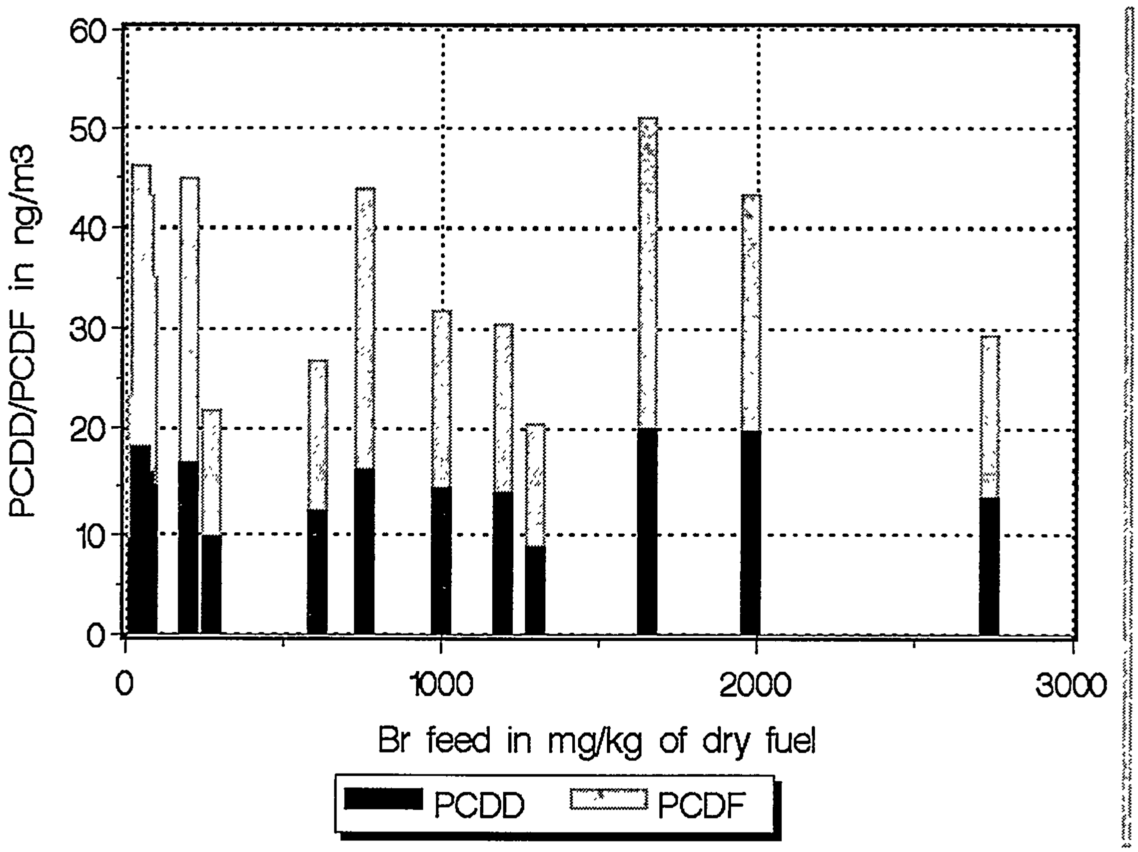

Fig. 7: Sum of PCDD/PCDF levels in the raw gas

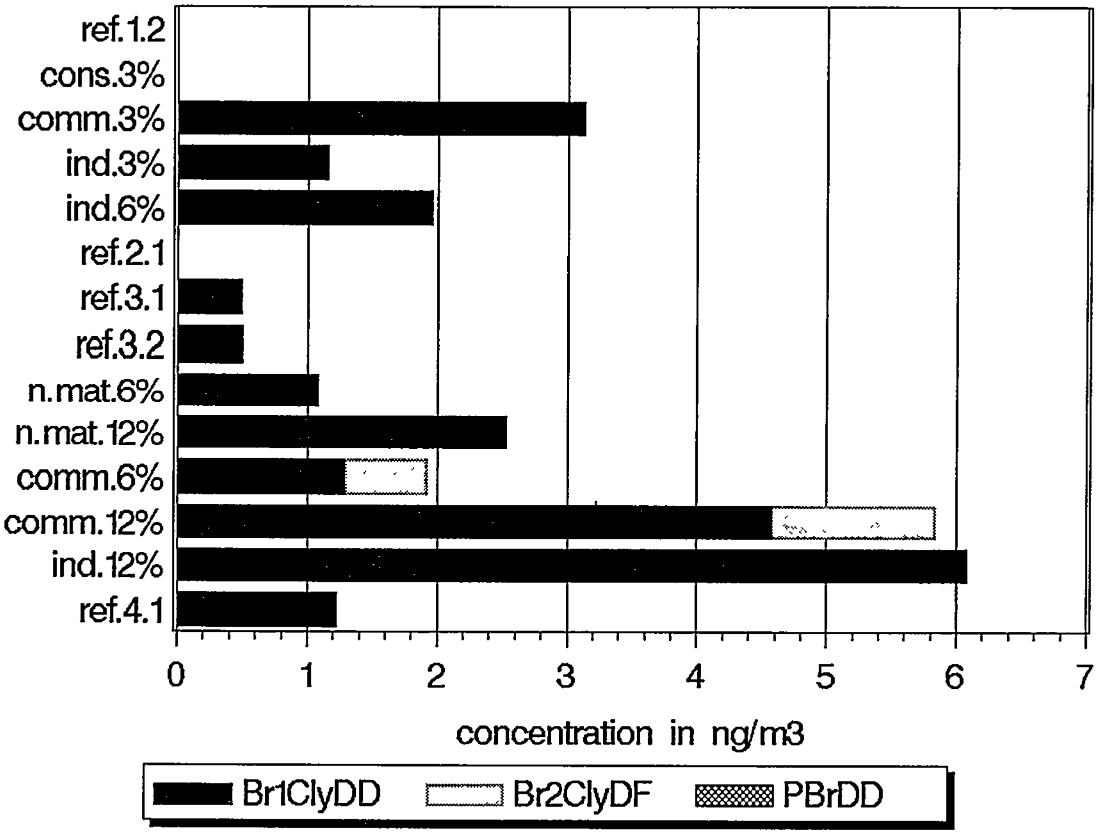

Fig. 8: Br containing dioxins in the raw gas

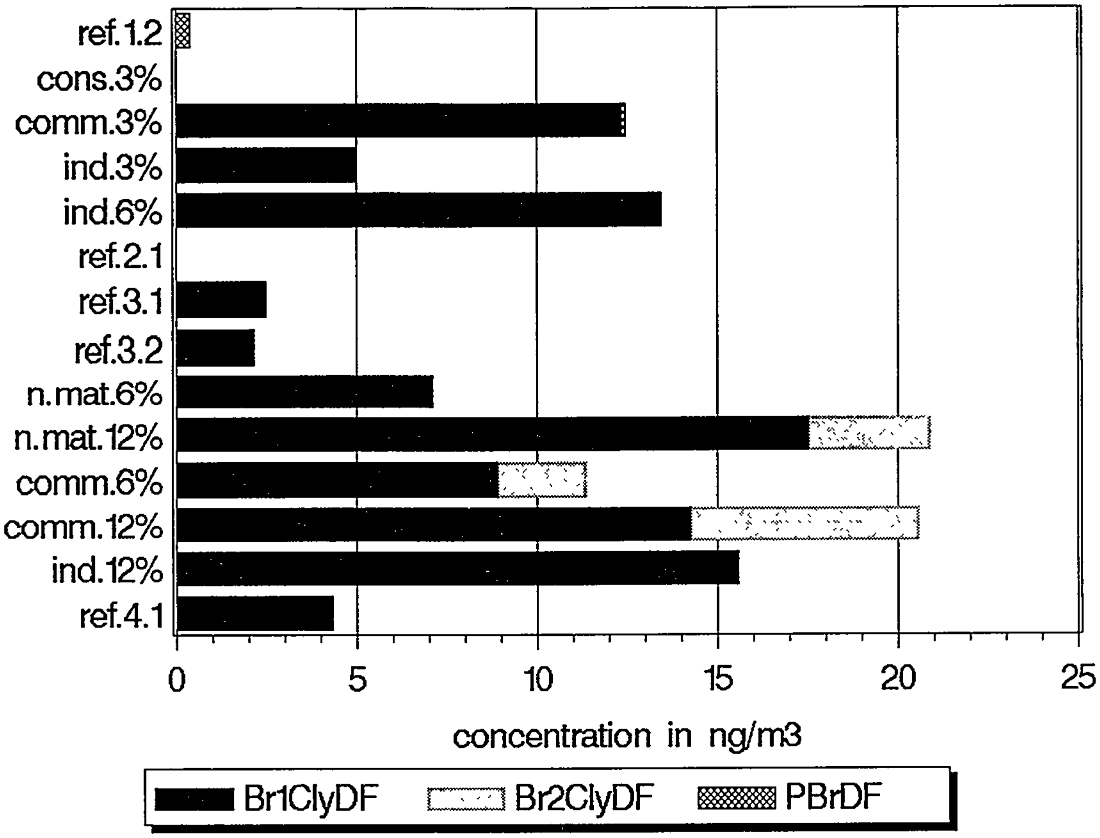

Fig. 9: Br containing furans in the raw gas

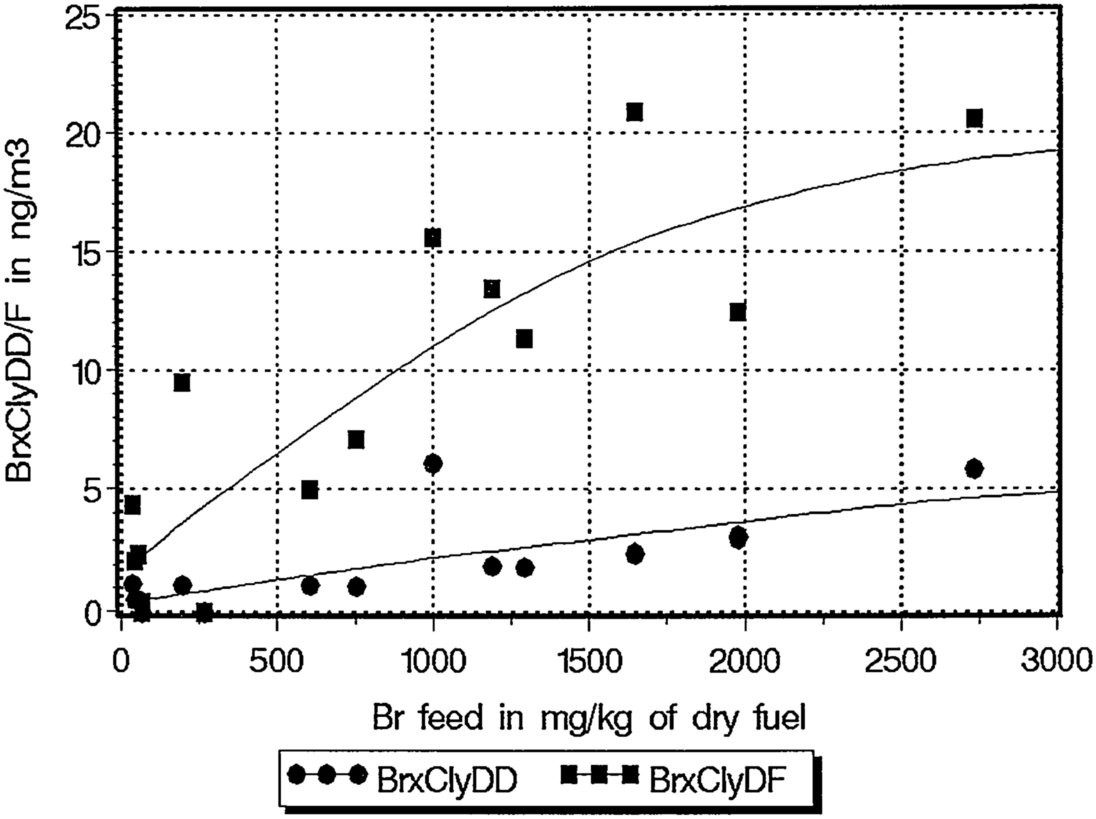

Fig. 10: Bromine containing dioxins and furans versus Br feed

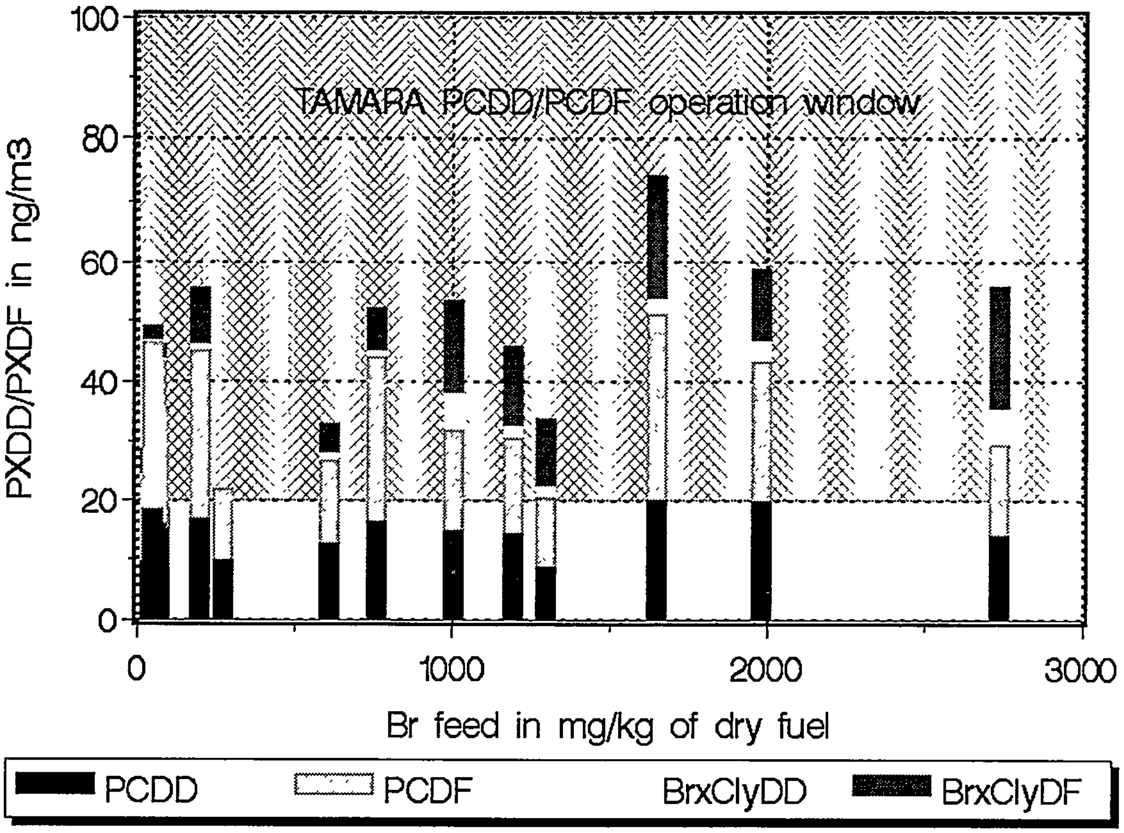

Fig. 11: Sum of halogenated dioxins and furans

Achieving 40 CFR Part 60 Subpart C_b CO Emission Requirement On Large RDF-Fired Municipal Waste Combustors

Mathew J. Clark
HDR Engineering, Inc.
128 S. Tryon St., Suite 1400
Charlotte, NC 28202

Bryan S. Sturgies
HDR Engineering, Inc.
128 S. Tryon St., Suite 1400
Charlotte, NC 28202

INTRODUCTION

Carbon Monoxide (CO) is a colorless and odorless gas that is created when carbon based fuels are incompletely combusted. Some level of CO is produced in all practical carbon fuel combustion operations. Exposure to concentrations of CO above the permissible limit has been determined by the scientific community to be harmful to the general public. Congressional passage of the 1990 Clean Air Act required the U.S. Environmental Protection Agency (EPA) to establish concentration limits for CO as well as other products of the combustion process for affected facilities. As a result, the EPA recently promulgated 40 CFR Part 60, Subpart C_b for existing Municipal Waste Combustors (MWC). Included in these new requirements will be a CO emission concentration limit.

The refuse derived fuel (RDF) fired plant is one category of municipal waste combustor (MWC) that will be subjected to the new requirements. RDF is produced when municipal solid waste is processed to obtain a smaller and more consistent fuel particle size. RDF can be combusted to release energy for steam and/or electrical production. RDF is usually combusted by feeding it onto a traveling grate although other means have been developed, including co-firing with other fuels and fluidized bed combustion. RDF-fired unit capacity ratings are determined based on tonnage of fuel combusted per day (tons/day). The EPA established the new emission requirements based on this capacity rating. Large RDF facilities (more than 250 tons/day) will be limited to a CO concentration of 200 ppmdv @ 7% O_2. Although a recent court ruling has delayed the execution of the new requirement, the final CO concentration limit for large RDF-fired "units" is expected to remain unchanged.

Eight large RDF plants were surveyed to characterize their ability (or inability) to meet the newly promulgated requirement for CO. The reported range of typical CO emission concentrations was from 50 to 400 ppmdv @ 7% O_2. Some units will not have difficulties meeting the new CO emission concentration limit and some will have to consider operational changes and possible equipment modifications to meet the new requirement. This paper attempts to define what equipment and operational characteristics allow for the performance differences observed and also identifies techniques that can be implemented to help compliance efforts.

RDF PLANT BACKGROUND

The history of the RDF-fired waste-to-energy (WTE) plant is relatively short in comparison to other forms of combustion technology such as coal, oil, gas, and wood firing. The first applications used RDF as a supplementary fuel for conventional electric utility boilers. RDF was usually suspension-fired in combination with pulverized coal or atomized oil or gas. By the mid 1970s, new plants were being designed primarily to burn RDF. The designs were conventional stoker grate arrangements.

The first RDF facility designs were based on the proven technology of wood firing. It was believed at that time that the combustion characteristics of wood were similar to RDF. Fuel feed systems and boiler design both relied heavily on wood fired designs. These wood fired based designs incurred various problems leading boiler manufacturers and equipment designers to make significant improvements in the combustion process of RDF on stoker grates over the next ten years.

Today there are approximately eleven large waste-to-energy plants operating twenty-eight boilers on RDF. Four boiler manufacturers dominate the landscape by providing the majority of boilers for these large RDF applications, they include; ABB-CE (12 boilers), Babcock and Wilcox (7 boilers), Riley Stoker (5 boilers), and Zurn Industries (4 boilers). Each of these manufacturers have their own design signature that encourage or inhibit compliance with the new regulations.

Due to implementation of more stringent 40 CFR Part 60 Subpart C_b emission requirements for existing large RDF-fired facilities, operators must consider their impact and possible retrofit options. Modifications may include acid gas scrubbers for hydrogen chloride (HCl) and sulfur dioxide (SO_2) control, fabric filter baghouses for particulate control, and selective non-catalytic reduction systems for nitrogen oxide (NO_x) control.

FACILITY DESIGN CONSIDERATIONS

The investigation of various CO emission levels was based on the "three T's of combustion", time, temperature, and turbulence. The majority of combustion takes place prior to the furnace exit. The design of the fuel feed system and furnace are two areas of system design that directly affect the three T's of combustion and determine how complete the combustion of the RDF will be. The fuel feed system must distribute the fuel evenly on the grate. This insures that a constant undergrate air pressure will deliver the air where it is needed. The geometry of the furnace and the overfire air (OFA) ports provide the turbulence necessary for good combustion. The grate area and furnace volume determine the residence time and temperature of the gas particle as it travels through the furnace.

Fuel Feed System

The typical fuel feeding system injects the fuel in the front of the boiler and tosses it towards the rear. The objective of the system is to get the best fuel distribution front-to-back and side-to-side on the grate. Typically, three to eight individual feeders are used. Some feeders have the ability to vary the transport air pressure to improve front to back distribution. These feeder types generally provide a more even bed depth and consequently better mixing.

Many types of conveyors and system designs are used to divide and consistently convey the RDF to the feeder. Two systems commonly found are shown in Figures 1 and 2. The largest contribution the conveying system can make to controlling CO concentration emissions is to not plug. A fuel system plug often results in high CO spikes while the plug is being cleaned. However, considering that the CO emission levels are based on a 24 hour average, the conveying system does not make or break a units ability to meet the limit.

Boiler Design

The furnace is the envelope in which the majority of combustion takes place. Fuel and air are introduced on the grate which provides the floor of the "box". The size (or volume) of the box determines how much time gas particles will spend before exiting. The grate size and speed determines how much time the fuel will spend in the furnace and the bed depth required to meet steam demand. Overfire air provides the oxygen and turbulence to complete the combustion process started on the grate.

One factor considered by boiler designers is the amount of energy (Btu/hr) released per cubic foot (ft^3) of volume. This factor is termed " furnace liberation rate" and is expressed in Btu/hr/ft^3. Table 1 depicts liberation rates for the RDF facilities surveyed. This number varies significantly for the identified units. The magnitude of this number is not significantly correlated to the CO level as can be seen by the accompanying graph of Typical CO vs. Liberation Rate, Figure 3.

