Environmental Implications of Resource Recovery

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"RESOURCE RECOVERY EMISSIONS AND CONTROLS"

by

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Abstract

This paper reviews current knowledge about emissions and controls relating to systems which recover energy from municipal solid waste (MSW) by combustion. Recent tests of operating plants for dioxins and furans show that well-designed and operated municipal waste combustors (MWC) have levels of emissions which are far below those reported in the past, because furnace temperatures are maintained sufficiently high and combustion air and the waste are supplied and mixed properly. Carbon monoxide (CO) measurements have been used to find and maintain optimum combustion conditions. Furnace temperature profiles determined by calculation and confirmed by test can predict the temperatures and retention times which can be maintained for various refuse heating values and excess oxygen levels. Guidelines are evolving for good design and operation of refuse combustion systems and post-combustion controls. Particulate emissions can be reduced to low levels by fabric filters and electrostatic precipitators, and alkaline sorbents can be added to absorb acid gases. Stack temperatures under 350 to 400°F are effective in condensing and removing heavy metals and condensibles organics such as dioxins and furans. Recent data shows that the quantity of lead and dioxins in the atmosphere, and dioxins and other toxics in lake sediments have already decreased substantially. It appears that due to the drastic reductions in emissions from municipal waste combustion facilities, they will not make a significant contribution to atmospheric background levels of dioxins and other pollutants in spite of the large number of such plants which are being built and anticipated.

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Introduction

Municipal solid waste (MSW) can be disposed of by source separation, recycling, combustion, pre- and post-combustion recovery of metals, and landfill. Whichever combination of these methods is used, combustion remains an effective means of elimination of organic materials and concentration of inorganics.

Combustion necessarily results in some quantity of emissions to the atmosphere and the need for disposal of inert residues. Effective combustion minimizes organic emissions, and effective emission controls can remove most of the particulate matter and acid gases from the emissions. The flyash and bottom ash residues which result from acid gas control systems are highly alkaline and thus buffered so that heavy metal leaching is minimized.

In order for the public to accept combustion as a satisfactory component of environmentally sound refuse disposal, it is necessary to demonstrate that combustion systems can be designed and controlled so that emissions do not contribute significant amounts to background levels of particulate, acid gases, metals and other pollutants of concern. In addition, concentrations of these pollutants must be shown not to exceed safe levels at the points of maximum concentration near the plants.

In the last few years great progress has taken place in developing methods to control organic emissions, especially dioxins and furans, and more effective methods for controlling particulate, acid gases and heavy metals emissions.

This paper reviews the present state of knowledge. The levels of ambient pollutants which were increasing at a rapid rate prior to 1970 are now found to be decreasing rapidly due to the effectiveness of improved combustion and emission controls in the last 15 years. Ambient levels of lead have already been greatly reduced by removing lead from gasoline. Atmospheric levels of dioxins and furans are also falling at a similar rate, according to recent tests.

Research efforts to find ways of minimizing dioxin and furan emissions have shown that sufficient temperature and good control of air distribution and fuel feed are effective. The use of carbon monoxide (CO) measurements has been found to be effective as a means for finding and maintaining optimum conditions for combustion and destruction of organics, especially toxic compounds such as dioxins.

The number of municipal waste combustors (MWC's) operating in the USA increased at a steady rate from 1948 until 1970, when there were about 300 plants with a total operating capacity of about 80,000 tons per day. When the Clean Air Act imposed emission controls on these MWC's they were only installed on a
few of them, and the rest shut down, resorting to the much less costly landfill. By 1981 only about 20,000 TPD were being burned. The energy crisis helped to propel the development of heat-recovery and refuse-to-power plants. At present about 60 of these plants are in operation, and the number is expected to triple in the next three years.

There is an increasing public concern about this return to combustion. Many remember the poor performance of the old plants, without combustion or emission controls. In order to gain public acceptance of MWC's, it will be necessary to demonstrate that the new plants will have extremely small emissions compared with the old ones, and will not be major contributors to atmospheric pollution nor a risk to health.

Dioxin emissions tests of municipal waste combustors

Many tests of collected flyash and stack emissions from municipal incinerators, especially those without heat recovery, showed high levels of dioxin and furan emissions, and caused worldwide concern. Major research programs were initiated, to discover causes and solutions, especially in European countries where most of their municipal wastes have been burned for years.

