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Review of Dioxins and Furans from Incineration
In Support of a Canada-wide Standard Review

A Report Prepared for

The Dioxins and Furans Incineration Review Group

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Acronyms, Abbreviations, and Measurement Units

The following definitions, acronyms, and measurement units are provided to clarify the discussion that follows.

Acronyms

ACR	activated char reactor
AMESA	adsorption method for sampling PCDD/F
APC	air pollution control system
ASME	American Society of Mechanical Engineers
CB	chlorobenzenes
CCME	Canadian Council of Ministers of the Environment
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CEMS	continuous emissions monitoring system(s)
CFR	Codified Federal Regulations (United States of America)
CWS	Canada Wide Standards
DIN	Deutsches Institut für Normung (German Institute for Standardization)
DMS	dioxin monitoring system
DRE	Destruction Removal Efficiency
ECT	evaporative cooling tower
EN	European Normals (Standards issued by CEN)
EPA (U.S.)	U.S. Environmental Protection Agency
ESP	electrostatic precipitator
EU	European Union
GC/MS	gas chromatography/mass spectrometry
HAP	hazardous air pollutant
HRSG	heat recovery steam generator
ITEQ basis	2,3,7,8-tetrachlorinated dibenzo-p-dioxin toxic equivalent based on the 1989 International toxic equivalency factors
LDR	land disposal restrictions (US Regulations)
LOD	level of detection
LOQ	level of quantification
LWAK	light weight aggregate kiln
MACT	maximum achievable control technology
MHF	multi hearth furnace
MOE	Ministry of the Environment (Ontario)
MRR	Material Resource Recovery - metal recovery operation in Cornwall, ON
MSW	municipal solid waste
MTEC	maximum theoretical emission concentration
NITEP	National Incinerator Testing and Evaluation Program
NESHAP	National Emission Standards for Hazardous Air Pollutants
NPRI	National Pollutant Release Inventory

OPG	Ontario Power Generation
PAC	powdered activated carbon
PAH	polycyclic aromatic hydrocarbons
PCB Total	CEPA Definition is sum of tri- to deca- isomers of polychlorinated byphenyls
PCDD/F	polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans
PIC	products of incomplete combustion
PM	particulate matter
POHC	principal organic hazardous component
RCRA	Resource Conservation and Recovery Act (US Regulations)
RDF	refuse derived fuel
RSI	Récupère Sol inc. - Bennett Soil Remediation facility in St. Ambroise, PQ
SCR	selective catalytic reactor
SVOC	semi volatile organic compound
TEF	toxicity equivalence factor
TEQ	toxic equivalent quantity
TCLP	toxic characteristics leaching procedure
TSMP	Toxic Substances Management Policy
UCL	Upper Confidence Limit (definition of upper bound of test results)
U.S. EPA	United States Environmental Protection Agency
WHO	World Health Organization
WHO_{98}-TEQ	2,3,7,8-tetrachlorinated dibenzo-p-dioxin toxic equivalent that includes co-planar PCB toxic equivalency factors

DEFINITIONS APPLIED TO CHARACTERISE INCINERATORS

Batch	incinerators that are loaded with waste before the waste is ignited and the door remains closed until the ash has cooled inside the furnace
Commercial	means those that charge a tipping fee for disposing of waste
Continuous	incinerators that are loaded periodically during operation and ash is removed during the burning phase (typically operate for periods from weeks to months)
Semi-Continuous	incinerators that are loaded periodically during operation but ash is only removed after a cool down phase (typically operate for periods of days)

Abbreviations and Measurement Units

Btu	= British Thermal Unit (measure of energy)
°C	= degrees Celsius (degrees Fahrenheit = (°C * 9/5 + 32)
dscf	= dry standard cubic feet (at 14.7 pounds per square inch, 68 °F)
dscm	= dry standard cubic meters (at 14.7 pounds per square inch, 68 °F)
g	= gram (454 grams per pound)
g/a	= grams per annum
gr	= grains (7,000 grains per pound)
MJ	= megajoules (energy input, 1 MJ = 947.82 Btu = 0.27778 kW.h)
kg	= kilogram (0.454 kilograms per pound)
kg/a	= kilograms per annum
kW	= kilowatt (measure of energy)
m^3	= cubic meter (35.3 cubic feet per cubic meter)
mg	= milligrams (10^{-3} grams)
Mg	= megagram (1.1 tons)
Mg/d	= megagrams per day
Mg/a	= megagrams per annum
ng	= nanogram (10^{-9} grams)
Nm^3	= normal cubic metre (at 0°C, 101.3 kPa)
ppmv	= parts per million by volume
Rm^3	= dry Reference cubic metre (at 25°C, 101.3 kPa and 11% O_2)

total mass basis = total mass of tetra- through octa-(dioxins/chlorinated dibenzo-p-dioxins and furans) dibenzofurans