A more important indicator of CO emission concentration controllability is the physical geometry of the furnace. The two lowest typical CO levels were reported by facilities with Babcock and Wilcox's $\mathrm{CCZ}^{\mathrm{TM}}$ design furnaces. This furnace design, shown in Figure 4, includes two opposing noses in the lower portion of the furnace. The significance of this furnace design is not related to furnace size, but to design features which promote better mixing of the fuel and available combustion air. In contrast, competing furnace designs do not encourage turbulence above the firing grate, mainly due to the lack of furnace constriction created by multiple noses.

Another design criteria used by boiler design engineers is grate heat release rate. This factor is expressed in $\mathrm{Btus/hr/ft}^2$ and is simply the fuel heat input divided by the grate area. For a desired grate heat release rate and known fuel input, the grate dimensions are set. The grate heat release rate is fairly consistent for the units surveyed as depicted in Table 2 and its accompanying graph, Figure 5. Again, little correlation was observed between CO levels and grate heat release rate. It is important to note that grate size and speed will mandate the bed depth on the grate for a given firing rate. From this data, it can be observed that there is consensus that a bed depth of 6 - 12 inches results in good undergrate air distribution and allows for burnout of the fuel on the grate, provided the fuel is evenly distributed front-to-back and side-to-side.

Overfire Air System

The goal of the overfire air (OFA) system is to promote mixing of fuel and combustion air to complete the conversion of carbon to carbon dioxide (CO_2) without adding substantially to the undergrate air (UGA) provided for primary firing of the fuel on the grate. Boiler suppliers have taken very different approaches and made significant changes to these systems during the design evolution. The conventional front and rear wall, multi-level ports were the starting point for all boilers. As Babcock and Wilcox developed the $\mathrm{CCZ}^{\mathrm{TM}}$ furnace for RDF firing, the main overfire air ports were located in the bottom nose. B&W also increased the diameter of the ports as their design evolved. This furnace configuration results in the lowest CO levels reported by the RDF plant operators surveyed. The design evolution of the ABB-CE boilers went to a proven technology implemented on CE utility boilers, tangential overfire air nozzles. This configuration is shown in Figure 6. While this technology has proven itself successful in many applications on different fuels, operators of ABB-CE RDF-fired boilers have chosen to return to conventional front and rear wall OFA nozzles, for reasons other than CO control. Other boiler designs are using OFA ports located at various elevations on the front and rear walls. Optimization programs have shown some success controlling CO with the conventional arrangement of OFA ports. To achieve this, operators must carefully set up a matrix of various OFA pressures and OFA/UGA splits while recording CO emissions. The settings can be optimized for the boiler load and fuel conditions at the time of setting. Unfortunately, these may not be the optimum settings for all conditions.

OPERATIONAL CONTROL MEASURES

Operational techniques can be employed by plant operations staff to help mitigate excess CO emissions resulting from combustion incompleteness. Measures such as controlling the fuel distribution and bed depth, steady steam load control, overfire air location and header pressure adjustment, and firing of auxiliary fuels can be implemented to reduce the average CO concentration measured and reported by continuous emissions monitoring systems (CEMS). Several facilities surveyed use these techniques, independently or in combination to help them comply with the existing and new CO emission concentration limits.

In general, these techniques can be categorized into two types; pre-combustion techniques which attempt to create optimum combustion so that generation of CO is limited, and post-combustion techniques which attempt to reburn the CO released from the grate before it exits the furnace.

Maintaining an even distribution of fuel on the grate is critical to controlling CO emission concentrations. Improperly delivered fuel to the grate can result in piles of fuel which create a reducing environment at the ignition point. Additionally, undergrate combustion air bypasses piled grate fuel due to the induced pressure drop created and compounds the problem, thus poor combustion and elevated CO levels. The causes for uneven fuel distribution include the design of the fuel delivery system, as discussed above, and instability of the fuel demand signal from the boiler controls.

The ideal conditions for CO control include a constant fuel feed rate and air flow. This is of course impossible due to variability of the fuel characteristics and changes in boiler demand. Fuel characteristics cannot be controlled by the plant operator, but steps can be taken to reduce changes in the boiler demand. The control system should be configured so that steam header pressure controls the fuel feed rate. Other control schemes may be currently utilized by operators that are counter-productive to CO control. For instance, programs which attempt to change boiler demand among operating boilers to optimize efficiency may result in additional fuel demand swings.

Unsteady fuel feed rates will lead to uneven distribution of fuel on the grate. It also can contribute to increased incidences of fuel system pluggage which further exacerbates the problem and leads to a vicious cycle.

Co-firing RDF with other grate fired solid fuels such as stoker coal or wood chips is another pre-combustion methodology for CO control. Co-firing with these higher heating value fuels increases furnace temperature and encourages CO destruction. This method is available but usually prohibitive due to the cost of the fuel and the operational and maintenance costs considerations. Operators of plants designed to co-fire solid fuels have found that higher grate temperatures lead to slagging problems on the grate, and have discontinued co-firing.

As previously discussed, injection of overfire air is a post-combustion CO control technique that is widely used by RDF-fired facility operators. The technique is employed to oxidize the CO in a high temperature, highly turbulent area of the furnace above the firing grate so that carbon reburn will occur. The most common problem associated with OFA injection is determining where to put the air and at what pressure it should be injected. CO gases are primarily emitted from the firing grate in a stratified manner and usually do not become evenly dispersed in the flue gas stream until after passing through the boiler's convection pass. Because the firing grate is in constant motion, excess CO emitted from the grate as a result of fuel piling becomes a moving target. To combat this problem, a grid of OFA should be generated above the firing grate to oxidize the excess CO regardless of where it is being generated on the grate. More specifically, OFA should be injected at different elevations and progressive pressures to allow for greater penetration and full coverage of the furnace. RDF facilities having success controlling CO inject OFA at elevations from 5 to 50 feet above the grate and vary OFA header pressures from 5 inches to 30 inches wg. Each individual boiler should be evaluated to determine the optimum locations for, and pressures of, injected OFA.

The use of auxiliary burners is becoming more widespread for CO control applications. Burners are located above the firing grate and fired with approximately 20% excess air to create a conducive environment for secondary combustion of the CO gases emitted from the firing grate. Clean burning natural gas is the fuel of choice, however, #2 fuel oil can be used if natural gas is unavailable. Dual fuel burners are recommended where gas curtailments are a potential concern. The burners must be strategically located above the furnace to reburn CO gases released from the firing grate. Control can be manual or automatic using a furnace temperature control signal and/or the CEMS corrected CO signal. This post-combustion CO control methodology, much like co-firing solid fuels, can be prohibitive due to the fuel and equipment costs. However, if CO compliance is unachievable through other methods described previously, introduction of a second fuel may be necessary to continue operation.

CO - DIOXIN EMISSION CORRELATION

The Subpart C_b CO emission concentration limit was developed with the assumption that both Dioxin/Furan and CO emissions were indicators of complete combustion. In a strict sense, this may be true, especially for plants built without acid gas control and designed for higher allowable particulate emissions. For these plants, dioxin emissions may be extremely high.

In the case of the Norfolk Naval Shipyard Steam Plant in Portsmouth, VA, operated by the Southeastern Public Service Authority of Virginia, Dioxin/Furan emissions are well below the proposed limits while CO levels have not been maintained below the proposed limit. This facility was recently retrofitted with spray dryer absorbers and fabric filters. Furthermore, Penobscot Energy Recovery Company (PERC) in Orrington, Maine has encountered a similar non-correlation as illustrated in Figure 7 which demonstrates that the perceived correlation between low CO concentration levels and low Dioxin/Furan levels does not always exist.

CONCLUSIONS

Control of CO emission levels in a RDF-fired application is not achieved by one single action or installation of a certain piece of equipment. The plant operator must be cognizant of all variables which affect CO emissions.

Most operators of large RDF plants have the tools and knowledge to operate within the new emission concentration limit for CO. Others will need to embark upon programs to identify and implement the changes required to lower CO emission concentration levels.

Based on the results of this study and considering the economics, the following recommendations would be made for an operator considering a CO control program. These items are listed in descending order of importance:

1. Implement boiler control program changes to level-out fuel feed rates to the greatest extent possible.

2. Develop OFA testing matrix and conduct tests to establish OFA settings and UGA/OFA splits for various loads and fuel conditions.

3. Consider boiler geometry retrofits which will result in better combustion.

4. Retrofit fuel feed system.

5. Implement natural gas and/or fuel oil auxiliary burners for CO control.

Actual equipment retrofits would require significant capital expenditures. Before any retrofit is implemented, an operator would need to extensively study the costs and benefits to justify the project and to make sure it would be effective in reducing CO emissions. The only benefit of such a retrofit may be achieving the future CO emission concentration limit. The actual benefit to the environment should be considered by governmental agencies prior to imposing costly permit requirements on individual operators.

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4. Mike DePero, Environmental Engineer, Solid Waste Authority of Palm Beach, West Palm Beach, Florida
5. Wayne Hanson, Plant Manager, United Power Association, Elk River, Minnesota
6. Robert S. Sommers, Plant Manager, Solid Waste Authority of Central Ohio, Columbus, Ohio
7. Mark Turner, Manager of Environmental Services, SEMAS RR Facility, Rochester, Massachusetts
8. Ronald Davies, Plant Manager, Honolulu Resource Recovery Venture, Honolulu, Hawaii

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Table 1. Comparison of Surveyed Units' Liberation Rate

Facility	Units	Capacity TPD/unit	Boiler Manufacturer	Boiler MCR steam/hr	Furnace Vol. cu-ft	Typical CO ppmdv	Liberation Btu / hr / cu-ft
Palm Beach	2	900	B&W CCZ	322,000	32,787	55	14,030
MERC	2	300	B&W CCZ	105,000	7,092	90	21,151
Elk River	1	600	B&W	176,000	16,895	125	14,882
SEMASS	3	900	Riley Stoker	280,000	42,120	140	9,497
PERC	2	350	Riley Stoker	133,400	11,232	200	16,967
Columbus	4	500	B&W	165,000	9,185	300	25,663
SPSA	4	500	CE, VU-40	180,000	17,658	400	14,562
Honolulu	2	890	CE, VU-40	244,000	26,532	100	13,138

Table 2. Comparison of Surveyed Units' Heat Release Rate

Facility	Units	Capacity TPD/unit	Boiler Manufacturer	Boiler MCR lbs steam/hr	Grate Area sq-ft	Typical CO ppmdv	HR Rate Btu / hr / sqft
Palm Beach	2	900	B&W CCZ	322,000	630	55	730,159
MERC	2	300	B&W CCZ	105,000	220	90	681,818
Elk River	1	600	B&W	176,000	399	125	630,147
SEMASS	3	900	Riley Stoker	280,000	600	140	666,667
PERC	2	350	Riley Stoker	133,400	294	200	648,202
Columbus	4	500	B&W	165,000	342	300	689,223
SPSA	4	500	CE, VU-40	180,000	399	400	644,468
Honolulu	2	890	CE, VU-40	244,000	396	100	880,230

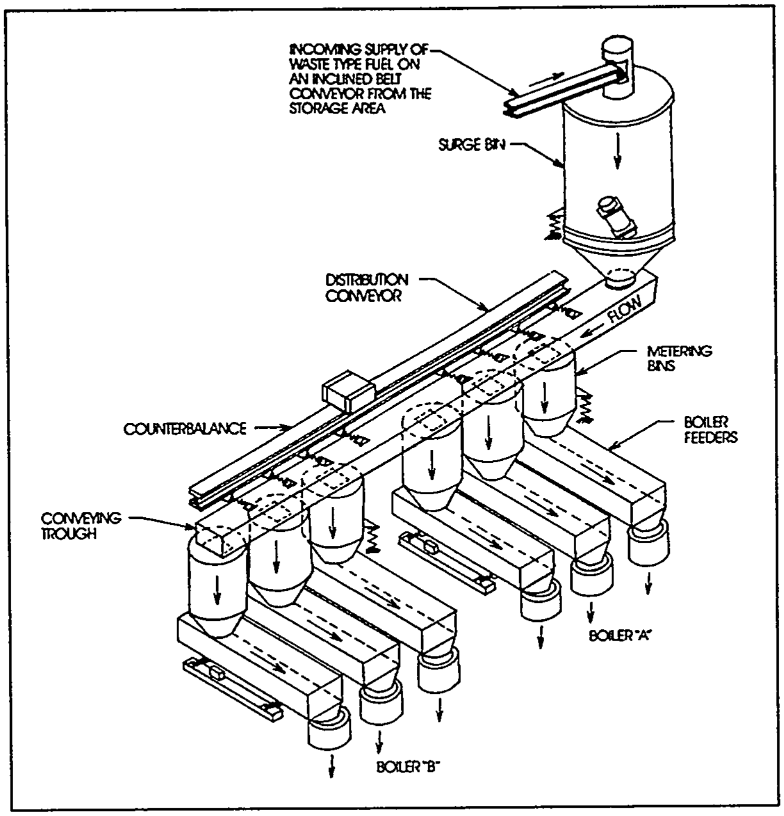

Figure 1

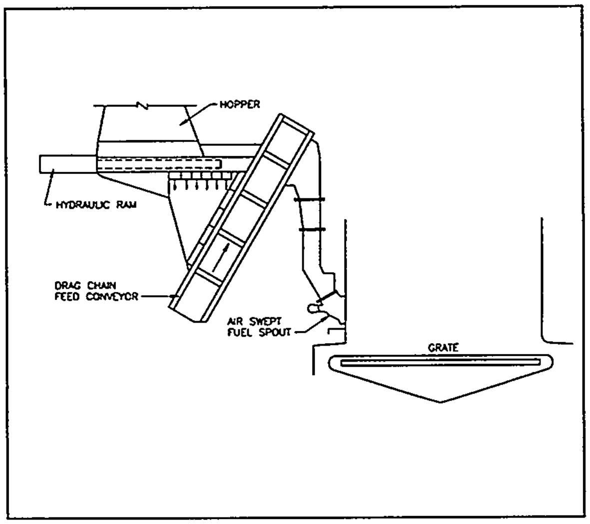

Figure 2

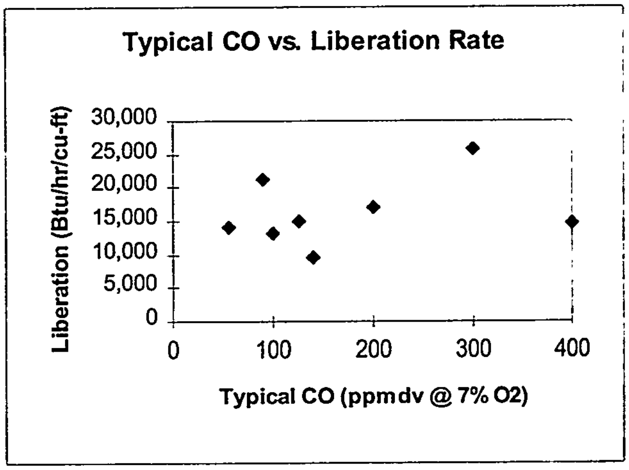

Figure 3

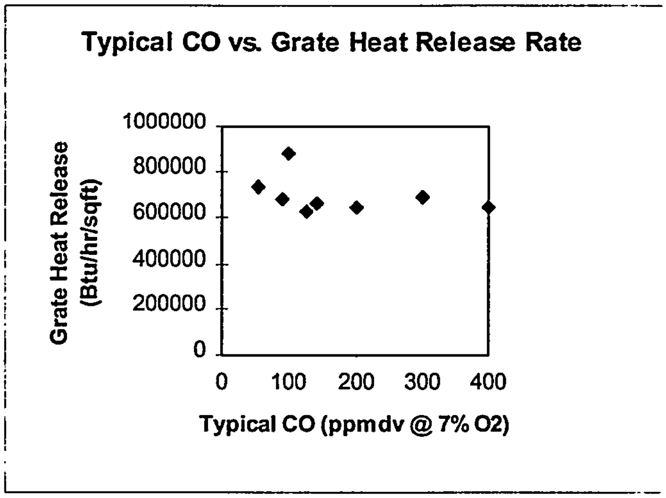

Figure 5

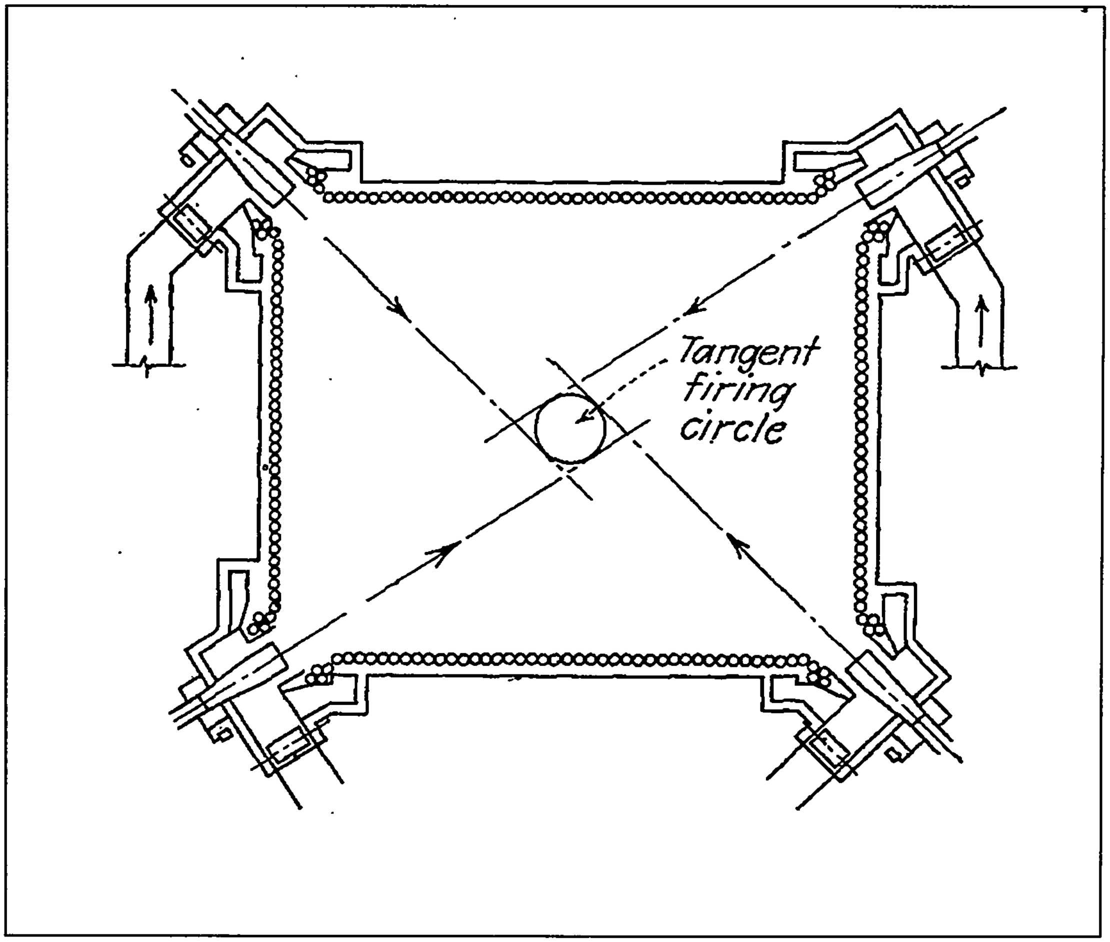

Figure 6

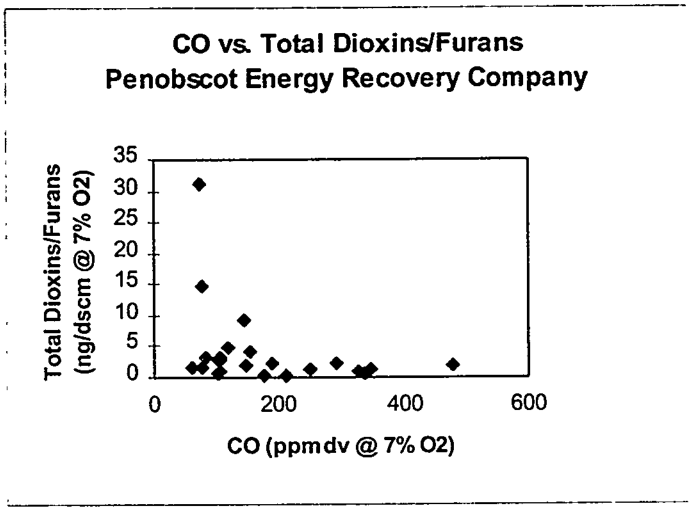
CO vs. Total Dioxins/Furans
Penobscot Energy Recovery Company
Total Dioxins/Furans (ng/dscm @ 7% O2)
35
30
25
20
15
10
5
0
0
200
400
600
CO (ppmdv @ 7% O2)

Figure 7

TECHNICAL SESSION II

Risk Communications

Promoting Positive Safety News -- The American Ref-Fuel VPP Experience

Lyle R. Hanna
American Ref-Fuel Company
777 North Eldridge Parkway
Houston, TX 77079

INTRODUCTION

American Ref-Fuel has a documented record of being a safety leader in our industry. In fact, American Ref-Fuel is only the third company of *any* industry to have all of its operating facilities designated as Voluntary Protection Program (VPP) Star worksites by the U.S. Occupational Safety and Health Administration (OSHA). While we we're proud of our safety accomplishments, this has presented a whole new challenge -- namely how to promote this message to a media and public who may be largely indifferent to our safety practices unless there is a major problem. This paper examines the company's rationale for pursuing publicity of our safety record as well as detailing implementation of that strategy to date.