Results from many of these studies are now becoming available. It has been concluded that high dioxin emissions were the result of poor combustion, or erratic control of combustion, and that efforts to improve design and operation have been successful.[1]

Basic combustion kinetics theory establishes the conditions of temperature and oxygen necessary to destroy organic materials. Dioxins and furans do not require exceptionally high temperatures, indeed not as high as are required by PCB's. Temperatures of 1600°F should be more than sufficient to destroy dioxins to four nines (99.99%) or better with the amount of excess oxygen normally supplied in MWC's (6% or higher), and retention times of 1/2 to 1 second in gaseous combustion are sufficient. The reasons for not destroying dioxins to acceptably low levels are mainly failure to feed and agitate the refuse properly, and to continuously supply combustion air in the right amounts and places.[2]

By using oxygen controls to maintain combustion air supply in the optimum range, and CO measurements to optimize the placement and quantity of combustion air, MSW combustors can be operated more efficiently (making more steam and power) and effectively, thus reducing organic emissions to extremely low levels. In fact, some plants have operated at less than 10 parts per million CO, and most less than 50 ppm during tests.[3]

Total dioxin (PCDD) and furan (PCDF) emissions which have been reported for various plants are shown in Fig. 1. They have
ranged from over 5,000 ng/m$^3$ down to under 20 ng/m$^3$ from the recently tested Peekskill plant. Other plants such as Prince Edward Island (PEI) in Canada, Umea in Sweden, and Stapelfeld, Germany had emissions in the same general range.[4]

Unlike the 'old days' when emissions testing was carried out without determining best, not to mention good, combustion conditions, nowadays optimization testing has generally been carried out prior to emissions testing. Since the dioxin tests are expensive, and sample analysis takes many months, there is a need for another surrogate to evaluate combustion effectiveness and perhaps anticipate PCDD/PCDF levels. Generally oxygen and CO measurements have been found to be the most useful combustion parameters for finding how the plant should be operated.

Most dioxin tests have been carried out under the normal operating conditions, without controlling variables in order to analyse their influence. A major diagnostic testing program was carried out at Hamilton, Ontario on the SWARU RDF-burning boilers.[5] The data from these tests clearly show the trends of dioxins with temperature, and with CO, although traditional statistical methods of analysis have led many to the conclusion that few trends or correlations could be found.

Recently highly detailed diagnostic testing programs have been carried out to find optimum operating conditions by systematically changing variables such as furnace temperature.

The recent Phase I tests at Pittsfield and the earlier tests of Prince Edward Island (PEI) show the effect of low furnace temperatures clearly.[3][6] This data, plotted along with data from Hampton, Hamilton, and other plants in Fig. 2 shows the strong trends with temperature.[4] Reverse trends are conspicuous in the case of one set of Hampton tests, and some of the Benfenati data.[7] This anomaly can be explained by poor mixing and insufficient oxygen. Likewise, the generally higher level of the Hampton and Hamilton data can be explained as the result of erratic control and poor mixing.

It has been known for a long time that CO emissions are a function of temperature, oxygen, and mixing effectiveness. It should be no surprise that this is also true when burning MSW.

Figure 3 shows the relationship between five-minute averaged CO readings during the Pittsfield tests.[3] In the temperature range from 1500 to 1900°F the CO was generally below 40 ppm. At lower temperatures a rapid rise is noted. Also, at higher temperatures a rise is noted, again, due to reduced oxygen concentration and the need for better mixing. Note that CO rose as oxygen fell below about 5.5%.
Now that considerable data is available it is becoming more clear how CO readings are related to dioxin emissions and how to find optimum combustion conditions.

Figure 4 shows how CO data relates to PCDD emissions from many plants. The trends cannot be denied, although reasons for differences require deeper understanding of the combustion system and controls.