Metric Prefixes The SI Prefixes used to form names and symbols of decimal multiples and sub-multiples of SI units are:

Prefix	Symbol	Magnitude	Factor
exa	E	1 000 000 000 000 000 000	10^{18}
peta	P	1 000 000 000 000 000	10^{15}
tera	T	1 000 000 000 000	10^{12}
giga	G	1 000 000 000	10^{9}
mega	M	1 000 000	10^{6}
kilo	k	1 000	10^{3}
milli	m	0.001	10^{-3}
micro	μ	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
pico	p	0.000 000 000 001	10^{-12}
femto	f	0.000 000 000 000 001	10^{-15}
atto	a	0.000 000 000 000 000 001	10^{-18}

EXECUTIVE SUMMARY

As part of the review stipulated in the CWS PCDD/F standard, this report examines the waste incineration sector and the progress that sector has made in reducing the release of PCDD/F to the environment. The CWS PCDD/F standard defines incineration in terms of the equipment as follows:

> *Waste incinerator*: a device, mechanism or structure constructed primarily to thermally treat (e.g., combust or pyrolyze) a waste for the purpose of reducing its volume, destroying a hazardous chemical present in the waste, or destroying pathogens present in the waste.

This implies that the standard applies to any thermal process, even though the definition lists combustion and pyrolysis as examples of thermal treatment. This in no way restricts application of the standard to any alternative method of heating and treating waste to reduce its volume or breaking down compounds within the waste. As such, the PCDD/F Waste Incineration CWS would apply to any forms of thermal treatment systems.

This report provides an overview of the furnaces that can be used for waste incineration and methods their designers use to ensure good combustion and low emissions. Air pollution control equipment is employed at larger facilities to further control the release of PCDD/F and the report summarizes the types of air pollution control systems that can be used. Monitoring the performance of systems requires that samples be collected and analysed to determine the quantity of PCDD/F being released at any time. A review of the accepted monitoring procedures and their limitations is included. How these results are reported and the regulations that the define the limits on emissions in various jurisdictions are reviewed to provide a comparison for the CWS standard. The original CWS standard was developed based upon a review of emissions from the incinerators operating in the late 1990's. Comparing estimated emissions in 2005 with those developed for the original inventory provides an important measure of progress made in reducing emissions. As the scientific community's understanding of how PCDD/F react in the environment has grown the measure of the toxicity of these compounds has changed. A review of some of the emission data from Canadian incinerators was conducted to confirm the anticipated effect of changing the toxic equivalency factors used to quantify PCDD/F emissions. During the review there were a number of findings and the author developed some conclusions from the study. These conclusions were used to develop a series of recommendations that should allow the industry to move towards the ultimate objective of the virtual elimination of PCDD/F emissions from the sector.

PCDD/F Formation

PCDD/F releases from combustion processes are generally considered to be unintentional. That is, the process is not designed to create these compounds and their presence is indicative of either their lack of destruction in the combustion process, or their formation by some mechanisms operating in the furnace.

The formation of PCDD/F as trace by-products of combustion processes has been studied

extensively because it is a highly complex phenomena involving multiple gas and solid phase reactions. Two main theories regarding the mechanism of formation of PCDD/F during combustion processes have been developed.

The *de novo* synthesis theory is considered the major mechanism. This theory suggests that PCDD/F is formed in the presence of fly ash containing chemically unrelated unburnt aromatics and metal catalysts. The reactions occur in the presence of oxygen and catalysts at temperatures in the range between 250^{O}C and 450^{O}C. For many incinerators, this temperature range is only found in the post furnace region, typically the waste heat boiler or in electrostatic precipitators (ESP). *De novo* synthesis experiments suggest that more furan than dioxin congeners are formed.

The Precursor Theory suggests simply that the various chemically-related chlorinated aromatics undergo condensation reactions on fly ash surfaces in the presence of metal catalysts. Thus, two precursor molecules are coupled to form a dioxin or furan structure. The optimal temperature range for such formation is the same as that observed for *de novo* synthesis (i.e., 250 to 450°C). Therefore, formation of PCDD/F from precursors must also occur in the post-combustion zones of thermal processes. This temperature range is often considered the "window of opportunity" for catalytic formation of PCDD/F on surfaces of fly ash particles.