WHY THE 'SAFETY FIRST' PHILOSOPHY EXISTS

Providing safe working conditions for employees and instilling work habits to help employees protect themselves and others are the right things to do, period. The moral and ethical values of individuals and companies dictate that accidents and injuries can, and should, be avoided. From a business standpoint, the cost of safe work practices need only to be contrasted against today's spiraling medical and legal costs to see the positive impact safety can have on the bottom line. A third consideration -- which incorporates both the ethics and business sense of the company -- is image. If a company is perceived in its market and the community it serves as being extremely safe (or unsafe), there will likely be associations made between that and other attributes of that same company.

So if safety is such a universally accepted concept, why are there so few "good news" stories about it? Why does the notion of an OSHA visit bring sweaty palms? Why do companies who accept, or are forced to accept, blame for accidents, not aggressively promote that fact they often take extraordinary efforts to prevent accidents and injuries? Some of these answers lie in the conventions of safety reporting, the nature of the media and its customers, a shortsighted view of OSHA's role and an underestimated value of what public relations can mean on this topic.

AMERICAN REF-FUEL AND THE VPP

According to OSHA, the Voluntary Protection Program was created in recognition that compliance enforcement alone can never fully achieve the objectives of the Occupational Safety and Health Act. Good safety management programs that go beyond OSHA standards can protect workers more effectively than simple compliance. VPP participants are a select group of facilities that have designed and implemented outstanding health and safety programs. Being designated as a Star participant means a company has met all VPP requirements. In OSHA's own words, "The VPP application process is designed to be rigorous, to assure that only the best programs qualify." The numbers back up the agency's claim. Of the six million worksites OSHA is responsible for monitoring, fewer than 300 have been designated as Star sites. When American Ref-Fuel received the Star designation at our Niagara Falls, New York facility in March of 1996, we joined Mobil Chemical (19 sites) and Aurora Meat Packing (2 sites) as the only companies in America with all of its multiple operating locations as Star sites. In addition to having the first waste-to-energy plants named as VPP stars, we believe that we are the youngest company to ever attain the VPP Star and that our Southeastern Connecticut plant has the fewest employees of any VPP Star site.

American Ref-Fuel first became involved in VPP when Nancy Adam's OSHA's Long Island area director encouraged Hempstead plant officials to participate. After attending a conference hosted by the VPP Participant's Association, American Ref-Fuel representatives saw the benefits of the program and how well it dovetailed with our collaborative culture that encourages employees to "think like owners." The next step was to create a task force to perform a self-assessment of how the Hempstead facility stood with regard to OSHA requirements and determine actions needed to bring the plant to VPP standards. More than 100 items were identified. The plant manager and safety supervisor then organized a kickoff rally where they invited a representative from Hoechst Celanese, a VPP mentor company, to explain the benefits of the program. Among those benefits are improved employee motivation to work safely, yielding better quality and productivity; reduced workers' compensation costs; community recognition; and generally 60 to 80 percent few lost workday injuries.

The OSHA Region 2 office examined records, training plans and other documentation. An examination team toured the plant, interviewing employees from across the entire plant staff to determine management commitment and employee participation in the safety process. As James Stanley, deputy assistant to the Secretary of Labor explained, "We look at companies where the overall philosophy is that employees are an asset, not just a cost."

The Hempstead plant was designated as a Star site in October of 1994. We were then able to build on this success with subsequent Star recognitions at Southeastern Connecticut in May of 1995, at Newark, New Jersey in August of 1995 and Niagara Falls, New York in March of 1996. American Ref-Fuel has since acquired the SEMASS facility in Rochester, Massachusetts. Our goal is to apply our safety culture and the lessons learned at our other facilities to make that plant a Star facility as well.

One example of how this attention to safety is reflected on the bottom line is in the area of worker's compensation coverage. The National Council on Compensation Insurance, Inc. calculates an annual rating on behalf of the insurance industry. One statistic used is an experience rating modifier (ERM) where an average company in a given industry is given a factor of 1.0. A higher or lower factor results in a higher or lower premium. Based on our favorable history, American Ref-Fuel's ERM factor is .77, resulting in a 23 percent credit on our base premium. Translated into dollars, that one fact alone is worth an annual savings to our company of approximately $155,000.

SPREADING THE NEWS -- WHY WE WANT PEOPLE TO KNOW WE'RE SAFE

Shouldn't we be satisfied that our people are returning home safely each day and that the company is saving money as a result? As someone who has spent his career in media and public relations, my answer is a definite no. There are several reasons to, in the parlance of the trade, "go positive" with this news. Among these are the opportunity it presents to report safety rather than lack of it, the chance to enhance relationships your employees and other stakeholders, the ability to counteract other types of media attention, the concept of "success by association" and to help satisfy an overall "thirst" for information.

Safety is something we have done well throughout our company's existence. The difficulty has been finding a way to state that fact in a positive sense. The reality is that safety reports are most often quoted in injury statistics, time lost due to accidents or other quantifiable terns that measure the *exceptions* to safety. As few as these incidents may be, they still don't present a positive message to an outside audience. Imagine a news release that begins, "XYZ company is proud to announce that only four people were hurt on its premises last quarter..." The elite nature of the VPP Star program, on the other hand, presents clear evidence that the company puts a high priority on safety, and delivers on that commitment.

In the evaluations American Ref-Fuel has received on our VPP applications, the OSHA personnel have always given us high marks for the level of employee involvement in the safety process. The employee input has been valuable in other ways as well. They are often the ones who present the image of our company. For instance, since our Hempstead plant began processing waste in 1989, more than 18,000 visitors have toured the plant. While there are more formal aspects of the tour, such as a video in the conference room, the more favorable comments usually have to do with how knowledgeable and friendly our crane operators and other plant personnel have been toward the guests. The VPP status gives these employees an extra sense of pride. This is further underscored by the fact that every time the company has been received a Star designation, there has been a big recognition dinner for all plant employees and spouses to gather and celebrate.

Our stakeholders extend beyond the realm of our employees. Community leaders attend our VPP events to congratulate our people and to share in the limelight of the positive image this casts on the community at large. In Connecticut, the state's Business and Industry Council has followed OSHA's lead in presenting its annual Safety Award to American Ref-Fuel's Southeastern Connecticut facility in Preston. Because American Ref-Fuel is a joint venture company of Browning-Ferris Industries, Inc. and Air Products, Inc., these two investor organizations have also been able to report our safety success to their stockholders and analysts who track their companies.

Garnering media attention has been more of a challenge. There certainly seems to be more "news" value to accidents and injuries than there is to prolonged periods of safe operation. As one television news reporter succinctly put it, "We don't cover airplanes that don't crash." We have, however, been able to "bridge" to our safety success and the VPP recognitions when talking to the media on other issues. For example, our Niagara Falls manager was a guest on a radio program where he had the opportunity to talk about safe disposal of citizens' discarded propane tanks. From an American Ref-Fuel perspective, the concerns about the tank disposal meshed well with a discussion of our safety culture and how this was a prime example of how that culture also looks after the bests interests of the community.

We were able, with news releases and follow-ups, to get coverage of the Star site ceremonies in several local newspapers in the host communities of our plants. While the articles were not extensive, the benefit of getting positive news on file at a newspaper is that it tends to stay on file. In today's newsroom, the classic newsroom "morgue" of old clippings has been replaced by an electronic version where a reporter writing a story on any given company can retrieve previously written information with just a few keystrokes. Therefore, companies should make a conscious effort to see that newspapers' file information grows to be a more of a listing of accomplishments than a listing of instances where the company has been in the news for some form of violation or public controversy.

The "success by association" is a twist on the old phrase "guilt by association." The type of industrial safety covered by OSHA differs from what is usually meant when people ask, "Is this plant safe." The latter is usually a reference to environmental standards. Still, there is a natural tendency for people to link the two. They may be right. In both cases, a successful outcome is the result of competent design, diligent attention to proper operation and overall atmosphere of pride of ownership. In both its organizational structure and its list of core principles, American Ref-Fuel links safety and environmental protection. Personnel in both departments report to a the same vice president. Both criteria are also considered among the bonus calculations for all operations employees. The ripple continues outward beyond safety and environmental protection. Three of our VPP sites have received awards in the Solid Waste Association of America's Waste-to-Energy Excellence Awards competition, as well as capturing numerous other accolades.

A final point on our opportunity to publicize our VPP Star participation has do with industry press. While we often hear about "information overload" and similar terms, modern communication capabilities have actually brought about a greater thirst for information to provide content for specialized or "niche" publications serving virtually every interest group imaginable. The waste and power industries are certainly no exceptions, with dozens of publications covering each. American Ref-Fuel has met with some success in promoting our VPP participation through these channels. We've then been able to compound this opportunity via reprints that we've used in our own promotional materials. These specialized publications also offer the benefit of reporters who are knowledgeable about our company and our industry, and who can produce articles in substantial detail. Their coverage is both a reward to our employees who deserve this tribute and a message to a broader audience who may sense a greater credibility when reading this information from a source outside of the company.

CONCLUSION

Certainly, safety is an issue that concerns us all. It's also an area where the small story can tell the big story in terms of conveying a company's attitudes and practices. American Ref-Fuel has parlayed our protection in the OSHA VPP Program into greater recognition for its employees, while attracting "good news" coverage of the waste-to-energy industry in a variety of publications. Industry opponents will continue to use the media as a forum and the more favorably inclined trade press will have ongoing needs for industry related story ideas. Given this scenario, it appears imperative that members of the waste industry consciously adopt strategies to promote positive events.

Crisis Communications: Challenges For The Waste-to-Energy Industry

Presented to the 1997 North American Waste-to-Energy Conference

Karen D. Alexander
Vice President, Public Affairs
Ogden Energy Group, Inc.
40 Lane Road
CN 2615
Fairfield, NJ 07007-2615
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COMMUNICATION FUNDAMENTALS

The communication process is comprised of four components: a sender, a message, a medium, and a receiver or audience. Effective communication requires us to understand the four components each time we communicate. We must understand ourselves--our bias, tone, even physical demeanor. We must understand the message--the words, pictures, and context. We must understand the medium--the bias of the written text or oral verse or video broadcast. Most of all, we must understand the receiver or audience--their bias, environment, experience, and education. Most of us take for granted that the meaning we give to our words will be accepted by the intended recipient. The existence of lawyers, counselors, and judges argues otherwise.

If you view communication as a process in which senders and receivers mutually influence each other by sending each other messages, you will strive to involve your audience before, during and after your interactions. with them in any one of the following communication situations:

- People in two person communication situations should be considered transceivers (transmitters/receivers) rather than communicator and communicatees. Each person simultaneously influences and is influenced by the other. We can also refer to those involved in this type of communication as both speaker/listener and listener/speaker because although the communication is going on simultaneously, one person usually initiated the contact.
- Three people can be called a small group. They get together and solve a problem, engage in a conflict, pursue common interests, or have a casual conversation. Our industry's organizations often engage in small group communication--in meetings with regulators, internal staff and colleagues, or community leaders. The uniqueness of the small group is that conflict occurs often in this relationship. Therefore, small group communication may demand more time to find common ground among the group if the goal is to build consensus or solve problems.
- The speaker-audience relationship demands the most preparation from those involved. The speaker who engages in formal presentations of issues must be prepared to research the issue, deliver the statement or speech, and attempt to make the audience feel and believe as she or he does. The audience, on the other hand, needs to develop good listening habits and be prepared to understand, if not agree with, the speaker's point of view.

During the course of any day, a public relations person engages in interpersonal (two persons, face-to-face) communication, small group (three or more), and speaker audience (formal presentations) situations. The importance of face-to-face communication is that feedback is immediate. Human communication, therefore, can be dynamic, with one communicative act influencing the next and change occurring in a continuous cycle as those involved strive to reach a common ground through immediate feedback.

Communication that is not face-to-face, does not have the luxury of immediate feedback. When sending our message by printed materials or through the electronic media, feedback most often is delayed. Interactive media in which feedback is delivered through a computer network strives to overcome the hurdle, but is as yet not as effective as face-to-face communication.

CRISIS COMMUNICATIONS AS A TOOL

Crisis communications is the ability to convey clear, concise, believable and caring messages to your organization's various publics or stakeholders when the unexpected negative event occurs. The event is usually, but not always, something catastrophic or of an emergency nature that adversely affects an organization directly, and/or adversely affects one or more of that organization's publics.

Crisis communications is a skill, a tool, a resource base and professional discipline upon which individuals and organizations can draw when confronted with an unexpected and potentially damaging event. It is a resource to draw upon to maximize the opportunity for positive outcomes even in the worst of situations. At a minimum, it can help an organization keep a bad situation from getting worse.

Successful crisis communications will require the use of all three modes of communication (two-person, small group and speaker-audience), with the later tending to be the most common and crucial during a crisis (the typical press conference or press release format). At the same time, it is the communication form most likely to present the greatest opportunity for failed communication precisely because of the phenonemon of distance and delayed feedback described earlier.

Every person with access to mass media, whether newspapers, radio, television or the Internet, regularly witnesses, participates in and/or judges how well or not crisis communication skills are exercised. Crises within the memories of most in this audience that have tested the abilities and fortitude of organizations include:

- the Exxon Valdez oil spill;
- the Oklahoma City bombing;
- the Three Mile Island accident;
- the Tylenol product tamperings;
- the space shuttle Challenger accident;
- the as yet unexplained explosion of TWA Flight 200.

Each of us saw or heard these events reported by the media and, based upon the impressions we had of what we heard and how and when the information was imparted, we drew conclusions in our minds about cause, culpability and consequences. If you know of any of these events, they undoubtedly hold lasting impressions for you--both of the event and of the organization at the center of it.

Communication is a tool for managing a situation, any situation. When the situation is a crisis, however, that tool becomes all the more important because how well or not it is used can directly and irrevocably affect the reputation of your organization.

Every public relations guru begins his or her lecture to a corporate client by stressing the importance of trust. "If the public trusts you," the consultant promises, "you will be accepted." Or, "I can help you because the public (or the regulator, or the politician) trusts me." The formula-seems simple: trust equals approval. Indeed, there must be an underlying acceptance that the person or entity sending the message is worthy of our attention. Trust, however, is only the beginning of effective communication.

There are numerous reasons why communication may not be effective even if the recipient of the message trusts the sender. Assume you are the receiver. You may trust and respect the sender, yet not believe her statements because you think she was mislead. You may not like the message because it is disturbing or disruptive to your beliefs. You nay not believe the medium, such as television, in which the message is delivered. You may not feel confident in your own experience or knowledge to trust your reactions to what you are hearing, reading, or viewing. Clearly, effective communication requires more than a simple formula.

Communication is most effective when trust, which is derived from the image of the sender, is combined with both empathy or rapport with the audience, and a message that seems logical to the receiver. To most communication professionals, image means developing "trust" and "credibility."

An important, although not exclusive, measure of successful crisis communications then is the degree of trust that you are able to instill in your audience. How well or not you are trusted, i.e., believed, can ultimately dictate not only the duration of the crisis but also whether you are judged by your publics to have brought it to a fair and responsible conclusion.

CRISES IN THE WASTE-TO-ENERGY INDUSTRY

Environmental protests.
Regulatory non-compliance.
Fire.
Corpse delivered to the pit.
Shredder or boiler explosion.

These are just some of the kinds of crises that have been faced within the waste-to-energy industry. The more tragic events--those where there was loss of life--while fewer, leave an indelible memory. Whether they leave an indelible scar has been a function of how the crisis was managed at the time.

Because the public and private sectors are involved in the waste to energy industry, the audiences are diverse. Critical to weathering any of these crises is to know your audience.

UNDERSTANDING YOUR AUDIENCE

Many of us make the mistake of thinking of the media as our exclusive audience. That is understandable because, when a crisis strikes, reporters often are the external people with whom we have the most contact.

But the media is not your only or ultimate audience. It is the vehicle through which your messages can be conveyed to your audience, but it is NOT in and of itself your sole audience.

Becasue the media can control or manipulate your message, they clearly are one audience. But also among your audiences are the various publics you serve or represent--employees, shareholders, authority board members, elected officials, clients, customers and the public at large. These are the people who are directly or indirectly impacted by the event and by how you manage that event.

Certainly, the media can influence the impressions of all of these publics. But if you know and understand all of your audiences, including the media, you can exercise a good degree of control over your message and how it is received. Properly performed, good media relations can provide the organization in crisis with infinitely more control than poor or no media handling skills.

It is important to remember that "The Media" as we call it, really is not one great monolith. It also is not the enemy. It is made up of competing organizations (most often, for-profit corporations) that are themselves made up of highly competitive people with as diverse backgrounds and predilections as those found in any other organization. The media have a job to do. They must tell **your** story to **your** publics. And it behooves you to help them do it well, because they can very easily and even unwittingly turn what should be your story into someone else's, if not their own. It is critical to understand whose story it is and to whom the story must be told before the crisis occurs.

WHOSE JOB IS IT ANYWAY?

Imagine that you are on the front lines of a major crisis being experienced by your organization. Who are you?

A. The chief executive?
B. The PR professional?
C. The General Counsel?
D. The Technical Expert?
E. All of the Above?

The Answer is "E," All of the above.

Crises are best managed by a team with clearly established roles and responsibilities that have been planned and rehearsed in advance. Depending upon the nature of the event, your team might include all of the above people as well as others. Crisis communication is not, however, the exclusive domain of the communications professionals in your organization. Some of the most critical decisions with potentially lasting consequences will be made during a crisis. It is at this time, like no other, that the best and broadest thinking minds of your organization will be needed. But the higher up in the organization the manager, and the further away from the communications function, the more likely they are to be on the front lines of a crisis. So in addition to being smart and resourceful, those who are most apt to be your team leaders, also need to be trained.

It is rare that the communications professional will be the decisionmaker or team leader in a crisis. But they can, and should, be among the best and broadest thinking minds on your team. In the end, every decision made as to how the crisis will be managed and how those decisions are implemented will determine how well you weather the storm.

GETTING "IT" DONE

The "it" is ensuring that your reputation and credibility are intact after the smoke clears. There are some basic tools and guidelines that most communicators agree are fundamental to achieving that goal.

Which of the following tools do you think would be most critical to you in managing a crisis? (you may chose only 1)

A. A PR Professional?
B. A PR Firm Expert in Crisis Communications?
C. An internal team knowledgeable and rehearsed in your organization's crisis plan and procedures?
D. A plan tailor-made for your organization.
E. A "How To" Manual

If you said "C," you are way ahead of the game. But why not the other answers? In truth, if you have any desire to manage your reputation, not to mention crises, ideally you will have a combination of these resources, and a PR professional would tie or rank a close second. But, you were asked to chose only one.

What about answer "A?" Certainly a strong communications staff is a must in this industry. But staff without the guidance of a well thought out plan, rehearsed procedures and a team that works shoulder to shoulder for the common good of the organization will be of only minimal value to you. Because even if they (and you) come through that first crisis well enough, left without the right tools, they will eventually burnout.

Why not outside consultants? Again, as a supplement to your crisis management team, consultants can be helpful. But do you really want--more importantly, would you trust-- the exclusive advice of outside experts on how to do the right thing and preserve your organization's reputation? Probably not.

These are the people you want to call on before you have a crisis, when you and they have time to study and analyze your organization, its audiences, the kinds of crises you might confront, and sit down with you to develop your plan. It is the extraordinary executive who, in the throes of a crisis, will rely on what are probably never before heard principles of crisis communication which are being conveyed (perhaps for the first time, but for certain over and over again) by any PR expert worth their fee. This is especially true for industries like ours that are so often already under public scrutiny. How many of you have been skeptical about the intuitive reasoning behind "getting out in front" of the issues, especially if it means publicity? Well, you are not alone.

Many of our public sector colleagues follow these principles of crisis communication either out of a commitment to and comfort with public disclosure or because in the past they've felt the wrath of political officials and public constituencies who have felt misled, uninformed or worse, lied to. Some, however, don't. And they too are excoriated in the press just as we in the private sector are for "mishandling, incompetence and bungling" of communications with their publics about the crisis. Oftentimes, public officials face even more immediate and dire consequences for botching crisis communications than does the private sector--after all, they are more directly accountable to their publics.

I chose "C" because, time and time again, experience has shown that the most valuable tool that your organization can have is a plan and a team that is well versed in and ready to implement that plan at a moment's notice.

CRISIS COMMUNICATIONS BASICS: THE PLAN

One can never over plan for a crisis. Becasue the most challenging test of public relations skills--and the fortitude of an organization--arises in times of crisis, preparedness is essential.

When an unexpeected development that has the potential to alarm the public occurs, the credibility and decency of the organization experiencing the crisis come under intense scrutiny. Often the media is in hot pursuit of the facts surrounding the incident and as a consequence, the pressure on the organization's executives can be severe.

There are three general courses that organizations may choose in times of crisis. First, some organizations "stonewall," denying the crisis' existence. Inquiries are not answered and a "public-be-damned" image emerges.

Second, many organizations choose to "manage" the news by releasing partial or delayed information while concealing unfavorable facts. Ultimately, the facts slip out through insider "leaks" or government inquiries, and the disclosure shatters the organization's reputation. (How many of us wonder to this day whether there is any truth to the missile theory proffered by Pierre Salinger as the cause of the Flight 200 explosion? If we all trusted the U.S. Government based on its past performance and repoutation, would there be such questioning and doubt? Probably not.) In either case, the media and the public learn not to trust the organization and subsequent communication--in crisis or day-to-day situations--grows ineffective.