**Guidelines for design and control of municipal waste combustors**

Guidelines intended to assure that municipal waste combustors (MWC's) will be designed and operated properly are in the process of evolution. An early version published by the California Air Resources Board (CARB) called for maintaining 1800+/-200°F for at least one second.[8] Others have introduced a two-stage concept, to exceed 1800°F for one second, and to maintain 1500°F for at least one second after the last addition of overfire air. The USEPA Office of Solid Waste is preparing a Report to Congress, which will contain guidelines referring to the volumetric heat release of the furnace, together with requiring carbon monoxide (CO) monitoring.[9] Volumetric heat release values are to be calculated to the plane where the gases reach 1500°F, based on clean boiler conditions. The guidelines may recommend that regulations require maintaining CO at 100 ppm or less, averaged over four days, and that CO should not exceed 400 ppm averaged over an 8-hour shift.

The heat release guidelines will have to be determined from actual volumes and temperatures which have been found to achieve acceptable CO emissions. They will have to be matched to various technologies, such as refractory furnaces, water-wall furnaces, mass-burning, refuse-derived fuel, and two-chamber starved-air and excess-air systems.

The relationship between retention time and furnace temperature for a water-cooled furnace is shown in Fig. 5, as determined by calculations based on 100% excess air. These curves are basically determined by the MSW moisture and heating value, the amount of excess air used, and the design of the furnace.[10] The time exceeding 1500°F is greater than 3 seconds even for 3800 Btu/lb MSW, but exceeds 1800°F for just one second for this heating value. Auxiliary burners may be needed when MSW with lower heating values are to be burned.

The refractory portions of furnaces do not cool the gases rapidly, providing long retention times, but the gases in any case have to be cooled down to temperatures at which they can enter boiler convection surfaces. This cooling can be accomplished by water-cooled surfaces or by air injection. The furnace volumes required to accomplish this cooling are thus mainly dependent on the technology used, not upon the need for any.
particular retention time.

The shape of the furnace, and the distribution of combustion air must be such that all gases pass through the minimum temperature required, and have sufficient oxygen to complete oxidation. Much research has been done, achieving low CO levels.\[11\]

Minimum dioxin emissions result from good design and operation

The consensus throughout the world is that well-controlled combustion can reduce dioxin emissions to acceptable levels, not constituting a risk to health. These conditions are generally accepted as requirements:

- All combustion gases must be subjected to above 1800°F for at least one second of time, and above 1500 for another second;
- Auxiliary burners should be provided to achieve temperatures of 1500°F or more during startup and shutdown periods and in case of upsets while refuse is burning.
- Continuous recording of furnace temperature, oxygen and carbon monoxide (CO) should be required so that upset conditions will be noted and corrected.
- The performance of combustion controls can be evaluated, if not controlled, by ability to hold oxygen within the limits which assure good combustion; CO readings are useful for optimizing combustion conditions and maintaining them.
- Operators of refuse combustors should have adequate training and certification.

The fact that efficient operation equates to high energy recovery and revenues from steam and electricity tends to assure that modern waste-to-energy plants will have low emissions of products of incomplete combustion.

Dioxin emissions and health risk

Environmental impact statements usually contain estimates of dioxin emissions, and modeling is done to determine ground level concentrations and thus serve to make health risk estimates. The relationship between PCDD and PCDF emissions and health risk has been estimated many times now. Generally the findings are that the emissions of well-designed and well-operated plants do not constitute a significant health risk after dilution of stack emissions at ground level.\[12\]

The procedure for estimating health risks is extremely complex. The first step is to select appropriate data on emission
### Table I - CALCULATION OF TOXIC EQUIVALENTS

#### BROOKLYN NAVY YARD FACILITY [12]

<table>
<thead>
<tr>
<th>Substance</th>
<th>Concentration (ng/m³)</th>
<th>Relative Toxicity</th>
<th>Toxic Equivalent</th>
<th>Percent Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,3,7,8 TCDD</td>
<td>0.42</td>
<td>1.00</td>
<td>0.42</td>
<td>1.7</td>
</tr>
<tr>
<td>Tri-CDD</td>
<td>13.3</td>
<td>0.01</td>
<td>3.07</td>
<td>12.4</td>
</tr>
<tr>
<td>Tetra-CDD</td>
<td>6.5</td>
<td>0.01</td>
<td>0.06</td>
<td>0.2</td>
</tr>
<tr>
<td>Penta-CDD</td>
<td>10.7</td>
<td>0.1</td>
<td>1.07</td>
<td>4.3</td>
</tr>
<tr>
<td>Hexa-CDD</td>
<td>16.4</td>
<td>0.1</td>
<td>1.07</td>
<td>4.3</td>
</tr>
<tr>
<td>Hepta-CDD</td>
<td>7.8</td>
<td>0.01</td>
<td>0.08</td>
<td>0.3</td>
</tr>
<tr>
<td>Octa-CDD</td>
<td>2.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total PCDD</td>
<td>57.7</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