The two theories are not necessarily mutually exclusive. The formation of PCDD/F in thermal processes is undoubtedly the result of a complex set of competing chemical reactions.

Regardless of which theory or theories best explains how PCDD/F are formed, certain operating conditions increase the potential for PCDD/F formation including:

1. incomplete combustion of a fuel
2. an oxidizing atmosphere
3. presence of a chlorine source
4. fly ash surfaces (carbon source)
5. fly ash with degenerated graphitic structures
6. presence of catalytic metals (especially copper, but iron, manganese and zinc are also indicated as potential catalysts for PCDD/F formation)
7. temperature/time history of at least 1 second at less than 600^{O}C (optimal temperature range lies between 250 and 450^{O}C)

Thus, good combustion, which reduces the concentration of products of incomplete combustion, both the gaseous and solid forms, must be the foundation of any measures to reduce PCDD/F emissions from incinerators. Secondly, limiting the time the gases are in the generation temperature window will further help reduce emissions.

Some suggest that controlling the amount of chlorine in the system might influence the generation of PCDD/F, however consistent analysis of the available data indicates that changing

the amount of chlorine has no discernible impact on PCDD/F emissions.

Combustion Control

Combustion control must compensate for:

- the natural variability in fuel quality; and,
- the controlling factors that govern the rate of chemical reactions.

Homogeneity of the waste stream is much better in sewage sludge and liquid hazardous waste systems than MSW, medical waste or even solid hazardous wastes. Each component of a waste stream has its inherent energy content and this must be matched with sufficient oxygen to ensure proper combustion. Incinerator operators understand the need to keep the operation at a steady level to achieve the best performance and typically mix the components as the first step. From there, combustion control systems compensate for the remaining fuel variability.

In two stage starved air and kiln systems a large quantity of fuel in the furnace will reduce the variability. In conventional mass burn MSW incinerators the rate of heat release is sensed and the supply of combustion air is adjusted to compensate for high or low heat-release rates. Alternatively, the fuel feed rate can be adjusted to compensate for the variability. Through these steps it is possible to establish an appropriate range for the concentration of oxygen in any system. Operation in this zone minimizes the release of CO and thus also minimizes trace organic releases.

Good combustion conditions leading to reduced organic emissions are those that:

- ensure complete mixing of the fuel and the air;
- maintain high temperatures in the presence of sufficient oxygen; and,
- prevent the formation of quench zones or low temperature pathways that would allow partially-reacted solids or gases to exit from the combustion chamber.

These design conditions must be combined with good operating conditions to ensure that the performance is maintained and organic constituents are reduced to the basic elements.

While much of the research emphasis has been focussed on defining the conditions conducive to minimising emissions of PCDD/F through the stack, these conditions also have implications for solid residue streams generated by combustion equipment. Obviously, ash from the grate of solid fuel combustion device will be exposed to temperatures in excess of that conducive to formation, indeed temperatures in the range where any PCDD/F will be destroyed. Rapid quenching of ash discharged from the grates should minimise the potential for any PCDD/F in that waste stream. On the other hand, residues from heat recovery systems, which operate in the critical temperature zone may be expected to have some PCDD/F present, but the amount will likely vary with the temperature regime where the ash was collected, and the time the ash

was in the gas stream at these temperatures. This suggests that the PCDD/F formation processes related to *de novo* synthesis or precursors may be inhibited if the gasses leaving the system are rapidly quenched to below the optimal temperature ranges.

Incinerator Systems and Air Pollution Control Equipment

Waste streams being incinerated in Canada include: municipal solid waste [MSW]; medical wastes; hazardous wastes; and sewage sludge. The waste streams differ in character and particularly in their energy value. Designers have developed different types of furnaces to handle the different waste streams but since there are also similarities some furnaces can be used for similar streams, provided the design takes into consideration the calorific values of the waste stream and provides sufficient air to the furnace to ensure good combustion. Thus MSW and medical waste can be burned in the same incinerator, albeit at different rates so the energy input to the furnace is maintained. The general classes of incinerators used in Canada are:

- two stage mass burn incinerators that handle up to 100 Mg/d of MSW and can handle medical waste at a feed rate approximately 50% that of MSW;
- European mass burn incinerators that generally are larger than the 2 stage systems and operate with air or fuel feed controls to minimise combustion upsets;
- liquid injection furnaces that stand alone for the disposal of hazardous waste or are used after rotary kilns handling solid hazardous wastes as a afterburner;
- multi-hearth furnaces for sewage sludge disposal which are being replaced by more effective fluidised bed systems that are capable of handling variations in the moisture content of the sludge;
- newer batch fed two stage combustion systems that can have capacities as small at 23 kg/hr and range up to 1 Mg/day; and,
- older designs such as multiple chamber incinerators used in research facilities and hospitals.