The third and best course of action requires an open dissemination of information that explains the crisis while keeping the situation in perspective by providing background facts. This policy is the safest bet to preserve credibility.

The open door method of handling a crisis may offer the highest rewards, but it also requires the most extensive coordination and trust. In a crisis, your organization will not be the only source of information and therefore must keep abreast and keep others abreast of current events. Others both inside and outside of your organization may be called by an anxious media or community to learn more about what is happening at the facility. All of these sources, whether the public sector client, the regulatory body or those internal staff assigned as spokespersons, must be kept informed and know in advance how to coordinate the flow of information. A structured and rehearsed procedure translates into less risk of surprises and inconsistencies.

The goal of a crisis communication plan is assurance that all sources speak in one voice as they explain the full story within context. Implementation of a good plan means the public and the players remain calm. After the crisis is over, all parties better trust the other to tell the truth and tell it in a timely manner.

CONCLUSION

In summary, the following principles are key to successfully managing crisis communications.

First and foremost, BE PREPARED. There is no such thing as "it can't happen to me." While unexpected in its timing, the event can be anticipated and planned for. Here are some general preparedness tools:

- prepare and update a crisis communications plan, including designating your team;
- have the team rehearse and rely on the plan (and their common sense);
- designate (and train) a spokesperson (and an alternate) in both presentation skills and media handling;
- have on-hand factual information on your organization, your facility, and any other general materials that will provide a context and background for your audience.

Second, remember your audience and decide in advance what they will want and need to know and tailor your messages accordingly.

Third, treat the media as a both an audience and a resource, a means of accomplishing your goal to maintain your credibility and reputation. When dealing with the media, whether through oral or written statements, abide by the following:

- don't be defensive (they want a story, not your head);
- be clear and concise;
- be helpful (otherwise they might want your head);
- be honest and forthcoming: tell the truth about what happened and why without speculating, while acknowledging problems or mistakes;
- show you care;
- be calm and sober;
- avoid favoritism (TV vs. Radio vs. Print).

A badly managed crisis can cost you, dearly. What is at stake?

1) Your reputation--for honesty, acceptance of responsibility and caring.

2) The loyalty of your clients/customers/shareholders/employees--all of your various publics or constituencies. That loyalty is linked to your past performance and reputation, but also to each of your stakeholders' perceptions of whether you can be trusted in this particular moment while the curent crisis is underway.

3) Money.

and, of course,

4) Time.

Thank you. I would be glad to respond to any questions.

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After Flow Control: The Steps Taken by Dade County to Ensure Continued Operation of Its Solid Waste Management System

Paul J. Mauriello, AICP and Diana Ragbeer
Metropolitan Dade County
Department of Solid Waste Management
8675 N.W. 53rd Street, Suite 201
Miami, Florida 33166

ABSTRACT

In the wake of the U.S. Supreme Court decision in the Carbone vs. Clarkstown case striking down waste flow control as unconstitutional, Dade County, Florida, one of the most severely impacted communities in the nation, has managed to stabilize its waste stream and balance its solid waste department finances; although the road taken to restabilization has been a difficult one.

At its peak in 1995, Dade County experienced an annual loss of solid waste in excess of 1,000,000 tons, or over 40 percent of the waste stream normally handled by the County. This diversion of waste was accompanied by a net revenue loss of $30 million per year. The County lost its ability to plan for future capacity needs, or to assure sufficient future waste flows to meet its put-or-pay obligation to the County's Resources Recovery plant operator. The County's solid waste management system bonds were downgraded by Moody's Investors Service and Standard and Poors.

With the help of a special solid waste management team, appointed by the County Manager, the department was able to rightsize its waste disposal operations to fit its reduced waste flows, stabilize its waste stream, and develop strategies to solve its long-term funding shortfall.

INTRODUCTION

Like many communities across the country, Dade County, Florida, has had to scramble to stabilize its solid waste management system (System) following waste diversion to disposal facilities in other jurisdictions. The U.S. Supreme Court's 1994 decision in the Carbone vs. Clarkstown case, striking down waste flow control (WFC) as unconstitutional, effectively foreclosed the use of WFC authority to solve Dade's waste diversion problem. The rapid and dramatic reduction in waste flow to County facilities forced the County to "rightsize" its disposal operations, find ways to stabilize its waste stream, and develop supplementary funding sources to fill the widening gap in its solid waste management budget. Understanding the Dade County experience in coping with waste diversion and lack of WFC authority may help other communities that are faced with similar challenges.

ORIGINS OF THE COUNTY'S SOLID WASTE SYSTEM

The Metropolitan Dade County form of government was established through amendment to the Florida State Constitution in 1956. Article 1, Section 9, of the Charter gave the Board of County Commissioners the power to provide and regulate, or permit municipalities to provide and regulate waste collection and disposal. At the time the Charter was adopted, solid waste disposal in Dade County was a sparsely regulated private and municipal activity. Commencing in the 1960's, federal, state, and local governments responded to the general public's increased environmental awareness, and concerns regarding the need for more aggressive efforts to protect the environment. The resulting regulatory climate left Dade County with over two dozen solid waste disposal facilities operating in an environmentally unacceptable manner by 1970. Only the County's Northeast Incinerator was operating in full compliance with mandated environmental regulations.

This situation prompted the creation, by the county manager, of the Solid Waste Management Task Force to review solid waste disposal and collection practices in Dade County. While the Task Force was in the process of soliciting requests for proposals for a resources recovery facility, the 1974 state legislature enacted the Florida Resource Recovery and Management Act (Act) which required cities and counties in Florida to adopt local resource recovery and management programs for approval by the state. The Act promoted the use of interlocal agreements between cities and counties to define which local agency would administer the program. The Act required, however, that if no interlocal agreement had been effectuated or special act become law by December 1, 1978, the Board of County Commissioners would be responsible for, and administer the program. Moreover, the Act prohibited cities from withdrawing from programs if bonds had been issued to finance solid waste management facilities by the December date, in reliance on the Act.

The County's program was adopted by the Board in 1979 and approved by the state in the same year. The program was accompanied by a WFC ordinance which allowed the Board of County Commissioners to designate a geographical area contiguous to a County solid waste disposal and resource recovery facility, for the purpose of directing waste generated in such area to the facility, if deemed necessary by the Board. The program included two major waste disposal facilities, a 3,000 ton per day waste-to-energy facility (refuse derived fuel) in northwest Dade and associated 80 acre ash monofill, and a 2,100 ton per day garbage and trash landfill (Class I) in South Dade. Three automated waste transfer facilities would also to be developed in strategic areas of the County to enhance waste collection efficiency and reduce trips to disposal facilities. The program was financed by 1972 Decade of Progress Bonds ($50 million) and 1978 State of Florida Pollution Control Bonds ($137 million). The 1979 program was amended in 1984 to include reactivation of the County's North Dade landfill (Class III) to handle trash generated in the northern portion of the County.

The 1974 Act was later superseded by the 1988 Solid Waste Management Act. The 1988 Act delegated to counties the "Responsibility and power to provide for the operation of solid waste disposal facilities to meet the needs of all incorporated and unincorporated areas of the county." The Act also provided that "Any local government which undertakes resource recovery from solid waste pursuant to general law or special act may institute a flow control ordinance for the purpose of ensuring that the resource recovery facility receives and adequate quantity of solid waste from solid waste generated within its jurisdiction." Furthermore, the Act included a recycling mandate for counties of 30 percent of their waste stream by 1994.

Adoption of the County's Comprehensive Development Master Plan (CDMP) in 1988, pursuant to the requirements of the 1985 Local Government Comprehensive Planning and Land Development Regulation Act (Growth Management Act), coincided with passage of the 1988 Solid Waste Management Act by the state legislature. The County's vision of creating a single integrated solid waste management system in Dade County, first articulated in the 1979 Resource Recovery and Management Plan, and later incorporated in the 1988 CDMP, had been nearly realized. The single remaining private solid waste management facility in the County, the United Sanitation, Inc. landfill in the City of Medley, Florida, was subject to a phase-out agreement with the County due to environmental problems, and was scheduled to be closed by the end of 1990.

The System facilities have been enlarged and improved upon since 1988, but no new facilities have been added. The Medley landfill continues to operate under an amended phase-out agreement, and the majority of environmental problems at the facility have been remedied by the operator.

THE CHANGING SOLID WASTE MANAGEMENT ENVIRONMENT

The state of relative stability in countywide solid waste management that existed during the 1980's was short-lived. In 1991, two large waste-to-energy facilities (approximately 800,000 tons per year each) became operational, immediately to the north, in Broward County. The new facilities are owned and operated by Wheelabrator Technologies, Inc., a subsidiary of WMX Technologies, Inc. (previously Waste Management, Inc.). These facilities were built in response to the solid waste management needs of Broward County, one of the fastest growing counties in the country.

Since Broward County's charter did not specifically delegate the power to provide and regulate waste disposal to county government, the County entered into interlocal agreements with all but four of its municipalities to provide waste to Wheelabrator. In its agreement with Wheelabrator, the County pledged to provide a specified amount of waste, on a put-or-pay basis, for a period of 20 years. This contractual arrangement enabled Wheelabrator to secure financing for its facilities.

While the facilities were built to accommodate Broward's increasing waste stream over time, significant excess capacity would be present initially. Those municipalities participating in the agreement paid a tipping fee rate sufficient to cover the fixed costs of the facilities; $76 per ton in 1995. Therefore, the excess or "merchant capacity" could be sold on the open market by the operator at "spot market" prices. Broward derives a financial benefit from the sale of merchant capacity, in that, to the extent the County is unable to satisfy its waste delivery obligation, fees from merchant tonnage offset its payment to Wheelabrator.

Wheelabrator substantially undercut Dade's $59 per ton tipping fee, and rates as low as $38 per ton were common. At the same time, other regional disposal facilities opened their facilities to waste from Dade County. At its peak in 1995, the diversion of waste from Dade County exceeded 1 million tons per year, or just over 40 percent of the County's normal disposed waste stream, and the potential existed for even greater waste diversion in the future (refer to figure 1).

FINANCIAL IMPACTS RESULTING FROM WASTE DIVERSION

The County's solid waste management system was sized to accommodate a waste stream of 2.3 million tons per year, and planning for capacity increases was an ongoing effort. The system was funded through the sale of revenue bonds as well as industrial development bonds, approximately $300 million of which were outstanding when waste diversion began in 1991. The revenue stream from waste disposal fees was pledged for repayment of the bond debt.

Approximately half of this outstanding debt was used for landfill capacity, landfill closure, and waste transfer facilities. The the remainder was set aside for construction projects at the County's Resources Recovery facility, such as, installation of a new air quality control system, stormwater management improvements, and expansion of plant capacity. Since the debt service cost on the bonds was fixed, declining waste tonnages were not directly offset by decreased expenditures.

The County's initial reaction to the waste diversion phenomenon was to take steps toward development of a means to fund the system's fixed costs that was not tied to waste flow. In August 1993, the County issued a request for proposals for development of a solid waste special assessment district. The County intended to levy special assessments on all improved properties that have the potential to generate waste for disposal. A consultant was hired to complete the project, however, due to strong popular opposition to the concept, only preliminary waste generation factors by land use type were developed; thereafter the project was abandoned. Although the County had a WFC ordinance in its solid waste management code, the pending U.S. Supreme Court case on WFC was a deterrent to active implementation of the ordinance.

By 1995, the County was forecasting an average annual budget shortfall in its department of solid waste management of $30 million. Moody's Investors Service downgraded the County's solid waste revenue bonds from A to Baa1 and Standard and Poors downgraded the bonds from A to BBB+. At this point, a Special Solid Waste Management Team, appointed by the County manager, consisting of the most senior Assistant County Manager and the County's Deputy Budget Director, was assigned to the department of solid waste management to "rightsize" the department and develop strategies to solve the long-term funding shortfall.

RIGHTSIZING AND STRATEGIC PLANNING PHASE I

In March of 1995 the Department eliminated 225 positions, primarily in disposal operations, support functions and administration. All non-essential capital projects were either deferred or eliminated. In April 1995, the Board of County Commissioners gave conceptual approval to the Phase I Strategic Plan for Dade County Solid Waste Management, identifying additional rightsizing initiatives, revenue enhancements and major business options. The key elements of the plan included restructuring of the department's debt to levelize debt service payments (refer to figure 2), renegotiation of the operations and management agreement with the County's Resources Recovery facility operator, and establishment of two additional sources of revenue to the department to pay fixed System costs.

Restructuring of the department's debt was accomplished in 1997. The County's existing Utility Service Fee, used to fund groundwater protection activities charged on the water and sewer bill, was increased by from 4% of user charges to 7.5%, with the additional revenue going to fund landfill closure and related activities. The additional 3.5% generates approximately $13 million annually. A Disposal Facility Fee program was also developed in which private solid waste haulers operating in unincorporated Dade County must pay a percentage of gross receipts (currently 10%) to the County to cover the costs of disposal capacity availability at County facilities. The Disposal Facility Fee generates approximately $5 million annually.

Renegotiation of the Resources Recovery Agreement

In 1990, $190 million in industrial development revenue bonds were issued for retrofit and expansion of the County's Resources Recovery facility. Installation of a new air quality control system (gas scrubbers and bag house) and a 50 percent capacity expansion were planned (2 additional boilers for a total of 6). Community concerns over the appropriateness of the expansion delayed the project to the extent that waste diversion became an issue as well. Along the way, the planned expansion was transformed into a planned trash-to-fuel facility whereby 270,000 tons of trash annually would be converted to a biomass fuel for energy production off-site. The trash-to-fuel project was much less objectionable to the surrounding community than the outright expansion of combustion capacity at the site.

The County then faced a situation where a facility valued in the hundreds of millions of dollars would have to be upgraded to meet federal air pollution control standards or be shut down, and the County had no means to assure adequate waste flow to the facility in the foreseeable future. Meanwhile, the plant operator, Montenay-Dade, Ltd., having been successful, along with the County, in convincing the community of the merits of trash-to-fuel over on-site combustion had entered into its own fuel delivery agreement with Okeelanta Corp. Okeelanta is a sugar producer in south central Florida that was building a waste-to-energy facility that would burn biomass fuel to create electricity for on-site use and export.

A grand compromise was struck between the parties that would allow for both retrofit of the Resources Recovery facility and development of trash-to-fuel. The new agreement, dated September 1, 1996, requires the County to deliver all the garbage available in the System, up to 936,000 tons, but no less than 572,000 tons. The County must also deliver a minimum of 400,000 tons of trash for trash-to-fuel and on-site combustion, the on-site portion of which may be displaced by garbage (130,000 tons). The result is an overall annual minimum waste delivery requirement of 972,000 tons and a maximum of 1,206,000 tons depending on waste flow (refer to figure 3). The County's previous minimum annual waste delivery obligation was 936,000 tons. On the retrofit side, Montenay agreed to lower its processing fee for waste processed through the fourth boiler (for tons processed over 702,000), from $25.19 per ton to $21.33 per ton, as a concession for allowing the boiler to be retrofitted without assurance of waste flow.

STRATEGIC PLANNING PHASE II

Phase II of the strategic planning process involved two key elements: (1) long-term waste disposal agreements with municipalities and private waste haulers for disposal at County facilities, at a reduced $45 contract tipping fee rate, and (2) long-term, low-cost, waste disposal agreements with regional waste disposal companies, to ensure disposal capacity availability for System waste without future capital outlays by the County.

Phase II - Part 1

Throughout the summer of 1995, the County engaged representatives of the Dade League of Cities, representing most of Dade's 26 municipalities, in a dialogue on a wide range of solid waste management issues. It soon became clear to County representatives that the municipalities, once captives of the System, had become somewhat hostile customers. The discussions, which proved healthy for all concerned, ultimately led to development of a standard interlocal agreement for use of the System by municipalities. The agreement was adopted by the Board of County Commissioners on September 14, 1995.

The standard interlocal agreement provided that each participating municipality would commit its waste stream to the System for a period of 20 years. A provision was included that allowed municipalities that had already contracted on a short-term basis with other waste disposal providers, to fulfill the terms of those contracts and then return to the System. The County pledged to provide sufficient capacity to meet the growth management needs of each participant at a per ton fee of $45, with no increases in the Consumer Price Index until October 1, 1998, which increases would then be capped at 5 percent per year for the duration of the agreement. In order to address the possibility that certain of the System facilities may be phased-out, the agreement established the right of the County to direct municipalities to particular facilities; provided that no municipality would have to deliver its waste to a facility that was farther than 20 miles from its nearest boundary. To date, 18 municipalities have entered into interlocal waste disposal agreements with the County, including Dade's two largest municipalities, Miami (180,000 tons annually) and Hialeah (70,000 tons annually). The total annual waste committed to the System under these agreements is approximately 420,000 tons (refer to figure 4).

In addition to securing waste commitments from municipalities, the County pursued its largest waste hauler, Browning-Ferris Industries, Inc. (BFI). BFI controlled approximately 520,000 tons, or 23% of the waste generated in the County. In 1995 approximately 175,000 tons of BFI's waste was being disposed of at County facilities, however, BFI was under no obligation to continue to deliver this waste to the County. The remainder of BFI's waste, approximately 345,000 tons, was being diverted to other facilities. BFI was eager to discuss a waste commitment to the County, provided the County would allow BFI to construct its own waste transfer facility. Without such a facility, BFI could not take advantage of transportation efficiencies that accompany the use of large capacity long-haul vehicles.

The County maintains countywide authority for environmental permitting through its department of environmental resources management, which acts as the local regulatory agency for the state department of environmental protection. The solid waste department is a review agency for resource recovery and management facility permits, as stipulated in the County Code. The department reviews each application for its anticipated impacts on the system from contractual, financial, and regulatory perspectives consistent with County bond ordinances and the County Charter. Through a process of negotiation between the County and BFI, a waste commitment scenario was arrived at that would mitigate the potential adverse impacts of the transfer facility on the System.

On October 17, 1995, BFI and the County entered into a 20 year waste disposal agreement. The agreement requires BFI to deliver 300,000 tons of waste to County facilities annually, a 42 percent increase in tonnage, all of which is committed to the system (refer to figure 3). The agreement also requires that 100,000 tons of the waste be delivered to County transfer facilities. The transfer facility delivery requirement enables the County to optimize the use of its existing transfer facilities. BFI's waste transfer facility was approved by the County and is currently in operation.

Phase II - Part 2

Part 1 of the Phase II strategic planning process has resulted in stabilization of the County's waste stream at approximately 1.6 million tons annually. Figure 3 shows the committed portion of the waste stream and its sub-components. The largest committed component is waste collected from the area of unincorporated Dade served by the County's own forces (613,000 tons annually). Other committed tonnages include: municipalities (417,000 tons annually), Browning-Ferris Industries (300,000 tons annually), Waste Management Inc. of Florida (88,000 tons annually under a 1987 agreement), and County agencies (87,000). The remainder of the 1.6 million tons consists of waste delivered by private haulers and others that is uncommitted (100,000 tons annually). The County's tipping fee for uncommitted waste is $59 per ton; $14 higher than the fee for committed waste.

Part 2 of the phase II strategic planning process focused on the County's transition from development of County owned facilities to fulfill future capacity needs, to contracting for this capacity with large waste disposal companies in the South Florida region. This fundamental change in the County's waste management philosophy is a practical outcome of the lack of WFC. The change allows the County guaranteed access to large volumes of waste disposal capacity, at low cost, without having to take on the debt required to construct, staff, and maintain a facility. The County can also preserve its existing landfill capacity for contingency purposes, and as leverage when negotiating future waste disposal agreements.

On October 27, 1995, the County entered into a 20 year waste disposal agreement with Waste Management Inc. of Florida at a tipping fee of $24.50 per ton. The agreement allows the County to dispose of up to 500,000 tons of solid waste annually at Waste Management's two regional landfills. The County must deliver a minimum of 100,000 tons of waste annually under the terms of the agreement. The agreement contains two five year options to renew upon mutual consent.

On December 29, 1995, the County entered into a one-year agreement with Wheelabrator South Broward, Inc. at a tipping fee of $26.50 per ton. The agreement contains six one year options to renew at the sole discretion of Wheelabrator, and three additional one year options to renew upon mutual consent. If Wheelabrator desires, the County must deliver up to 100,000 tons of waste annually. The unusual structure of this agreement is due to the fact that the Wheelabrator facility is a waste-to-energy facility, which may or may not require additional waste from Dade depending on market forces. Since the County's tipping fee rate with Wheelabrator is low, Wheelabrator has an incentive to attract other waste streams that are willing to pay higher fees, therefore displacing Dade's waste.

Conclusions

As the most populus county in Florida (over 2 million people), Dade County has always tried to take a leadership role in its approach to fulfillment of state and federal solid waste management initiatives. The solid waste management system built by Dade County is second to none in this regard. Environmental protection and community awareness of fundamental environmental issues such as groundwater protection and air quality have been primary objectives of the County's solid waste program since the 1970's.

Converting from disposal fee based funding to other sources is extremely difficult for local government, and its degree of difficulty should not be underestimated or simply ignored. Quilting together long-term waste commitments through interlocal agreement or contract is also a long and arduous process. Moreover, while providing encouragement, bond rating agencies have been unwilling to raise ratings based on Dade's newly implemented funding and waste stream stabilization program.

The County dutifully accepted its responsibility for countywide solid waste management, and has had to find creative ways to pay for facilities that were built in sole reliance on a revenue stream based on waste flow control. The level and scope of the County's investment in solid waste disposal facilities was driven by state and federal mandates. And let's not forget the U.S. Environmental Protection Agency's hierarchy of waste management methods which touts combustion over landfilling as a more desirable waste management option.