#### WESTCHESTER WASTE/ENERGY FACILITY [13]

<table>
<thead>
<tr>
<th>Substance</th>
<th>Concentration in Flue Gas (ng/m³)</th>
<th>Relative Toxicity</th>
<th>Toxic Equivalent</th>
<th>Percent Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,3,7,8 TCDD</td>
<td>0.276</td>
<td>1.0</td>
<td>0.28</td>
<td>4.8</td>
</tr>
<tr>
<td>Tri-CDD</td>
<td>--</td>
<td>0.01</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Tetra-CDD</td>
<td>2.1</td>
<td>0.01</td>
<td>0.02</td>
<td>0.3</td>
</tr>
<tr>
<td>Penta-CDD</td>
<td>2.1</td>
<td>0.1</td>
<td>0.21</td>
<td>4.0</td>
</tr>
<tr>
<td>Hexa-CDD</td>
<td>2.9</td>
<td>0.1</td>
<td>0.29</td>
<td>5.5</td>
</tr>
<tr>
<td>Hepta-CDD</td>
<td>4.2</td>
<td>0.01</td>
<td>0.04</td>
<td>0.8</td>
</tr>
<tr>
<td>Octa-CDD</td>
<td>6.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total PCDD</td>
<td>18.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Toxic Equivalent = 5.81/0.276 = 21

#### Resource Recovery Emissions and Controls

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levels. Ideally, they can be obtained from tests of the same type of plant as that proposed. Lacking that, an intelligent selection must be made based on similar plants which have been tested.

The data from tests of the 12-year-old Chicago Northwest plant has been widely used as a basis for estimating dioxin emissions. Data from recent tests show that much lower numbers can be achieved.

The toxicity of the various congeners of dioxins and furans differ widely. A generally accepted relative toxicity table is shown in Table I, which presents calculations of toxic equivalent calculations based on Chicago data for the Brooklyn Navy Yard, and on the recently published Westchester (Peekskill) tests.[13]

Note that the Westchester PCDD/PCDF are 1/5 to 1/9 of the Chicago data on which the Hart calculation was based, and that the equivalent toxicity is one third.

Note that the major contributors are the TCDF's, especially the tri to hexas. The penta and hexa PCDD's are the only significant contributors in the dioxins. Octa's are considered to have relatively zero toxicity for both dioxins and furans. The Chicago tests did not include the tetras; the values listed were interpolated. The tri-PCDD is unusually high, raising the estimate of the tetras.

Based on the Westchester data, the risk assessment calculated for the Brooklyn Navy Yard would appear to be a conservative estimate.

There remains a tendency to predict emissions from planned facilities based on averages of test data from a wide range of facilities. This practice, while extremely conservative, mixes 'good' plants with plants which were not performing well at the time of the test. Statistical analysis shows that there are 'classes' of plants which tend to produce similar levels of emissions. Data from individual plants as well as types of plants generally fall on straight lines on log-probability paper. Figure 6 illustrates this with a few data. Inclusion of more data reinforces this principle.[14][15]

Figure 7 shows the quantities of congeners with various numbers of chlorine atoms attached to the PCDD and PCDF. The averages of nine incinerators are substantially higher than those for Chicago, and show an entirely different "footprint." The PCDD of the average of nine plants is one or two orders of magnitude greater, the PCDF about 15 times higher. The Pittsfield emissions at 1850°F furnace temperature are substantially less than those at 1250°F, and exhibit a different footprint.
Czuczwa and Hites compared PCDD/PCDF footprints and quantities of flyash samples from a municipal incinerator and a coal-fired power plant with congener profiles in cores taken from Lake Huron.[16] They noted that PCDD/PCDF started rising in 1940 parallel with production of chloro-aromatic chemicals, whereas coal use was fairly constant since 1910. They concluded that PCDD/PCDF in lake sediments were the products of combustion of municipal and industrial wastes. They also compared average emissions from coal combustion in 1974 with those from MSW combustion in 1971 (when there were about 300 MSW incinerators operating), and concluded that since the concentrations on coal particulate were 100 times less, and coal particulate was three times as great (nationally) as that from MSW, that dioxins from coal were 1/30 of those from waste burning.