All incinerators have a zone where the waste is ignited and mixed with air to promote combustion. Most incinerators provide additional air to complete the combustion process. After the waste has been oxidized in the furnace, residues, generally referred to as bottom ash, must be removed from the furnace. The energy available in the hot gas stream generated by combustion may be recovered in a heat recovery steam generator [HRSG] or boiler thereby creating steam that can be used to produce electricity or hot water for process or space heating.

While an HRSG installed in the system will reduce the gas temperatures, if there is no heat recovery equipment, but there is an air pollution control system, a rapid quench system will be used to reduce gas temperatures to the range that is appropriate for the APC system to treat. Such quenching limits the potential for *de novo* synthesis because the gas temperature moves rapidly through the critical temperature range. Furnaces equipped with neither an HRSG or an APC system typically release high temperature gases directly to the atmosphere.

If an air pollution control system is installed to treat the gases leaving the incinerator it is generally sized for the volume of gases produced at the lower temperature. Air pollution control equipment typically involves injecting reagents to control acid gas releases, sorbents to trap mercury and PCDD/F and high efficiency particulate matter control devices to minimise the release of dust to the atmosphere. Solid residues, fly ash, deposited in HRSG units, or collected in air pollution control systems are removed for disposal, generally at hazardous waste disposal facilities. The quantity of PCDD/F present in the fly ash streams can vary depending upon the temperature history and where the fly ash is removed from the system.

Typical APC systems used in Canada include:

- wet spray humidifiers/dry scrubbers/fabric filters with or without powdered activated carbon addition to the gas stream used in large MSW and commercial medical waste incinerators as well as some hazardous waste incinerators;
- wet scrubbers used alone in sewage sludge incinerator installations, or in combination with powdered activated carbon and fabric filters in one hazardous waste facility;
- one hazardous waste incinerator employs an electrostatic precipitator rather than a fabric filter for particulate control;
- one facility has an activated char bed filter installed after a quench system and another one will be installed in 2006; and,
- one facility has installed a selective catalytic reactor that includes provisions to destroy PCDD/F reaching the catalyst downstream of a wet spray humifier/dry scrubber/PAC injection/fabric filter system.

Details of the various types of incinerators and air pollution control systems and their performance characteristics are presented in the report.

PCDD/F Sampling Methods

Measurements of PCDD/F concentrations in the exhaust gas streams of combustion sytems were required to develop the understanding of the formation mechanisms and prove Air Pollution Control system performance. Some of the early Canadian sampling studies used techniques that have now evolved to be recognized as one of the standard methods for sampling and analysis of PCDD/F in stacks. The Environment Canada procedures are very similar to those used by the US EPA. Similar developments have taken place in Europe where three different sampling systems have been developed and applied. Since the mid-1990s much of the emphasis in this field has been on improving methods to ensure that the quality of the reported results, and to meet the increasing demands posed by lower and lower emission concentrations.

The methods currently incorporated in North American and European regulations and permits

are similar. Gas being exhausted is sampled by extracting a portion of the flow stream isokinetically; filtering the extract to concentrate the species of interest; and, recovering the concentrated sample from the sampling system so the laboratory analysis can be completed using HRGC/HRMS techniques are the basic steps in all methods. Being similar, they should produce similar results if the methods are employed by trained samplers and chemists who take care with their tasks.

Even if testers provide reliable measurement results, the methods have limitations. It is difficult to quantify the mass of PCDD/F present in samples collected from systems operating as very low emission rates, unless long sampling times are employed. Converting that quantity to an emission concentration measuring the sample volume and the stack gas flow. When all the measurements are combined some uncertainty is inherent in the reported results.
Thus, due to limits in the level of PCDD/F that can be quantified and the variations in these measurements, the European standard incorporates a procedure to define the level of quantification for each PCDD/F congener and lists the uncertainty that was determined for results from a large comparative testing programs.