The fact that the U.S. Supreme Court decided against the interests of local government in the Carbone vs. Clarkstown case is no ones fault. But that does not mean that no one has a responsibility for properly managing the impacts of that decision. Just as local governments step up to the plate to fulfill state and federal mandates, the higher levels of government should ensure that appropriate legislation is passed to protect local governments when they are hurt as a result of their participation in furthering a larger social agenda.

Many point to Dade County's experience in coping with the loss of waste flow control as evidence that no action by Congress is needed. But in fact, Dade County faces two potential threats to the stability of its solid waste management system without WFC flow control:

1. Dade County is experiencing a watershed of incorporation and annexation activity. Most incorporations are on hold pending further study by the County of their potential effects on the remainder of the unincorporated area. In February 1996, the County passed an ordinance which allows the County to maintain control over waste generated in newly incorporated municipalities. The waste collected from within the unincorporated area of Dade County is the single largest component of committed waste tonnage to the system.

2. By ordinance, the County does not allow the development of private solid waste management facilities in Dade County in instances where a facility's operation would have an adverse impact on the System.

While the County Attorney's Office has found both of these ordinances to be legally sufficient, a successful legal challenge to the County's authority in these areas remains a possibility. The County endorses Congressional legislation establishing WFC to the extent necessary in order for any municipality or county to retire debts incurred based on a state solid waste management act, or other state or federal laws, or regulatory requirements regarding local government solid waste management responsibilities.

References

1. The Home Rule Amendment and Charter, as amended through March 16, 1993. Metropolitan Dade County, Florida.

2. Official Florida Statutes 1995. Published by the State of Florida, Tallahassee.

3. The Strategic Plan for Dade County Solid Waste Management (Phase I), March 31, 1995; Adopted the Board of County Commissioners, April 4, 1995; Resolution number R-410-95.

4. Third Amended and Restated Operations and Management Agreement by and between Metropolitan Dade County, Florida and Montenay-Dade, Ltd., September 1, 1996; Resolution number R917-96.

5. Interlocal Agreement Between Metropolitan Dade County and Contract Cities for City Use of the County Solid Waste Management System, Adopted by Board of County Commissioners, September 14, 1995; Resolution number R-1198-95.

6. Non-Exclusive Agreement Between Metropolitan Dade County, Florida and Browning-Ferris Industries of Florida, Inc. for Commitment to Use the County Solid Waste Management System for Municipal Solid Waste Disposal, October 17th, 1995.

7. Non-Exclusive Agreement Between Metropolitan Dade County, Florida and Waste Management Inc. of Florida for Provision of Municipal Solid Waste Disposal Services, October 27, 1995.

8. Non-Exclusive Agreement Between Metropolitan Dade County, Florida and Wheelabrator South Broward, Inc. for Provision of Municipal Solid Waste Disposal Services, December 29, 1995.

DEPARTMENT OF SOLID WASTE MANAGEMENT
DISPOSAL REVENUE TONS
(BY THOUSANDS)

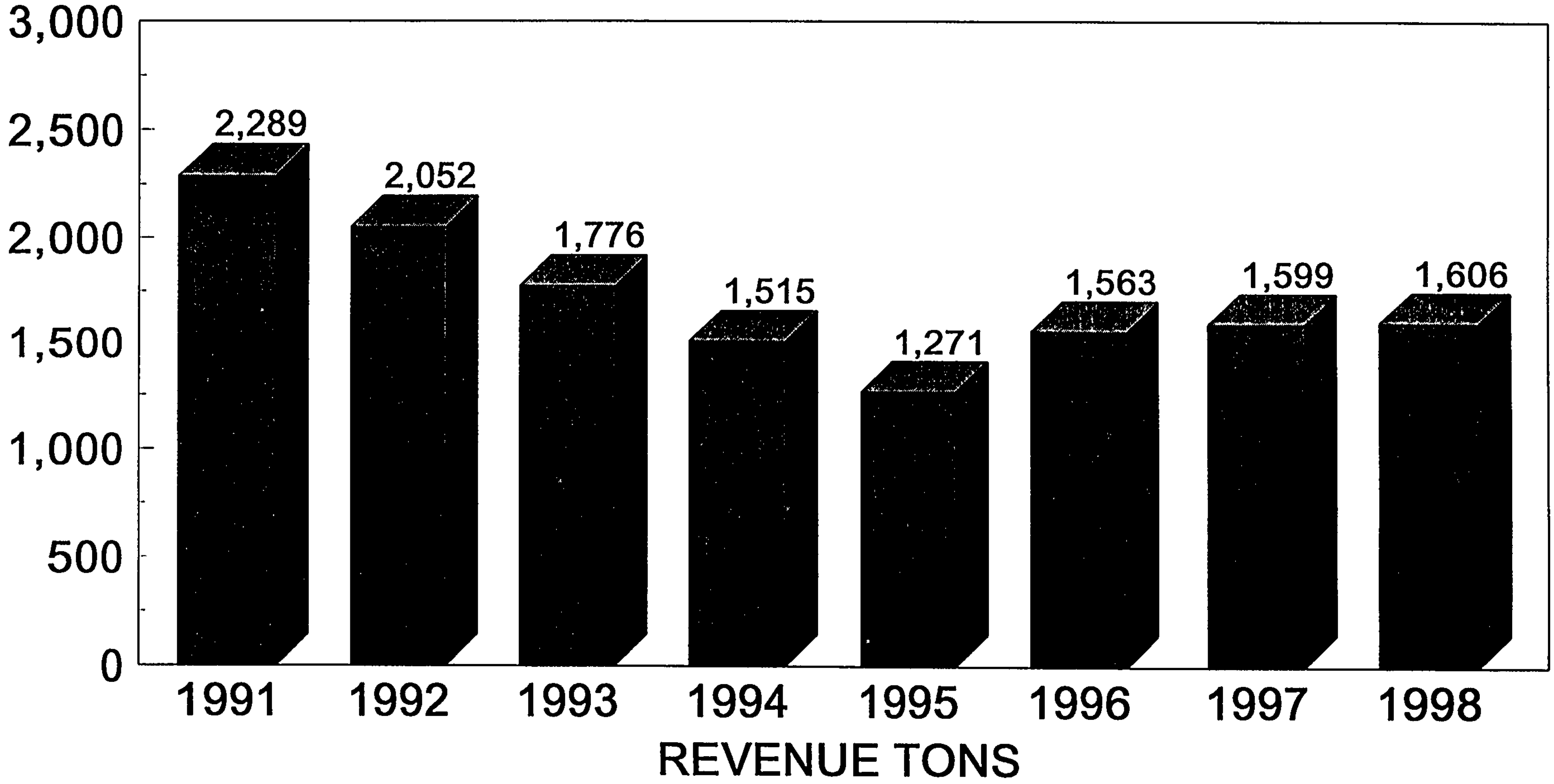
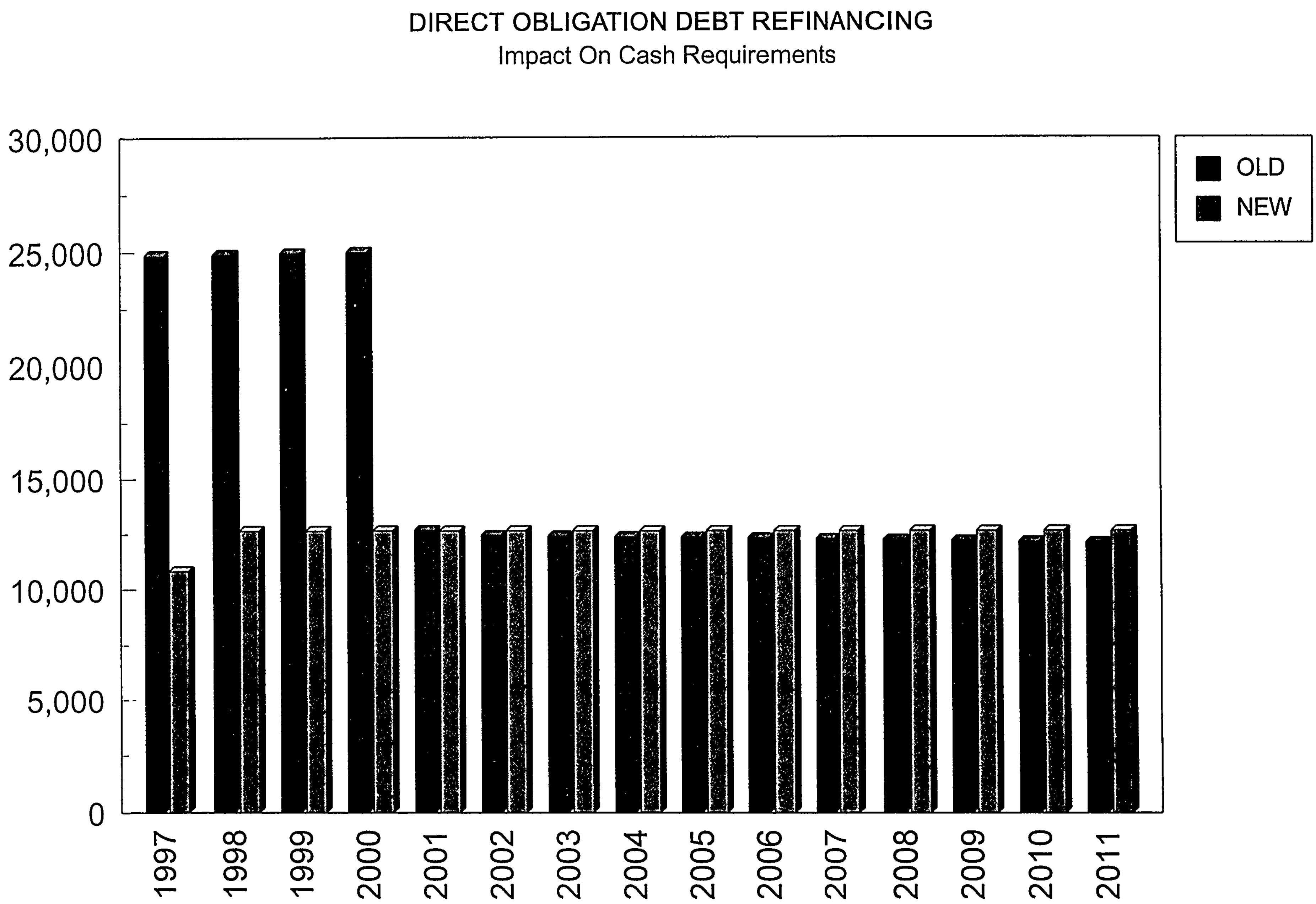


Figure 1



DIRECT OBLIGATION DEBT REFINANCING

Impact On Cash Requirements

Figure 2

DADE COUNTY, FLORIDA
RESOURCES RECOVERY FACILITY
GARBAGE AND TRASH COMMITMENTS
September 1, 1996

From:
September 1, 1996

AOSWGT*	Garbage Minimum	572,000
	Trash Maximum	364,000
Total		936,000

After:
RTIAPCD**

AOSWGT	Garbage Minimum	572,000
	Trash Maximum	130,000
	Subtotal	702,000
ARTGT***		270,000
Total		972,000

MAXIMUM WASTE DELIVERY AMOUNTS

If garbage is available for delivery, County must deliver up to -	936,000
ARTGT -	270,000
Maximum Waste Delivery Amount -	1,206,000

*AOSWGT - Annual On-site Waste Guaranteed Tonnage
**RTIAPCD - Recyclable Trash Improvements Actual Performance Completion Date
***ARTGT - Annual Recyclable Trash Guaranteed Tonnage

Figure 3

DEPARTMENT OF SOLID WASTE MANAGEMENT
COMMITTED TONNAGES

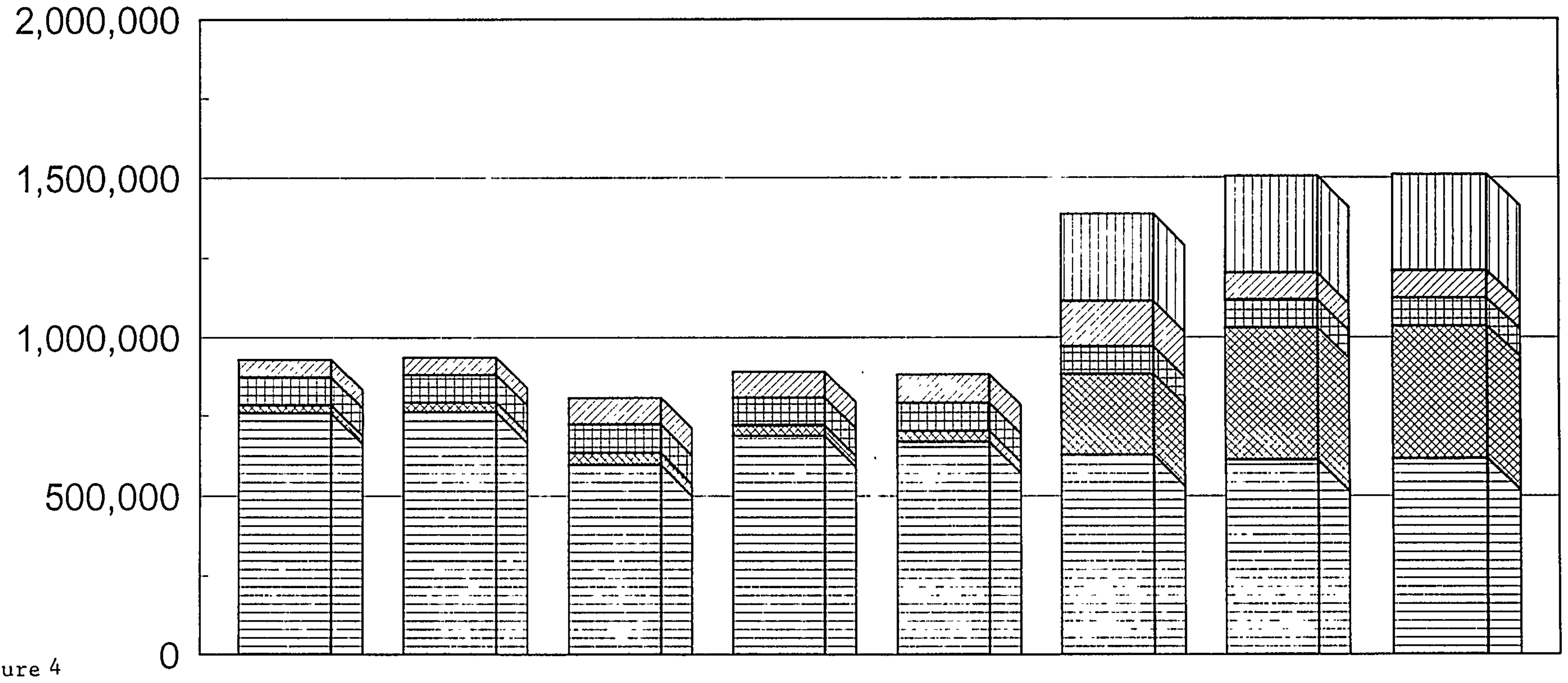


Figure 4

	1991	1992	1993	1994	1995	1996	1997	1998
UNICORP. ▤	758,193	761,700	596,926	687,843	669,661	628,969	613,000	616,000
MUNICIPAL ▩	27,153	31,022	38,004	33,172	34,212	255,332	417,865	421,000
WMI ▦	88,400	88,400	88,400	88,400	88,400	88,400	88,400	88,400
CNTY. AG ▨	57,312	57,446	86,088	83,138	92,214	143,994	86,667	86,400
BFI ▥						272,684	300,000	300,000

TECHNICAL SESSION II

Emissions Measurement & Monitoring

Dioxin Surrogates — Are There Any Meaningful Ones?

H. Gregor Rigo
Rigo & Rigo Associates, Inc.
1 Berea Commons, Suite 211
Berea, Ohio 44017

INTRODUCTION

A number of easily measured pollutants have been offered up as dioxin surrogates—easily measured pollutants or process variables that consistently parallel dioxin emissions. Surrogates are a very attractive concept because the expense of direct dioxin measurement could be avoided. Also, the public can be assured that as long as easily and potentially continuously measured surrogates are within acceptable limits, people are not being exposed to excessive amounts of pollution. The question remains, however, is there a meaningful surrogate at conventionally regulated levels? Or, perhaps more importantly, at elevated levels that provide a comfortable margin of safety between normal operations and the conditions likely to represent elevated dioxin emissions?

For example, the preamble to the April 16, 1996 proposed Hazardous Waste Combustor Rule, states that particulates are a surrogate for trace organic HAPs, yet the supporting documents in the docket pronounce that "the plots between organic emissions and PM... ... show no apparent trends for cement kilns or other systems..."[1] U.S. Environmental Protection Agency (EPA) found no statistically significant correlation between particulates and trace organics. Further, EPA's surrogate analysis concludes that "...PM are not good surrogates" (for SVOC and VOC)[2]. As the following analysis shows, MWC data buttresses EPA's supporting documentation, not the rhetoric in the Preamble. The suppositions provide a good starting point for evaluating the efficacy of various surrogates. However, in the course of developing the regulations or providing public assurance, peer-reviewed hypothesis and not unproved theories should be the basis of surrogate selection. It is particularly discouraging to realize that surrogates are sometimes offered even though the EPA has test data that can be used to test hypothesized relationships.

APPROACH

The following steps were undertaken to perform the analysis:

- Express all concentrations in common units and at the same diluent concentration.
- Check the database against laboratory and field data sheets to minimize errors and examine the database to identify outliers which much be corrected or flagged for inclusion and exclusion in the analysis.
- Use only values that exceed the reference method practical quantitation limit (RMPQL) in statistical procedures —relationships between values less than the RMPQL and higher values are meaningless since RMPQL results have an uncertainty of ±30 percent. Relationships between pairs with at least one concentration below the analytic (laboratory) detection limit equivalent concentrations (ADLE) or the RMPQL concentration are simply due to chance. Table 1 is a summary of the results of a recent methods validation study conducted as an add-on to the DOE/NREL sponsored performance demonstration test at EAC/Pittsfield[3]. In this test, reference method testing was conducted using a quad-train. 40 CFR 63 Method 301[4] method validation criteria were used to calculate the method's practical quantitation limit, "the lowest concentration which can be accurately measured"[5] .
- Use International Toxic Equivalent (ITEQ) dioxin concentrations. The general linearity of tetra- through octa-dioxin and furan homologue totals and ITEQ has been established[6]. Given the international interpretability and trend toward summarizing complex dioxin and furan mixtures as an equivalent amount of 2,3,7,8 tetrachlodibenzo-p-dioxin using the international weighting scheme, this approach has been selected even though it is at variance with current EPA MWC regulations.

- Use localized regression (loess) curves to identify the potential for relationships between paired variables. Loess curves are good for identifying the general shape of a trend through data. They are calculated, in this case, using the 30 or 50 percent of the data that surrounds each point and represent the curve drawn through the center of what is effectively a rolling average. When there are two or more underlying relationships in the data, the loess curves are shaped like hockey sticks. Forcing a straight line through such data is incorrect. A trial and error approach can be used to establish the breakpoint between various segments or splines. Absent such an extensive effort, statistical significance cannot be assigned to any particular inflection point or curve segment.
- Employ Spearman Rank-Correlation techniques when the use of individual scattergrams becomes unduly burdensome (such as in the analysis of the relationship between particulates and a plethora of trace organic HAPs) so that the underlying form of the distribution does not affect the comparisons of data above the RMPQL. Also, since this is really an exploratory data analysis — we cannot assume any specific hypothesis is true before analyzing the data — use multiple comparison statistics to identify significant results.

ANALYSIS OF POTENTIAL SURROGATES

A number of potential dioxin surrogates have been suggested. The relationship between air pollution control system (APCS) operating temperature, carbon monoxide and total hydrocarbons and dioxins are explored. Additional relationships between trace contaminants that may be less expensive to monitor, such as chlorobenzenes and dioxins, are explored. Surrogate relationships between dioxins, particulates and a host of additional trace organics that EPA has hypothesized are associated with particulates are also investigated using the techniques just described.

Dioxins Versus APCS Operating Temperature

Figure 1 is a plot of the ITEQ dioxin data collected from more than 150 MWCs since 1976. The loess line shows that there is no meaningful relationship between dioxins and APCS operating temperature below about 300 °F. Above that temperature, there is a generally linear relationship showing increasing dioxins with increasing APCS operating temperature. This supports EPA's finding underpinning the regulatory requirement to keep APCS temperature at no more than 30°F above the highest temperature demonstrated during the most recent compliance demonstration. Looking at the detailed data underlying this scattergram, it becomes apparent that the slope of the ITEQ dioxin — APCS operating temperature line for each facility is generally similar as long as emitted concentrations are above the RMPQL. That is, they are measured with reasonable precision. There is considerable scatter among plants indicating that more than APCS operating temperature is involved in determining dioxin emissions from MWCs.