These calculations were interesting, but different results would be obtained based on what is happening today. In 1971, there were about 300 MSW incinerators operating. I have estimated that they were burning 80,000 tons per day of MSW. Most of these plants had poor, if any, emission controls, having emissions averaging in excess of 0.08 g/dscf. Today the average emission level is probably less than 0.03 g/dscf and moving downward. They also had poor combustion controls. Hence their organic emissions could easily have averaged 100 times those of a plant built today.

By 1979 the tonnage burned in MSW incinerators had fallen to below 30,000 tons per day, and by now may have again passed this number, on the way up.

What is important is that present-day and future emissions will be drastically lower than they were in 1971.

**Fate of dioxins and furans in the atmosphere**

The toxic equivalent calculated by the above methods assumes that the PCDD/PCDF emitted by the stack reach the ground level and are taken in by humans without any change in the congener profiles, that is, the distribution of various degrees of chlorination.

Evidence has been found that dioxins and furans released to the atmosphere are transformed from a mixture of congeners to primarily the octa form, which is not considered to be very toxic. The time needed for this transformation is not known.

The lastest paper by Czuczwa and Hites studies PCDD/PCDF found in the atmosphere, and finds that the congener distribution is similar to that found in lakes supplied only from the atmosphere.[17] Lakes fed by polluted rivers showed a different distribution, similar to that noted in MSW and industrial waste incinerators.
Of great interest is the graph they have drawn of the flux of PCDD and PCDF to Siskiwit Lake versus the average year of deposition (Figure 8). After rising to 30 pg/cm²-year, in 1970-1975, levels have fallen to 23 by 1983. Lake Erie showed a drop from 3500 to 1900 pg/cm²-year. Note that the flux to Siskiwit Lake (supplied by the atmosphere only) received about 1/100 the flux of Lake Erie, indicating that land and water sources were involved. Figure 9 shows that the congener distribution found in the atmosphere is mainly octa-PCDD and PCDF.

Figure 9 shows bar-graphs of congener distribution of PCDD/PCDF from various emission sources, atmospheric concentrations, and lake sediments.

Distributions from many of the combustion sources show a peak in the penta or tetra forms, which are also the most toxic. Distributions in atmospheric samples and lake bottoms show mainly octas, with relative traces of the lower chlorine-bearing forms.

Their conclusions are significant:

"In the environment, we found a predominance of OCDD compared with combustion sources. We interpreted this as evidence for the loss of the less chlorinated dioxins and dibenzofurans.

"The public perceives all dioxins and dibenzofurans as unacceptable hazards. There is strong political pressure to prevent the incineration of hazardous wastes, even though the alternative--landfilling--has sometimes had disastrous results. The results of our work on combustion as a source of dioxins and dibenzofurans are partially reassuring. We find a predominance of OCDD in all environmental samples, one of the least toxic isomers. Only low concentrations of all TCDD's were detected. Anthropogenic combustion may have made PCDD and PCDF ubiquitous in populated areas, but it is probably not a major source of the highly toxic 2,3,7,8 tetrachlorodibenzo-p-dioxin isomer."

They noted the following:

- Chlorinated organics from various sources other than combustion contribute to lake sediments;

- Atmospheric PCDD/PCDF shows mainly the octa congener: it appears that the lower chlorine-content dioxins and furans do not survive well, breaking at the hydrogen bonds, leaving the octas.

In relative toxicity analyses, octas are rated as having zero toxicity. Thus it would appear that emissions from combustion of
PCDD/PCDF which actually reach the ground have a much lower risk to health than is currently perceived.