In Canada the approach to dealing with samples with low concentrations has been to refer directly to the laboratory reports. When the laboratory lists the results as being below the detection limit, the detection limit value is substituted into the calculation procedure when determine the TEQ value for the test. The resulting TEQ value is then compared to a value of 32 pg I-TEQ/m^3 @ 11% O_2, the value stated by Environment Canada as being the level of quantification, or the stack concentration level that Environment Canada suggests can be reliably measured. If the resulting level is less than this Environment Canada LOQ, PCDD/F are interpreted as having been virtually eliminated. When reporting to NPRI, sources with results below 32 pg I-TEQ/m^3 @ 11% O_2 can report zero emissions.

The European approach requires that the concentration of each congener be determined and these data be incorporated into the calculation of the ITEQ value of the sample. If the concentration of any congener is less than the LOQ derived from applying the equation LOQ_i = 0.5 [pg/m^3]/I-TEF_i, the ITEQ value for the emission concentration must be reported in two ways using the quantification level to substitute for values below that level and using zero to substitute for the concentration of the particular congener.

The implications of this approach are that, laboratories might be able to report lower values and some do. Conversely, the LOQ calculated from the data can also be above the permissible LOQ. If this is the case, and the overall ITEQ exceeds the applicable standard, the laboratory might be required to do more clean-up of the sample, or analyse the sample on another column to confirm the results. If the problem still exists, the other alternative is to extend the sampling time thereby increasing the volume and the congener quantity.

The variability in sampling results was examined in two studies. In Europe the results reflect those from comparison sampling with different methods and using different testing teams. The

results suggest that the external variability, and hence the uncertainty of the measurements of PCDD/F, was ± 50 pg I-TEQ/m^3 at a mean measured concentration of 35 pg I-TEQ/m^3. The results suggest that no conclusions on differences in emissions could be made if the results are less than 85 pg I-TEQ/m^3 because the data is within the range of the uncertainty. North American data was examined in a study conducted for the American Society of Mechanical Engineers. This study compared the results of dual train testing at various venues. Based upon the data available and an upper 95% confidence interval the study found that, at 32 pg ITEQ/m^3 the uncertainty is ±18.6 pg ITEQ/m^3. The uncertainty rises to ±49.5 pg ITEQ/m^3 at an average concentration of 80 pg ITEQ/m^3. The author of the study recommends that more data at the extremes of the range is required to improve the model used. The North American study suggest that at the current CWS limit for incinerators, 80 pg ITEQ/Rm^3, the uncertainty in the measured value would extend from less than the LOQ to approximately 130 pg ITEQ/Rm^3.

While there is considerable discussion on the application of the standard PCDD/F sampling methods, costs and timeliness of data availability have prompted the development of alternative approaches for determining PCDD/F concentrations. There are two similar long term sampling methods employed in Europe. These essentially collect samples over 30 day periods and the samples are analysed by the same methods used for stack sampling trains. These approaches offer a longer sampling period average which is comforting to people who are concerned that not all stack sampling is conducted under typical operating conditions. They are also less expensive due to the reduction in man power needed to collect the sample. Having not been incorporated into legislation at present, these methods have seen only limited application.

Another method that promises faster cheaper results is a bioassay approach. Bioassay procedures use a dioxin specific antibody for dioxins and dioxin-similar compounds to detect and quantify a sample directly as an I-TEQ sum value. Bioassays are extremely sensitive (0.001 pg - range), and can be used for samples with a minor PCDD/F content, typically feed and food samples. Indeed, in Japan, bioassay was adopted as one of measurement method in the Law Concerning Special Measures against Dioxins (Dioxins Law). One presumes that should the bioassay suggest a sample has failed to meet the limits, there would be a need to verify this conclusion by completing the detailed testing.