Dioxins Versus Carbon Monoxide

Figure 2 is a scattergram relating dioxin emissions and carbon monoxide. Again the loess plot displays the hockey-stick pattern characteristic of emissions that are unrelated below a trigger concentration and linearly related above that level. Carbon monoxide (CO) becomes a meaningful surrogate for dioxins when its concentration exceeds 200-400 ppm_{dv} @ 7% O_2. Below that level, there is no meaningful relationship. Consequently, a facility that exceeds EPA's CO emissions standard of 100 ppm_{dv} @ 7% O_2 <4-hr average> for MWCs or up to 250 ppm_{dv} @ 7% O_2 <24-hour average> for other sources is unlikely to emit increased dioxins until sustained levels above 300-500 ppm_{dv} @ 7% O_2 are realized.

This finding is generally consistent with the mid-1980's data underpinning EPA's Good Combustion Practices. Back then, sustained operation under furnace conditions conducive to comparatively elevated dioxin emissions were standard, although rapidly becoming antiquated. Modern facilities generally operate at much lower sustained CO concentrations. Environmental impairment is not indicated when EPA's regulatory levels are exceeded for most plants. Only when emissions approach two to three times the permitted levels for sustained periods of time does the potential for a problem appear.

Note that these data were not analyzed using statistical techniques that account for confounding factors such as design and operating differences. If a surrogate is to be generally useful, it must be robust. That is, it must represent what it is supposed to be true in general and not just in special cases or under specific conditions. Examination of the loess curve and data points in Figure 2 indicate that when the curve breaks upward, the dioxins are generally below the levels found to produce theoretical multi-pathway health risk levels that trigger superfund site cleanups.

Dioxin Versus Total Hydrocarbons

Figure 3 is a scattergram showing the relationship between dioxins and total hydrocarbons. Interestingly, the loess line is essentially horizontal indicating no relationship for all the data. When the dioxin data are trimmed to eliminate concentrations below the RMPQL, the loess line is again a clear hockey stick with an inflection point in the vicinity of 10-20 ppm_{dv} @ 7% O_2. In fairness, it must be pointed out that THC data are available over a comparatively restricted range and a stronger relationship might exist at higher THC concentrations. On the other hand, these results are from operating facilities, and even with the operational abuse imposed on some of them during research efforts and performance demonstrations, it is unlikely that higher concentrations will be observed at commercial installations.

Carbon Monoxide Versus Total Hydrocarbons

Since both CO and THC monitors are commercially available (although some would quickly point out that THC monitors are unreliable without extraordinary care), the question arises which analyzer should be employed. Figure 4 is a scattergram showing the relationship between CO and THC. The loess curve displays the same hockey stick pattern that characterizes the relationship between dioxin and CO. In fact, the break point is the same CO concentration. This indicates that either CO or THC could be used as a dioxin surrogate at "high" emitted surrogate concentrations.

Dioxins Versus Chlorobenzenes

For many years, researchers have been using chlorobenzenes as a surrogate for dioxins, arguing that when they affect a change in chlorobenzenes they affect a similar change in dioxin emissions. Figure 5 is a scattergram relating dioxins and total chlorobenzenes (homologue totals — mono- through penta-chlorobenzenes). Once again, the loess curve shows the hockey-stick pattern that characterizes a change in formation mechanisms, or simply a shift from highly uncertain data to comparatively accurately known concentrations. In this case, below about 2,000 $\mu g/dsm^3$ @ 7% O_2 of chlorobenzene, there is no co-trending. Above that level, a relationship begins to emerge.

Additional insight can be obtained by looking at the simultaneous dioxin and chlorobenzene data collected during the recent EAC/Pittsfield testing, the testing conducted at Davis County[7] and the ongoing compliance testing performed at the Peel Resource Recovery Incorporated (PRRI) facility in Brampton, Ontario, Canada. Each of these test programs involved splitting the Method 23 catch at the analytic laboratory and analyzing dioxins and chlorobenzenes in the parent samples. Also, these samples were all taken by the same field teams and analyzed by the same analytic laboratory so that between-team and between-laboratory variance sources are eliminated.

Figure 6 shows that EAC/Pittsfield and PRRI display no relationship between dioxins and chlorobenzenes. At Davis County, however, a relationship becomes apparent when the total chlorobenzene concentration exceeds 6-8,000 µg/dsm^3 @ 7% O_2. Interestingly, the chlorobenzene concentrations at Davis County are characterized by a single normal distribution, but the dioxins fall into two groups. This is not surprising since activated carbon was used to reduce dioxin and mercury emissions during the Davis County demonstration test. The lack of change in chlorobenzenes is an indication that activated carbon does not affect chlorobenzene emissions. Also, when the simultaneous data from these three plants are considered as a single group as in Figure 7, the same 2-4,000 µg/dsm^3 @ 7% O_2 inflection point that characterizes the entire data set is indicated by the loess curve. This indicates that chlorobenzenes may be a good surrogate at high dioxin concentrations, but the relationship has no utility at the below MDPQL levels that characterize today's MWCs and probably is non-existent at facilities using powdered activated carbon to reduce dioxin concentrations. It also issues the caution that laboratory studies analyzing chlorobenzene levels are reached and conclusions drawn by such studies must be taken as tentative.

Dioxins and Other Trace Organic HAPs

Because of the number involved, the relationship between dioxins and a plethora of other potential surrogates and less exactingly measurable parameters was investigated using multiple Spearman Rank-Order Correlation techniques. The following statistically significant relationships between ITEQ dioxins greater than the RMPQL and the potential surrogates were identified:

- Hexachlorobenzene
- Pentachlorophenol
- Total PAHs (California list)
- Acetanaphthylene
- Total Chlorobenzenes
- Phenanthrene
- Particulates
- Carbon Monoxide
- Total Hydrocarbons

Only hexachlorobenzene accounts for more than 50 percent of the simultaneous change in dioxin concentrations. That is, even though there is a statistically significant relationship between dioxins and the other listed parameters, the amount of change in dioxins explained by a change in the other is too small to be practically significant and explain an important amount of the variability.

Below RMPQL dioxin data were eliminated from this analysis, so the above correlations are for concentrations that are likely to be representative of actual emissions. Analysis of the scatter plots for CO, THC and Total Chlorobenzenes demonstrate that there is a critical level below which no meaningful relationship exists. Further analysis and exclusion of low level concentrations without apparent relationships might produce stronger correlations. For example, for CO concentrations above 250 ppm$_{dv}$ @ 7% O_2, the amount of dioxin change explained rises from 7% to 26%. Further improvement could be realized by optimizing the breakpoint. The result of this sort of analysis is identification of concentrations above which a meaningful surrogate relationship exists so that exceedances are indicative of an increase in dioxins.

Particulates With Organic HAPs

During the development of the proposed HWC Rule[8], EPA suggested that particulates were a surrogate for dioxins and other trace organic HAPs. The following statistically significant correlations were found with particulates for all data sets characterized by dioxin concentrations above the RMPQL:

- Phenanthrene
- Napthalene (a contaminant in Method 23 recovery chemicals)
- Pentachlorophenol, and
- Acenapthylene

Interestingly, the vast majority of the trace organic HAPs investigated, another 48 Section 112 organic HAPs for which we also have simultaneous particulate data, show no relationship with particulates. Consequently, having low emitted particulate concentrations does not provide assurance that trace organic HAPs emissions are also low; there is no obvious relationship.

CONCLUSION

A statistical review of more than 1000 dioxin test runs conducted at MWCs indicates that conventional regulatory and permitted levels of surrogates like CO and THC are not associated with increased dioxin emissions. The variables identified by EPA's good combustion practice strategy (CO and THC) are sufficiently related that keeping CO below say 250-500 ppm_{dv} @ 7% O_2 <4-hr average>, and THC below 20 ppm_{dv} @ 7% O_2 <4-hr average>, provides reasonable assurance that dioxin emissions are not increasing.

An increase in dioxin emissions begins to occur when the APCS operating temperature rises above 300-400°F; but below that operating temperature window, dioxin emissions are below the RMPQL. So, imposing an incremental temperature restriction on low temperature systems is not environmentally beneficial. Whatever relationship that might be found is likely the result of chance relationships among variables. At the upper limit of the available data, however, a meaningful relationship probably exists.

The surrogate relationship is not apparent, or even necessarily incipient, at current regulatory levels. Consequently, it is incumbent upon regulators, operators and the public to realize that violating extremely restrictive combustion-related emissions restrictions is not equivalent to belching unregulated pollutants.

Particulates are not good surrogates for dioxins or other trace organic HAPs emissions. Consequently, monitoring particulates with a continuous particulate monitor would not provide any additional assurance that these emissions are being minimized.

Public assurances of continuous compliance can be provided, however, by a second, much higher limit for the surrogates. Arbitrarily restricting surrogates to low levels simply does not enhance environmental protection. Concentration limitations for surrogates should be based on the potential of each pollutant to do environmental harm.

Annex A - Statistical Considerations

When multiple comparisons are done in an exploratory effort, there is a great risk of chance findings. When working at the 95% statistical confidence level (α, the statistical significance level, is 0.05), 5 percent or one out of 20 comparisons, are expected to be "statistically significant" when there is nothing significant to be found. To get around this problem, multiple comparison techniques are used. There is little dispute that if the significance level is greater than the Bonferroni significance level of $\alpha/\{n(n-1)/2\}$ for the n variables being compared, then a significant finding has been uncovered. For significance levels between α and the Bonferroni level, individual critical levels for each comparison should be based on the False Discovery Rate (FDR) level of $i\alpha/\{n(n-1)/2\}$ where i is the rank order from least to most significant of the comparison.

Dual-train calibration type analysis to establish the RMPQL is slightly complicated because the RMPQL is established by comparing two simultaneous, but unknown results. Unlike the implicit assumptions in Method 301 that the average of a pair of results is its true value, the field testing cannot achieve that goal because there is no "reference method" known to produce true values and no way to guarantee that slight spatial deviations do not produce real differences. Consequently, either member of a twin pair of results could be considered first and the other second. Fisher's symmetrical table approach aligns each pair first with one member to the left and then again with it to the right in a duplicate pair used, an upper bound for the RMPQL is produced. If the data are aligned with the largest of each pair on the same side, the minimum residual variance lowest likely RMPQL is produced. EPA's Method 301 method of calculating data variability produces a number between the two limiting values.

Given that the underlying experiment used the same sampling team and analytic laboratory, the upper limits are probably more representative of the true RMPQL than the lower limit. So, concentrations larger than the RMPQL calculated using Fisher's symmetrical table were taken as probably exceeding the RMPQL and accurately measured in this assessment.

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1. Energy & Environmental Research Corp., Surrogate Evaluation for Thermal Treatment Systems, USEPA, October 17, 1994, pg. 22.
2. *ibid.*, pg. 76.
3. H.G. Rigo and A.J. Chandler, Retrofit of Waste-to-Energy Facilities Equipped with Electrostatic Precipitators—Phase II—Sensible Heat Recovery, (EAC/Pittsfield), an ASME Research Report to be released May 1997.
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7. H.G. Rigo, A.J. Chandler, and W.S. Lanier The Relationship Between Chlorine in Waste Streams and Dioxin Emissions from Waste Combustor Stacks, an ASME Research Report, CRTD-36, August 1995.
8. Federal Register, V. 61 No. 77, April 19, 1996.

Table 1. Reference Method Practical Quantitation Limits for Method 23,26 and 29 measurable parameters.

pollutant	units	nominal sample volume (dsm^3)	Analytic (Laboratory) Detection Limit Equivalent Concentration ADLE	Reference Method Quantitation Limit RMPQL
HCl	ppm_{dv} @ 7% O_2	1.800	0.006	126 to 218
Cl_2	ppm_{dv} @ 7% O_2	1.800	0.003	9 to 11
HBr	ppm_{dv} @ 7% O_2	1.800	0.016	0.4 to 0.7
HF	ppm_{dv} @ 7% O_2	1.800	0.005	5 to 15
Particulates (Front-Half)	$gr/dsft^3$ @ 7% O_2	3.714	0.001	0.11 to 0.058
Cd	$\mu g/dsm^3$ @ 7% O_2	3.714	0.5	46 to 77
Hg	$\mu g/dsm^3$ @ 7% O_2	3.714	0.008	47 to 74
Pb	$\mu g/dsm^3$ @ 7% O_2	3.714	5	825 to 1,700
ITEQ Dioxins	ng/dsm^3 @ 7% O_2	3.714	0.19 (0.03)	0.22 to 0.47
Total Dioxins	ng/dsm^3 @ 7% O_2	3.714	0.84 (0.03)	10.9 to 19.6

Note: The ADLE is based on the laboratory DL and the stated sample size. The upper two tailed tolerance limit provides 99 percent coverage of future tests at the 95 percent statistical confidence level within 30 percent for the measured value. The duplicate Method 23 and 29 results and quadruplicate Method 26 results were analyzed using statistical calibration techniques. Given that this testing was done by one field team, at one site, using one analytic laboratory, the upper bound of the RMPQL is probably most representative.

Figure 1. Scatter plot displaying the relationship between dioxins and APCS operating temperature.

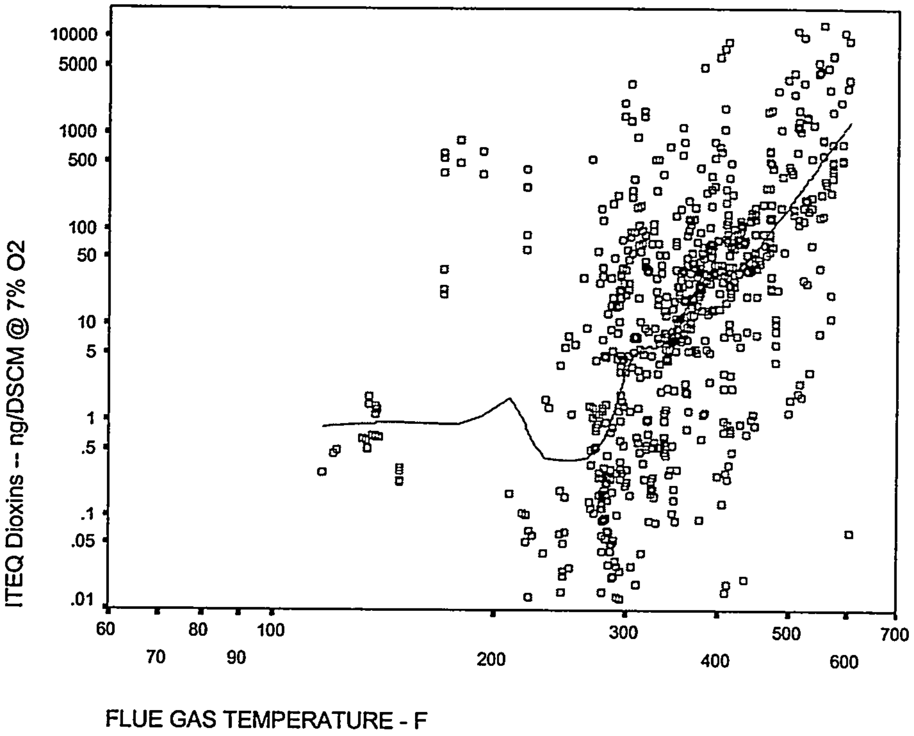


Figure 2. Scatter plot displaying the relationship between dioxins and CO.

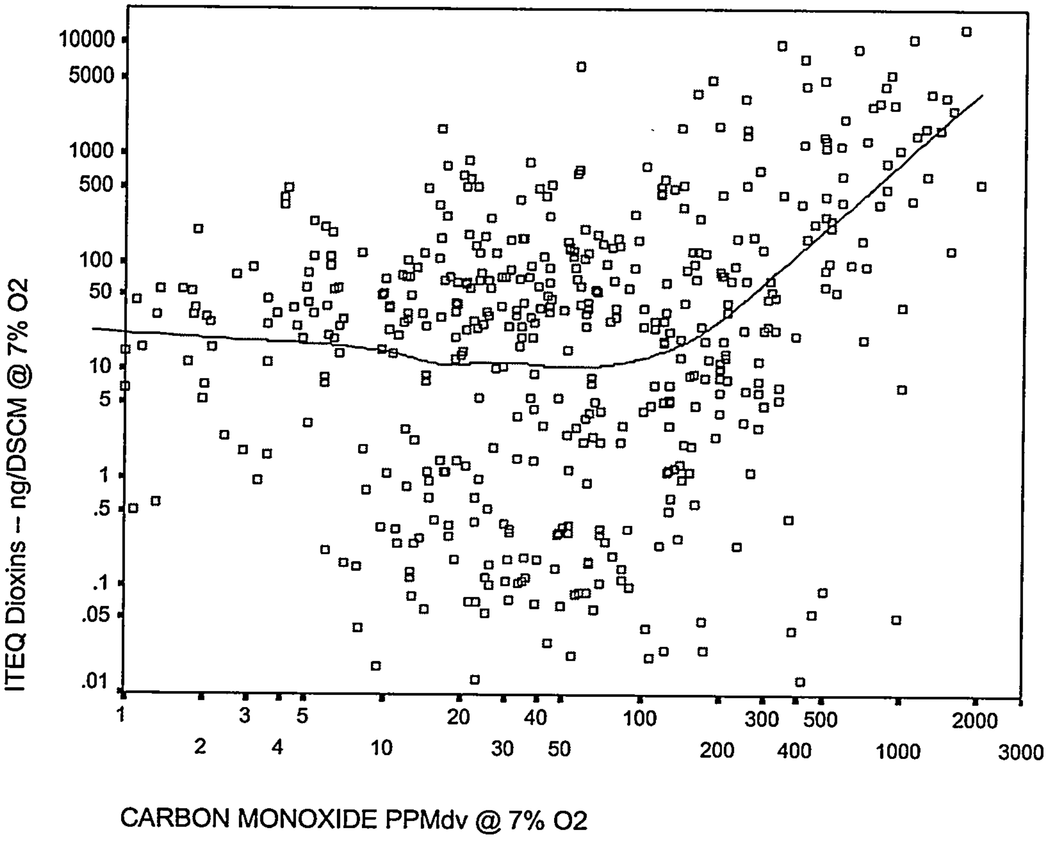


Figure 3. Scatter plot displaying the relationship between dioxins and THC.

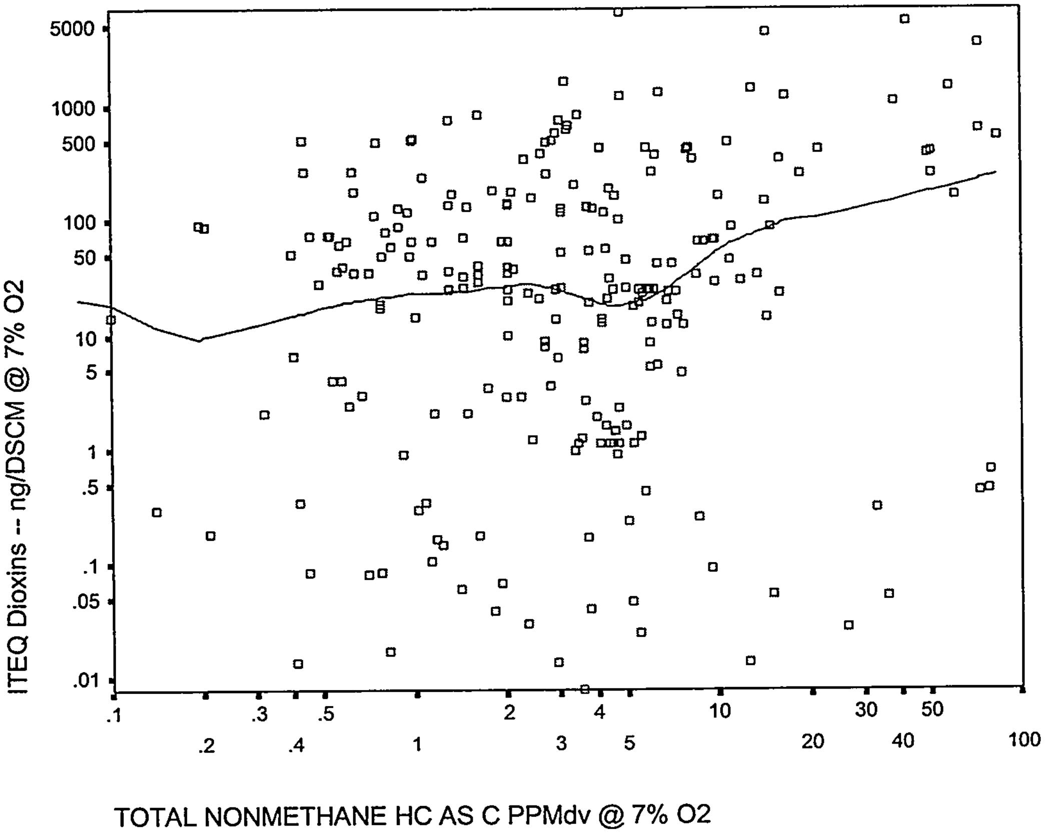


Figure 4. Scatter plot displaying the relationship between CO and THC.