The above information, translated to health effects from combustion of MSW indicates that the risk to health is low, and that multiple MWC's constructed in large urban areas will not contribute significant amounts of dioxins or metals to the atmosphere;

**Provision of acid gas and fine particulate control**

The provision of acid gas controls which will contribute to a general reduction of acids in our atmosphere, will also reduce dioxin and heavy metal emissions at efficiencies from 95% to 99% or more. Figure 10 shows some data on removal efficiencies of dry powder (dry venturi) and spray-dry scrubbers for control of sulfur dioxide emissions. The dry powder scrubber data indicates that more lime is needed to equal the performance of the spray-dry scrubber. In many cases, this additional lime might cost much less than the capital and operating cost of the spray-dry system. Removal efficiencies for HCl at the same lime/acid ratios are much higher, generally over 90%, when both acids are removed simultaneously.

Lime injection into the furnace is being investigated as a means of retrofitting coal-fired boilers to achieve limited acid gas control. This approach has potentials in the combustion of MSW and RDF.[18]

The report on a major investigation of dry-powder versus spray-dry scrubbers with either electrostatic precipitators or fabric filters (bag houses) has just been published by Environment Canada, under the NITEP program.[19]

**Condensation of heavy metals and dioxins**

The NITEP report confirms previously sparse evidence that stack temperatures under 300°F or so are effective in causing heavy metals, dioxins and other products of incomplete combustion to condense onto particulate which can be collected.

Figure 11 shows test results collected by Marjorie Clarke from various plants.[20] The removal efficiencies for mercury show a broad general tendency with outlet gas temperature. The plants having scrubbers are shown with stars, and those with fabric filters and electrostatic precipitators are also identified. The fabric filters showed higher efficiencies than ESP's, probably due to the fact that filters retain the particulate for long periods of time, allowing reactions to approach completion.

A similar graph can be plotted for dioxin removal. The data points are remarkably close to those for mercury. This should be expected, since mercury chloride and dioxins have similar
condensing curves vs. temperature.

**Evidence of a general reduction of environmental pollutants**

Perhaps the best news of all is the finding that our environment, long abused, is showing many signs of reduced abuse, and a rapid trend toward background levels of yesteryear. The decline in atmospheric lead resulting from reduction in leaded gasoline and reductions in sulfur oxides over the last few years appear to be taking place in emissions of dioxins as well.

Figure 12 shows the rise in lead content of ambient air over the period when it was increasingly used to raise the octane rating of gasoline, and the dramatic reduction which has taken place since 1970, as a result of the Clean Air Act. A return to early levels appears to be imminent as a result of rapid elimination of leaded gas.

Figure 8, above showed that atmospheric dioxins are also in the process of decline, most probably due to improvements in combustion. These improvements may be from shutting down of obsolete and inefficient combustors and installation of more efficient equipment.

**Concern about ash residues**

There is a world-wide concern about ash residues from combustion of MSW, which has resulted in extensive testing. As a result of requirements for testing residues for toxic metals, residues will have to conform to higher standards.

In some localities there has been concern about possible PCDD/PCDF content of residues from MSW combustion. In some cases they have exceeded the standard for soil contamination of 1 part per trillion.

A review of data on dioxin content in MSW and residues shows that:

- Raw municipal waste contains dioxins. Tests at Hamilton, Ontario, showed that under the relatively poor combustion conditions at the time of the tests PCDD in the MSW was roughly equal to the stack emissions. Tests at Prince Edward Island showed about 60 to 95% destruction of refuse PCDD under good combustion conditions. On the other hand, little if any PCDF was found in refuse, and emissions were greater than PCDD. [5][6]

- Dioxins in residues go down with stack emissions: hence the dioxin content of residues from well-controlled plants are extremely low. Dioxins in bottom ash residues were measured at Hamilton; the dioxins in the residue were proportional to
Dioxins attach so firmly to ash residues that they are extremely difficult to remove without destroying them. Dioxins on ash residues are essentially insoluble in water, but may be removed by certain solvents and strong acids, as could happen in a landfill.

**Health risks associated with combustion of MSW**

When evaluating the risks to public health from emissions from any source, the ground level concentrations resulting from the source is compared with both the background concentration and the health standard.

Environmental Impact Statements (EIS's) prepared for waste/energy facilities proposed near or in urban areas generally show that background levels are often quite high, compared with the health standard. On the other hand, the contribution from the MSW-burning facility is usually very small, generally less than 1-2%. The data in this figure shows that emissions could be ten to forty times as high without exceeding the health standard.