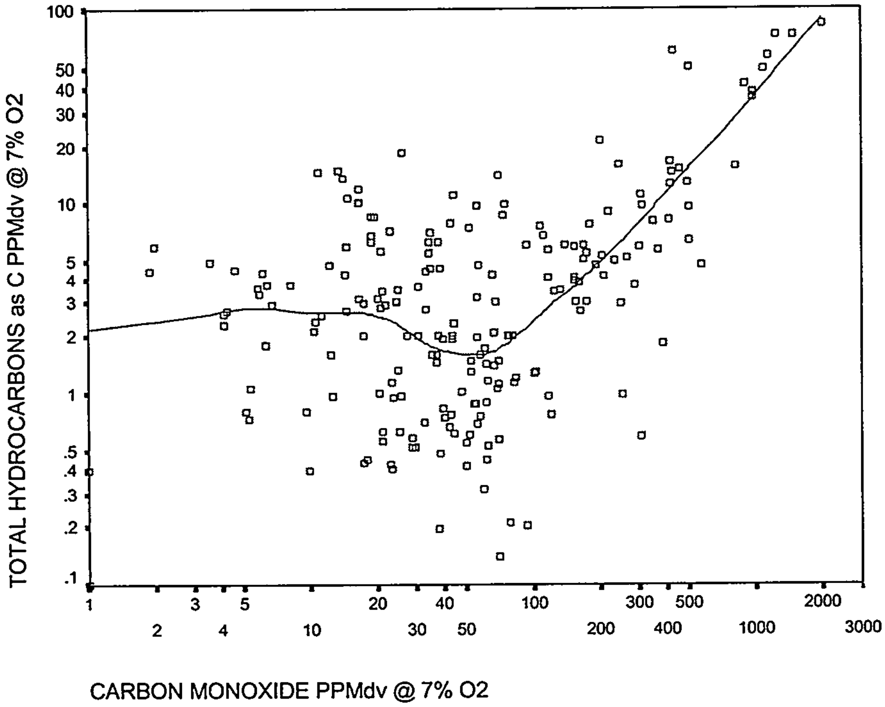


Figure 5. Scatter plot displaying the relationship between dioxins and total chlorobenzenes.

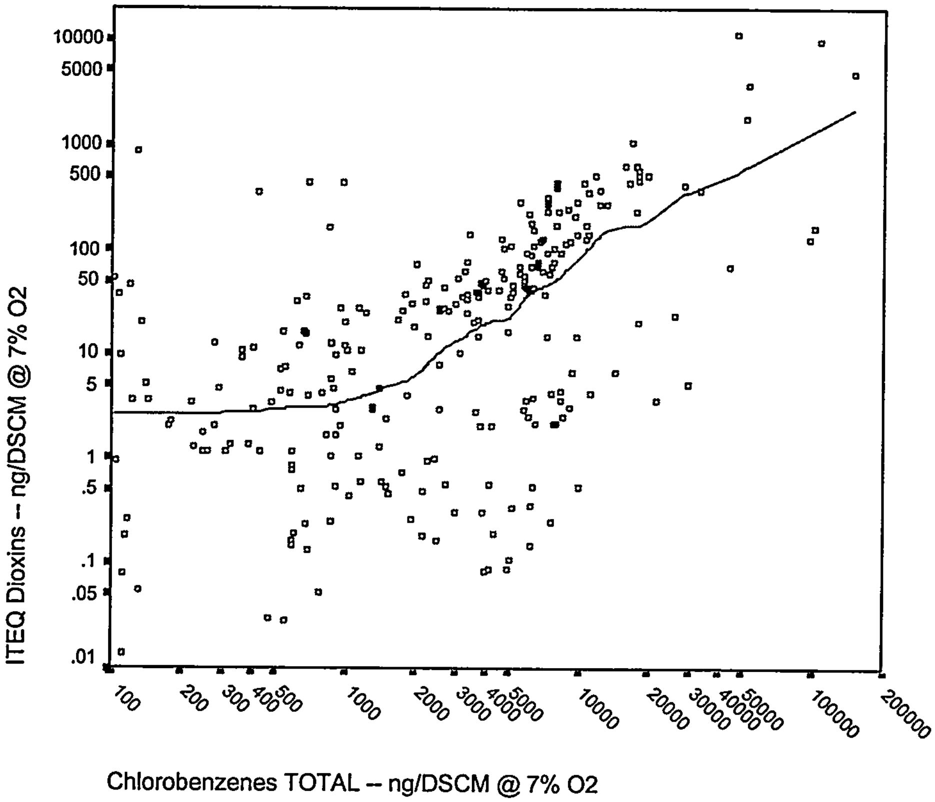


Figure 6. Scatter plot displaying the relationship between dioxins and total chlorobenzenes for three simultaneously measured facilities.

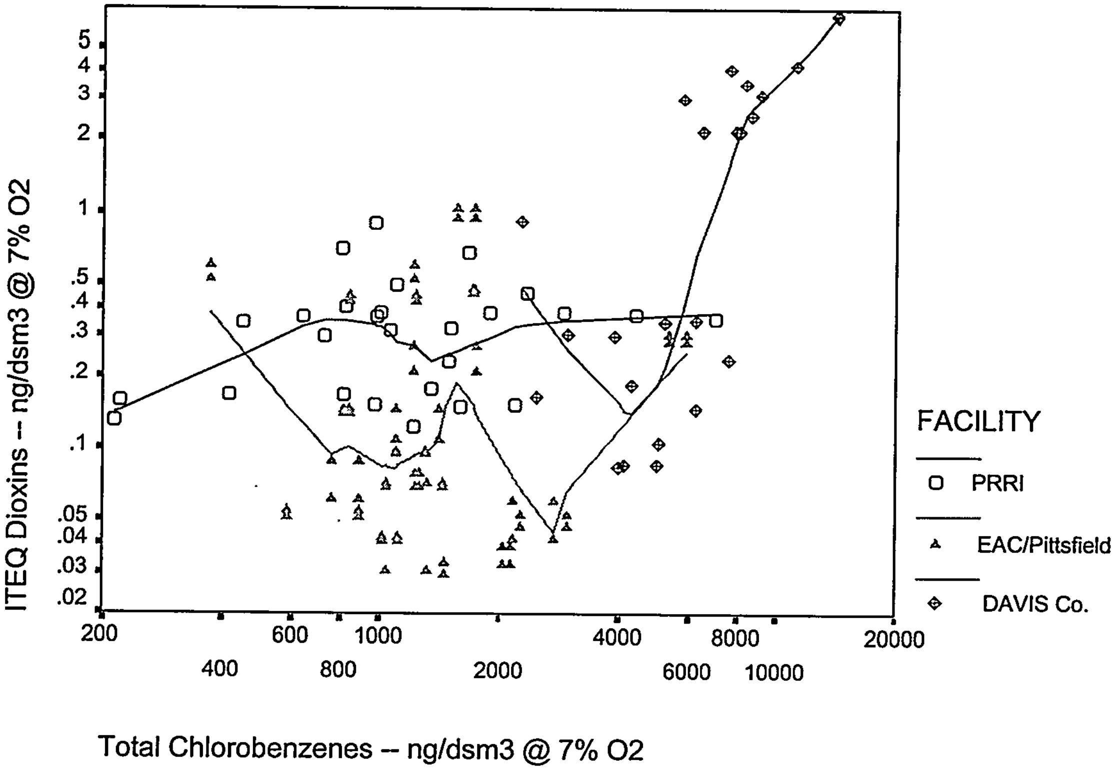
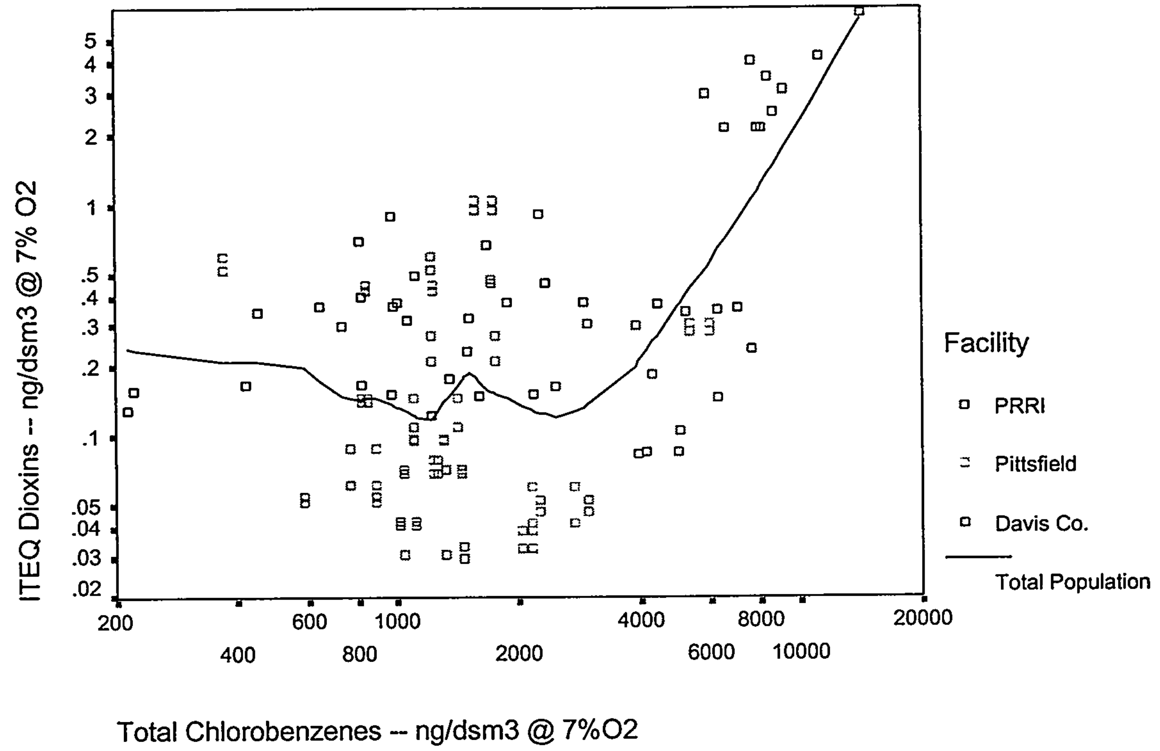


Figure 7. Scatter plot displaying the relationship between dioxins and total chlorobenzenes for three simultaneously measured facilities treating the data as a single group.



Continuous Monitoring of Metals Emissions

Robert G. Barton, Gary D. Hinshaw, Brian Cage, and Paul Gorman
Midwest Research Institute
425 Volker
Kansas City, MO 64110

INTRODUCTION

Continuous monitoring of emissions can assure the public of the safe operation of combustion facilities. Because of this, continuous monitors for many materials that have not been previously subjected to continuous measurement are being developed. Trace metals are one such material. A novel concept for the continuously monitoring toxic metals emissions, in gaseous and particulate form, has been developed and is being tested at Midwest Research Institute (MRI). The concept is based on the use of the SpinCon® gas-liquid contactor with an inductively-coupled argon plasma emission spectrometer (ICAP) or an ion chromatograph. This combination of technologies is called SPICAP. The SpinCon® uses a high-velocity cyclonic gas-flow to transfer both soluble gases and particles from a contaminated gas stream to a concentrated liquid medium. The liquid medium can be transported to an appropriate analytical device on a continuous, semi-continuous or batch basis.

As described by French and Durham[1], the most common approaches used to continuously measure concentrations of multiple metals are based on the measurement of emissions spectra generated when stack gas samples are subjected to strong excitation sources. The SPICAP system may be operationally more complex than these competing systems due to its requirement for a liquid medium. However, it is capable of concentrating metals in the liquid stream yielding lower detection limits. In addition, the SPICAP is currently the only system that is capable of collecting samples that can be used to continuously measure hexavalent chromium (Cr^{+6}) emissions.

MRI's development program consists of three concurrent tasks. In the first, a computational model of the capture processes is being developed and refined. This model was used to predict the capabilities of the device and suggest new areas of development. In the second task, a series of controlled laboratory experiments were conducted to evaluate system operation and performance. The final task involves conducting field tests using prototype units.

EQUIPMENT

The CEM developed by MRI is based on the patented SpinCon® gas sampling system[2]. This device transfers contaminants from a gas and concentrates them in a liquid. A simplified schematic of the device is shown in Figure 1. Gas samples are drawn from a stack through a Teflon line at a controlled rate. The line can be continuously rinsed as in the standard Cr^{+6} method[3]. Gas samples can then be passed through a saturation tower equipped with an air-atomized spray nozzle to cool and saturate the gas. The saturation tower is only used when sampling gases that are not saturated with moisture and are above approximately 200°C.

Gas samples then flow into a transition chamber from which they are drawn through a slit in the wall of the SpinCon®. The slit is cut tangentially into the wall of a cylindrical collection chamber forcing the gases that enter to flow horizontally around the interior circumference of the chamber. After one revolution the gases exit up the center of the cylinder. Liquid is introduced through a small hole in the wall of the collector. The cyclonic air flow forces the liquid to form a thin film on the wall of the collector. When the film encounters the slit, it is atomized to form a jet of fine droplets. The droplets move with the entering air across a chord of the collector and collide with the wall. After the collision, the film is reformed. The air flow is induced by a pump downstream of the collector. Air and liquid flows are controlled independently. Decreasing the liquid flow relative to the air flow allows the device to reach lower detection limits at the expense of longer response times.

Figure 2 illustrates the mechanisms that control the capture of material in the device. As the particle laden air enters the device, it encounters a cloud of slow-moving drops that have just been formed by atomization of the film. Particles are transferred from the gas stream to the liquid by inertial impaction with these drops. The drops rapidly accelerate to the speed of the air jet. Within the cloud of drops, very small particles, those with diameters less than about 0.1 μm, move to the droplets due to Brownian diffusion and are collected. When the drops collide with the wall of the collector, the gas and liquid are separated and the film is reformed. The gases then move around the inner wall of the collector in a thin layer near the wall. Particles move outward toward the wall due to the centrifugal forces. Any particles that reach the wall of the collector or the liquid film will be removed from the gas stream.

The collection of vapors occurs primarily in the cloud of droplets. Any soluble vapors diffuse to the droplets and are absorbed into the liquid. The mechanisms are enhanced by the large quantity of available liquid surface area in the droplet cloud. Once the liquid reforms the surface film, the available surface area decreases significantly and little additional removal of gases occurs.

MODELING

A computational model based on the mechanisms described above has been developed. All of the mechanisms except Brownian diffusion are accounted for. Table 1 summarizes major components of the model and the associated computational approaches. The model was used to predict the effect of several operational parameters on the predicted collection efficiency of the device. Two parameters found to exert a strong influence on the collection efficiency were particle size and slit coverage.

Figure 3 illustrates the predicted capture of particles and gases at the baseline conditions summarized in Table 2. The zone where particles collide with stationary droplets captures 67 percent of the particles initially in the gas stream. Centrifugal forces resulted in the capture of an additional 27 percent of the particles initially present. The predicted overall particle collection efficiency for the baseline conditions was 94 percent on a mass basis. Significant collection of soluble vapors is predicted to occur only in the cloud of droplets. Baseline vapor collection is predicted to be 40 percent by mass.

Figure 4 illustrates the impact of particle diameter on the predicted collection efficiency. The calculated efficiency was close to 100 percent for particles greater than 3 μm in diameter and decreased rapidly for smaller particles. The collection of particles less than 0.1 μm in diameter is the device will probably be much greater than predicted due to the influence of Brownian diffusion.

The fraction of the slit covered by the liquid film was thought to be an important operating parameter. When the film completely covers the slit, 90 percent of the particulate mass is captured by impaction in the spray and another 7 percent is captured in the centrifugal zone. When the fraction of the slit covered is decreased, the fraction of the material captured in the spray decreases proportionally. However, the relative quantity captured in the centrifugal zone increases. The overall capture efficiency decreases only slightly as the fraction of the slit covered by liquid decreases. Because most gas capture occurs in the droplet cloud, the capture of vapors is a strong function of slit coverage.

LABORATORY TESTING

The system's ability to collect hexavalent chromium has been tested in the laboratory[4.] Hexavalent chromium was selected as the target metal for these tests for three reasons. First compounds containing hexavalent chromium are often much more volatile than compounds containing the more common trivalent chromium. In combustion systems, compounds containing hexavalent chromium will vaporize in the high temperature regions and then condense as the gases cool. These processes result in the formation of particles typically about 0.2 µm in diameter. Particles in this size range are the most difficult to capture in most collection devices. Second, none of the multiple metals CEMs under development are capable of determining chromium speciation. Third, hexavalent chromium is a potent carcinogen and of significant environmental concern.

A DeVilbiss nebulizer was used to generate an aerosol consisting of particles composed of CrO_3. The aerosol was sampled using the SpinCon®, the standard EPA method for hexavalent chromium[3] and an inertial impactor. The collected material was analyzed for Cr^{+6} using ion chromatography. The results of these tests are summarized in Figure 5. The concentrations of Cr^{+6} found in the SpinCon® solutions were within 11 percent of those in the solutions produced by the standard method.

FIELD TESTS

Two series of field tests have been conducted using prototype sampling units. It both test series, samples of the collection liquid were obtained and shipped to an off-site laboratory for analysis. The tests were conducted at a hazardous waste incinerator and a mixed waste incinerator.

Hazardous Waste Incinerator

In these tests, the SpinCon® sampler was used concurrent with a standard EPA hexavalent chromium sampling train at a hazardous waste incinerator. Figure 6 summarizes the results of the tests. Much variation was observed because the emitted concentrations were close to the detection limits of the testing methods used. The detection limit of the SpinCon® system can be lowered by retaining the liquid in the collector for a longer period. However, that approach was not used in the field tests. No particle size analysis was performed. Due to the mechanism described previously, the particles containing the hexavalent chromium probably ranged in size between 0.2 µm and 1 µm.

The relative accuracy of MRI's approach was assessed using draft EPA performance specifications for multi-metals continuous emissions monitoring systems[5]. The documents specify two criteria for assessing the relative accuracy of an experimental CEM. The relative accuracy of the experimental method must be:

- Within ±20 percent of the mean value of the EPA reference method
- Within ±10 percent of the applicable standard.

The relative accuracy obtained using the SpinCon-based approach varied from that for the EPA reference method by 27 percent. However, the relative accuracy was calculated to be 7.1 percent of the applicable standard. Thus, the system conformed to the second criteria.

Mixed Waste Incinerator

The second series of tests were conducted at the U.S. Department of Energy Oak Ridge Reservation, located near Oak Ridge, Tennessee. A mixed waste incinerator designed and permitted for thermal destruction of radioactively contaminated polychlorinated biphenyl (PCB) and other hazardous compounds. Emissions were measured using the SpinCon-based system and EPA Method 29 simultaneously. Thirteen metals were targeted—antimony, arsenic, barium, beryllium, cadmium, chromium, lead, silver, manganese, cobalt, nickel, selenium, and uranium.

Figure 7 summarizes the results of the testing. The data show that the SpinCon-based unit generally indicated lower metals concentration than Method 29. However, the concentrations of all but four metals were below 10 µg/dscm. As these low levels, small variations in measured concentrations result in large relative errors.

For the four metals present at concentrations above 10 µg/dscm (Ba, Pb, Sb, and U), the EPA Method 29 results are higher that the CEMs results by a factor ranging from 1.1 up to 3.0. This difference may be caused by carryover of liquid from the sampler which removes some of the metal analytes. More recent improvements in the collector's level control system have reduced this problem.

CONCLUSIONS

The development of the SpinCon® sampler is an ongoing project at MRI. Testing and modeling work indicate that the CEMs is promising and has several unique capabilities. These include:

- Efficient collection of fine particles and soluble vapors.
- High gas sampling rate
- Low liquid volume and flow rate
- Adjustable concentration ratio (i.e., the ratio of the concentration of the component captured in the liquid to the concentration of the component in the gas being sampled).
- Capable of detecting hexavalent chromium

However, additional development is needed before the device can be commercially available.

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2. Cage, B.R. and Drinkwine, A.D. (to Midwest Research Institute) U.S. Patent No. 5,011,517, 1991.
3. "Determination of Hexavalent Chromium Emissions from Stationary Sources (Method 29);" *Methods Manual for Compliance with BIF Regulations Burning Hazardous Waste in Boilers and Industrial Furnaces*; PB 91-12006; U.S. Environmental Protection Agency, 1990.

4. Gorman, P.G. and Hinshaw, G.D. "Progress in Development of a Continuous Monitor for Metals and for Cr+6," in *Proceedings of the 1995 AWMA Annual Meeting*, Air and Waste Management Association, 1995.
5. "Draft Performance Specifications for Multi-Metals Continuous Emission Monitoring System," U.S. Environmental Protection Agency, September, 1994.
6. Lefebvre, A.H., "Twin-Fluid Atomization: Factors Influencing Mean Drop Size," in *ICLASS-91*, Gaithersburg, MD, 1991.

7. Wark, K., and Warner, C.F., *Air Pollution: Its Origin and Control*, Harper and Row, New York, 1981.
8. Geankoplis, C.J. *Mass Transport Phenomena,* Ohio State Bookstores, Columbus, OH, 1972.

Table 1. Modeling approaches used to investigate behavior of the SpinCon®.

Process	Approach
Atomization	Twin fluid atomizer (after Lefebvre[5])
Particle-Droplet Inertial Impaction	Modification of venturi scrubber model (after Wark and Warner[7])
Capture due to Centrifugal Forces	Force balance (similar to cyclone analysis)
Vapor Absorption in Film	Diffusion limited rate. Turbulent boundary layer (after Geankoplis[8])
Vapor Absorption in Cloud	Diffusion limited rate. Droplets and vapor have same velocity (after Geankoplis[8])

Table 2. Baseline conditions used in the model.

Parameter	Value	Units
Liquid Properties		
Surface Tension	72.12	dyne/cm
Density	0.9965	g/cm3
Viscosity	0.8532	centipoise
Heat of Vaporization	2.26×10^6	J/kg
Average Molecular Weight	18	g/mol
Solids Properties		
Density	2.28	g/cm3
Particle Loading in Gas	100	µg/m3
Mean Particle Diameter	2	µm
Standard Deviation of Size Distribution	1	µm
Gas Properties		
Density	1.179×10^{-3}	g/cm3
Viscosity	1.97×10^{-5}	centipoise
Vapor Contaminant Concentration	100	µg/m3
Diffusivity of Vapor in Bulk Gas	0.288	cm2/s

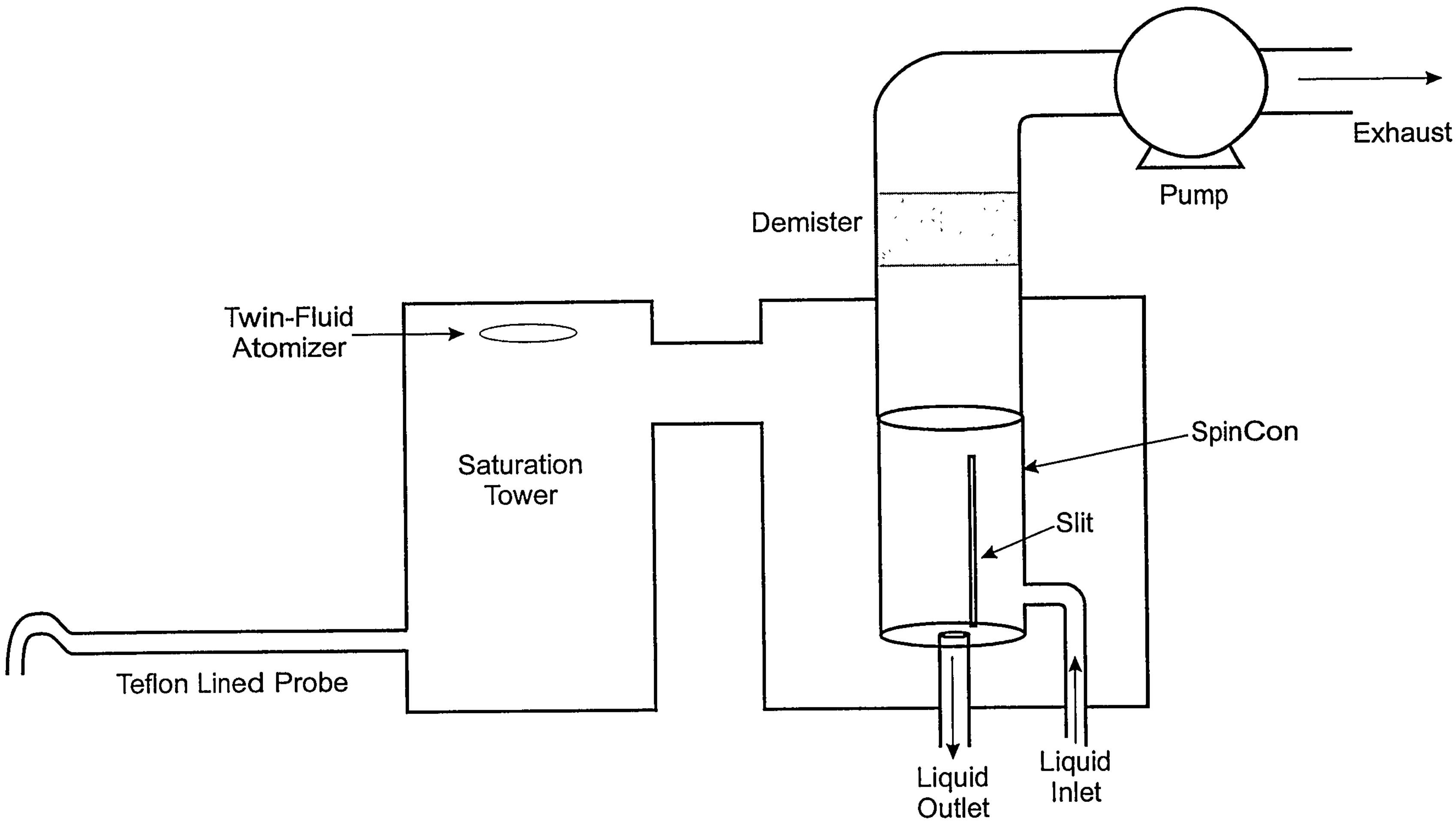

Figure 1. Schematic diagram of the SPICAP system.

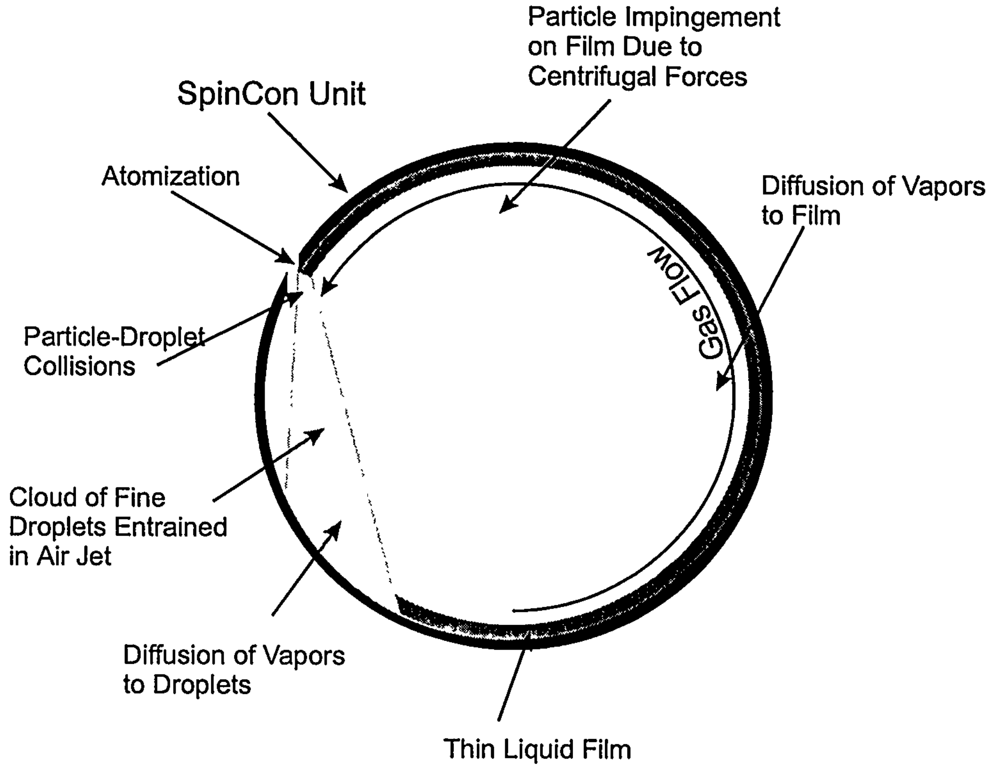

Figure 2. Mechanisms that control the collection of metals in a SpinCon collector.

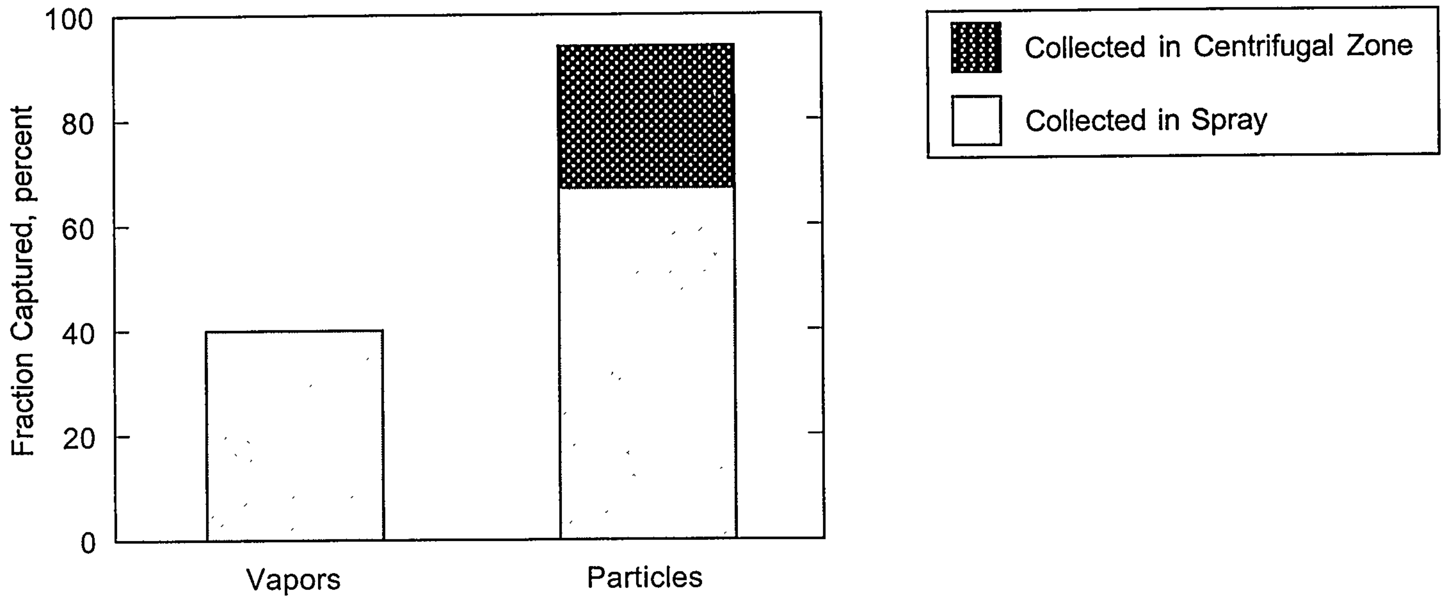

Figure 3. The predicted fraction of vapor and particle contaminants remaining in gas samples at two locations in the SpinCon collector.

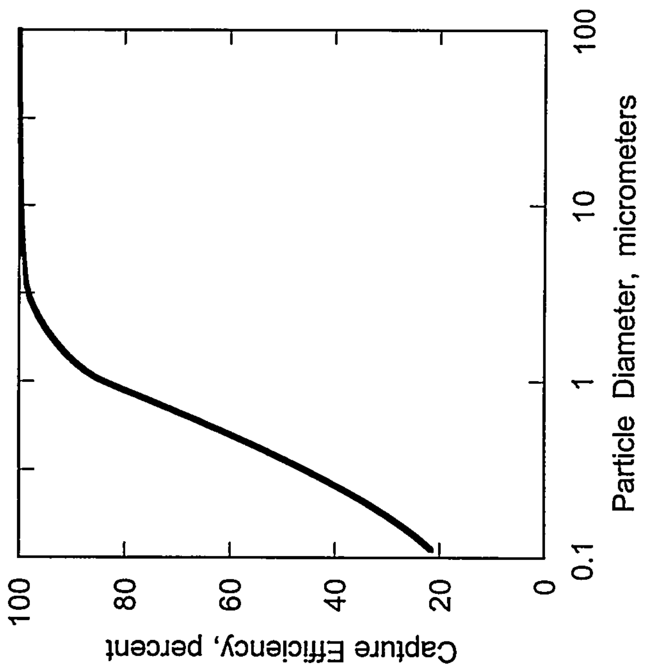

Figure 4. The predicted impact of particle size on capture efficiency.

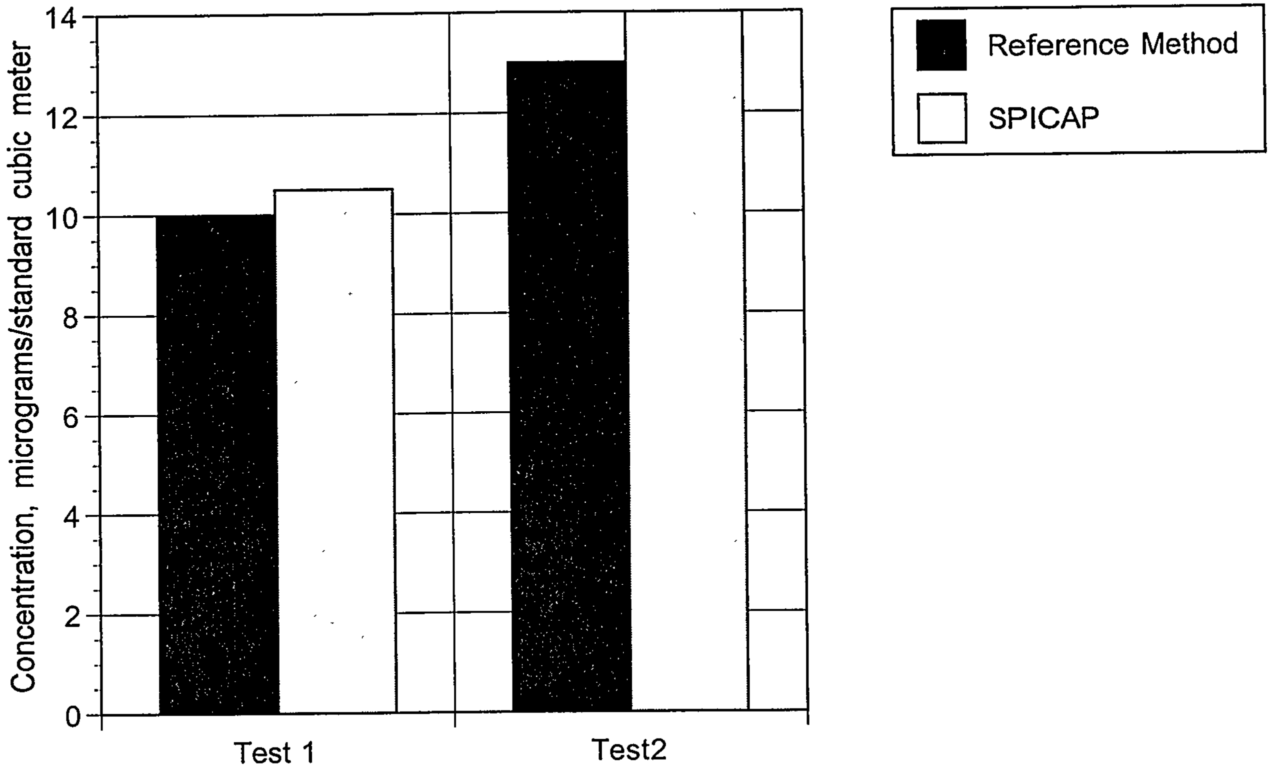

Figure 5. Hexavalent chromium concentration measured in laboratory system using the SPICAP and the EPA reference method.

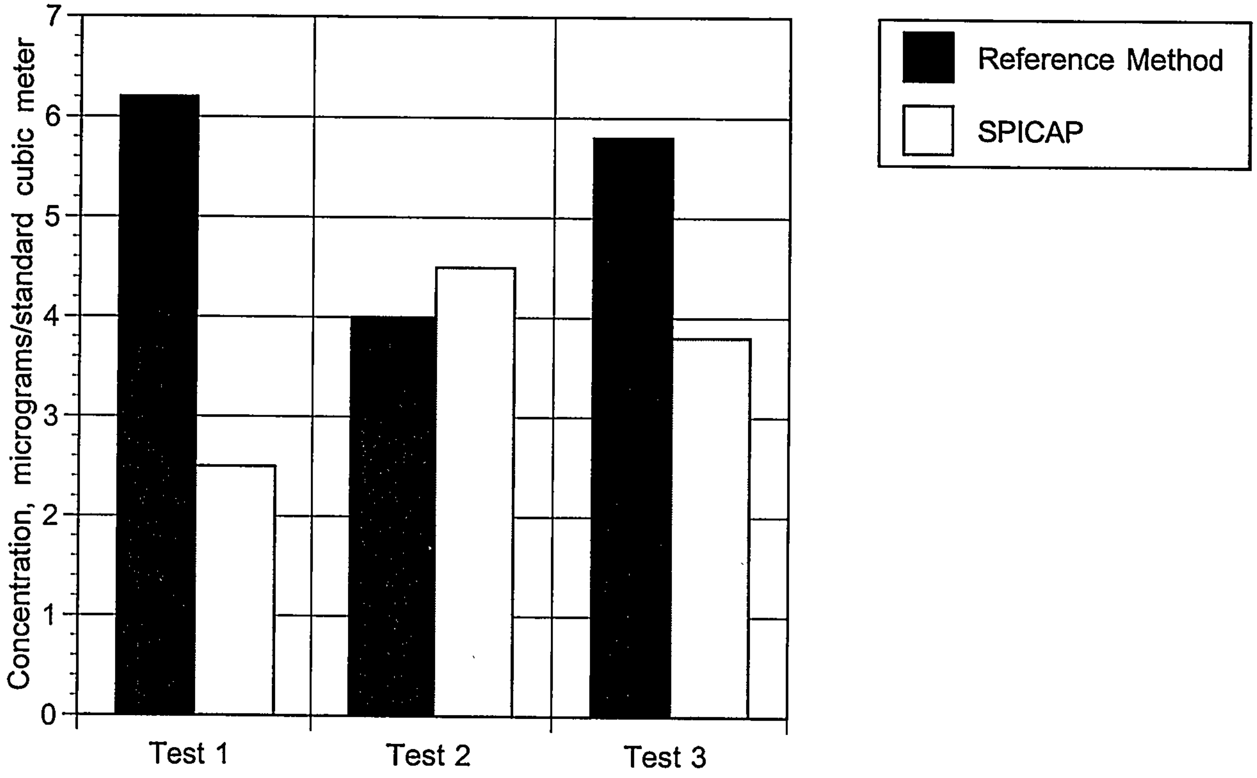

Figure 6. Hexavalent chromium concentration measured in incinerator exhaust gas using the SPICAP and the EPA reference method.

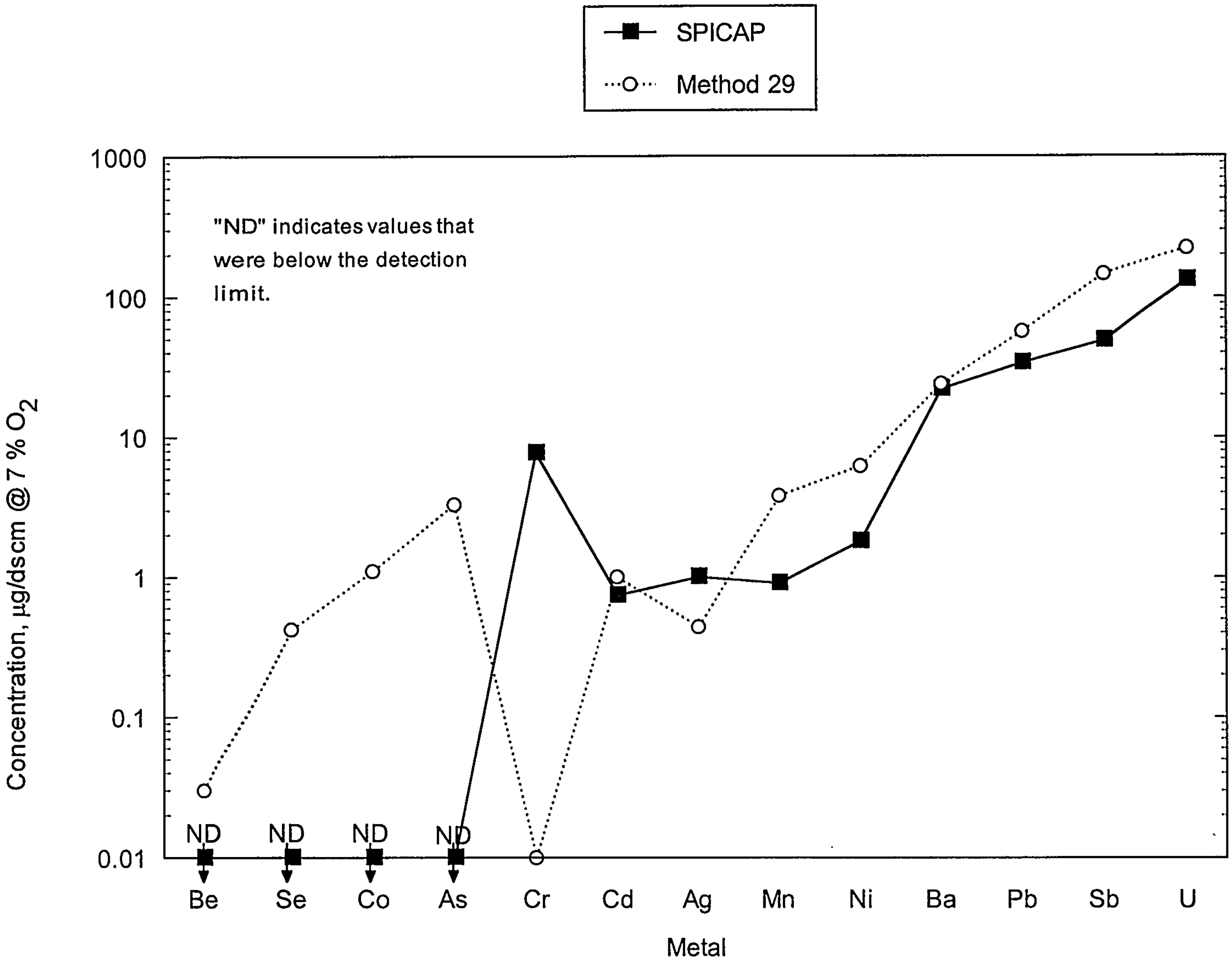

Figure 7. Results of sampling the exhaust gas of a mixed waste incinerator using SPICAP and the EPA reference method.