It is valuable to put the emissions of dioxins into a similar perspective: How does this rate of intake compare with background levels?

Dr. Hermann Poiger, of the Swiss Federal Institute of Technology, reported that he had deliberately swallowed dioxin to trace its course through his body. He found that a single dose of 1.14 ng/kg of body weight of TCDD raised the concentration in his fat tissue to about 3 pg/g within two weeks. Daily excretion was measured to be about 30 pg/day. On the basis of recent report that the average American's fatty tissue contains about 7.2 ppt of TCDD. Since these levels stay fairly constant, it would be reasonable to assume that we are receiving about 72 pg/day.[21]

Based on this actual measurement, and this calculation of the rate at which we continuously take in dioxins, the contribution from the nine incinerators in Los Angeles would be less than 1% of the background level.[23]

We do not actually know the health risk of PCDD/PCDF to humans. Estimates extrapolated from animal studies have been used to make estimates for human risk. The general consensus today is that 1 to 4 fg/m³ is an acceptable level of ground level concentration, equivalent to 1 to 10 additional cancer cases per million population exposed for 70 years. This level of risk is equivalent to the drinking water standard, which is greatly exceeded by drinking water in New Orleans and Miami, for instance.
The New York Times, Friday, April 18, 1986, provides this information:

Dr. Arnold Schecter, at the annual meeting of the American Chemical Society, pointed out that the average American, whose fatty tissue contains 7.2 ppm of 2,3,7,8 TCDD. "This means that the general population of this country cannot be considered a control group in assessing health effects on people known to have had unusually high exposure to dioxins." Noting that South Vietnamese have a level of 23 parts per trillion, as compared with North Vietnamese, who contained no detectable dioxins, it would be interesting to do health studies on these two populations.

In Britain, Dr. Peter King, general secretary of the British Society of Chemical Industry, asserted that the dioxin scare was mainly the product of distorted reporting and was most severe in the United States, "an essentially gullible country."

"Scientists reported today that they had found abnormalities in the immune systems and livers of Missouri residents exposed to the chemical dioxin for a long period of time, but no more illness than normal. ..There was no significant difference in the medical conditions of the two groups. But laboratory tests showed that critical cells in the immune system were depressed or impaired and that biochemical functions in the liver were also affected, although not necessarily damaged."

Dr. Rappe, a world renowned expert on dioxins, came to the conclusion, after considering the risk of living where he does, at a peak GLC from his local incinerator, that his intake from breathing this contaminated air was extremely small compared to what he takes from drinking cow's milk and fish. In fact, he should limit milk to a pint a day and Baltic salmon to once per week (his normal habits?), and stop worrying.[22]

SUMMARY AND CONCLUSIONS

Reasonably good estimates of health risk relating to combustion of MSW can be made, compared with other alternatives and risks. We now know how to reduce the emissions of dioxins from refuse combustion to extremely low levels by optimized combustion control.

Sufficiently high temperatures in the furnace, and low temperatures in the stack minimize not only heavy metals (especially mercury), but also trace organics, including dioxins and furans.
Proper design, good operation (supervised and controlled by continuous monitoring, coupled with training of operators), and surveillance of regulators and the public, can assure that combustion can be favorably compared with other alternatives of disposal.

Acid gas controls, using alkaline materials in the combustion zone or boiler outlet, are not only effective in adsorbing sulfur and chlorine acids, but also augment collection of particulate and heavy metals.

Continued testing and development will further improve the operation of waste combustion systems. New developments and plants coming on line in the next few years will represent substantial improvements.

The comparative risk to our drinking water from existing landfills should be made. At this point it appears that the landfills might be a big loser.

Source separation, recycling, and other methods of recovering wastes without landfill, must be considered to be compatible and complementary to combustion. No matter how effective recycling, there will always be a major fraction which is best disposed of by combustion.
FIGURES

1. PCDD versus PCDF measured in the stack emissions at various plants.
2. PCDD emissions versus furnace temperature measured at various plants.
3. Carbon Monoxide (CO) versus temperature, measured at Pittsfield Facility, compared with DRAV data (Sweden).
4. Carbon Monoxide versus PCDD emissions reported at various plants.
5. Temperature of combustion gases versus retention time, calculated for various MSW heating values at 100% excess air.
6. Log-probability graph of total PCDD emission factors for various types of plants, plotted on 'equal probability' basis.
7. PCDD and PCDF emissions showing the various congeners (number of chlorine atoms) from tests at various plants.
8. Total flux of PCDD and PCDF to Sikskiwit Lake and Lake Erie based on cores showing years 1920 to 1982 and 1950 to 1983, respectively. (Czuczwa and Hites)[17]
9. Congener profiles of PCDD and PCDF in air particulates from Washington, DC, St. Louis, MO, and sediments from Lakes Michigan, Erie, Ontario and Siskiwit. (Czuczwa and Hites)[17]
10. Sulfur Dioxide Removal Efficiency of various types of acid gas control systems, including dry powder and spray dryers, versus lime/acid ratio.
11. Removal Efficiency for Mercury reported for various acid gas and particulate control systems, with ESP or baghouses. (Clarke)[19]
12. Atmospheric lead source function compared to measurements of atmospheric lead concentrations in aerosol and precipitation. (Eisenreich)[20]

REFERENCES


DC, Feb. 1986 (preliminary draft).


Resource Recovery Emissions and Controls Hasselriis 18
PCDD and PCDF Emissions of Various Municipal Waste Combustor Tests

Hasselt, 4/15/86

PCDD - ng/m³

PCDF - ng/m³

PEEKSKILL
PITTSFIELD 1850 F
STAPFELD
PEI 1300 F
PEI 1450 F

CHICAGO

PITTSFIELD 1250 F

HAMILTON

HAMPTON

HAMPTON

OXY

FIG. 2
DIOXIN EMISSIONS VS. FURNACE TEMPERATURE (°F)

TOTAL DIOXINS - PCDD - MICROGRAMS/CUBIC METER

FURNACE TEMPERATURE - DEGREES F.
CO VERSUS TEMPERATURE

MRI PROJECT 8449L

CO PPM (Thousands) vs TEMPERATURE (Degrees F)

5-min averages.
Statistical Distribution of PCDD Emissions

PCDD - lb/million tons

0.1 1.0 10 100

Percent Greater Than

0.1 1 10

ZURICH

CHICAGO

STAPELFELD

MVA I AND II (HAMBURG)

MVA I AND II

HAMILTON

Hasselweg 4/80

FIG. 6
CALCULATED FURNACE GAS TEMPERATURES VERSUS TIME
FOR VARIOUS MSW HEATING VALUES

HASSELRIS 4/5/86
Figure 5. Flux of PCDD and PCDF to Siskiwi Lake (SL). Total flux (pg cm\(^{-2}\) year\(^{-1}\)) is plotted vs. average year of deposition.

Figure 6. Total flux of PCDD and PCDF to Lake Erie sediments: Lake Erie 1 (○) and Lake Erie 2 (×). Total flux (pg cm\(^{-2}\) year\(^{-1}\)) is plotted vs. average year of deposition. The linear regression line for the flux data from the two cores for the years 1950–1977 is shown (r = 0.867; a = -134.100; b = 69.3).

Figure 3. Atmospheric lead source function compared to measurements of atmospheric lead concentrations in aerosol and precipitation: (□) Argonne National Laboratory (39); (○) Argonne National Laboratory Health and Safety Laboratory (HASL) Reports (48); (●) National Air Quality and Emissions Trends (NAQE) Reports, 46 sites (49); (▼) atmospheric Pb precipitation fluxes, Marcell (rural site); (▲) atmospheric Pb precipitation fluxes, Minneapolis (urban site). Regional atmospheric Pb loading rates (y-axis) are based on data collected in 1970 by
Comparison of efficiencies - SO2 semi-dry and all-dry systems

Stoichiometric ratio - lime/acid
THE RELATIONSHIP OF TEMPERATURE AND CONTROL DEVICE ON THE REMOVAL OF MERCURY

- Scrubber
- Baghouse
- ESP or Unabated

Mercury Removal Efficiency %

Temperature °C

Quebec City
NYborg
Avesta
Nyborg
Syssav Malmö
Munich-North
Tsushima
Brunner
Vogg

Marjorie J. Clarke
"NYC Department of Sanitation"