PCDD/F Regulatory Standards

There are 210 isomers of PCDD/F and 209 isomers of PCB that could be identified in the analytical procedures. Tracking these substances for the purposes of: setting limits; identifying control techniques; or, even determining the mechanisms by which they are formed, would be extremely onerous. When scientists identified that particular isomers were responsible for the effects noted during exposure to PCDD/F they reasoned that, if the degree of effect caused by different isomers could be measured, it could be possible to express the amount of PCDD/F present based upon the anticipated effect of the mixture. Thus, the concept of assessing PCDD/F emissions on the basis of toxicity was adopted. This approach has become known as

the TEQ or toxic equivalence method, based upon applying toxic equivalency factors [TEFs] that relate the toxicity of each isomer to that of the most toxic dioxin congener, namely 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). Two schemes have been used over the past 15 - 20 years. The first scheme was based upon the 1989 International Toxic Equivalency Factors [I-TEQ]. The second scheme evolved from increased knowledge about the effects of these chemicals and incorporates values for the co-planar PCB compounds. A review of the affect of the application of the two different approaches suggests that the latest scheme, the WHO_{98}-TEF approach, would add about 15% to the total PCDD/F emissions. To date no jurisdiction has adopted this approach to expressing emission standards.

In reviewing emission regulations from various jurisdictions it is evident that not all concentrations are expressed in the same manner. Different jurisdictions have attempted to standardize such readings by defining how the results should be expressed. While temperature and pressure affect gas volumes, and are specified in most standards, concentration can also be influenced by the amount of air present in the gas stream. If more air is added, the concentration is reduced, but the mass flow rate of the pollutant of interest does not change.

The regulatory standards for different jurisdictions are shown in the table on the next page. The Emission Limit units are expressed as [pg I-TEQ/Rm^3 @ 11% O_2], where the reference conditions are 25^{O}C and 101.3 kPa.

Summary of International Emission Regulations for PCDD/F from Incinerators

COUNTRY	Incinerator Type	Emission Limit	Comments
European Union	All	92	diluent corrections note applied when < 11% O_2
Australian & New Zealand	All	92	
Japan (based upon size and age)	>4 Mg/hr	92	existing facilities have limit of 920
	2 - 4 Mg/hr	920	existing facilities have limit of 4600
	<2 Mg/hr	4,600	existing facilities have limit of 9200
United States	MSW		no I-TEQ standards rather use total PCDD/F [ng] existing >225 Mg/d c/w ESP = 25 w/o ESP = 21 new all sizes = 9 ng total/Rm^3 @ 11%O_2 small units <225 Mg/d with Class I total site >225 existing Class I c/w ESP = 50 w/o ESP = 25 existing Class II = 88 ng total/Rm^3 @ 11%O_2
	Medical (existing)	1,610 10,500	Existing urban total = 88 ng total/Rm^3 @ 11%O_2 Existing rural total = 560 ng total/Rm^3 @ 11%O_2
	Medical (new)	182 1,610	<90 kg/hr continuous or <725 kg/day batch (87.5 ng total/Rm^3 @ 11%O_2) >90 kg/hr continuous or >725 kg/day batch (17.5 ng total/Rm^3 @ 11%O_2)
	HazWaste	142 78	without dry APCD system or waste heat boiler with dry APCD or waste heat boiler
	Commercial & Industrial Waste	287	>32 Mg/day capacity
	Other Solid Waste		<32 Mg/day = 23 ng total/Rm^3 @ 11%O_2
Canada (per CWS 2001)	Municipal	80	existing by 2006, all new construction after 2001
	Medical	80	existing by 2006, all new construction after 2001
	Hazardous	80	existing by 2006, all new construction after 2001
	Sewage Sludge	80	all new construction after 2001, existing facilities limited to 100 pg ITEQ/Rm^3 @ 11%O_2

The Canadian Incinerator PCDD/F Inventory

As part of the original Canada Wide Standards [CWS] PCDD/F committee's work an inventory of operating facilities was assembled in 2000. The incinerators operating at that time, and the estimated emissions from these facilities are summarized in the table below.

Based upon the total number of incinerators in the list, 54% were used for medical waste disposal. The medical waste incinerators were estimated to account for 72% of the annual PCDD/F emissions. The other large category were the facilities on federal lands which made up a third of all the incinerators listed, however these were estimated to account of only 20% of the annual emissions. Only a few of the medical waste incinerators had been tested at the time the inventory was prepared and no data was available for the federal facilities. Thus, emissions had to be estimated based upon both the estimated tonnage processed by these incinerators and emission factors from the literature. The emission factor selected for these sources was 4.67 mg I-TEQ/Mg waste burned.

Table 1 Summary of Incinerators used in 2000 Evaluation of PCDD/F Emissions

Incinerator Classification	Number of Incinerators by Province													Totals
	AB	BC	MB	NB	NF	NT	NS	NU	ON	PE	QC	SK	YK	
Municipal	1	1			2		1		2	1	3			11
Medical			37	3		6			46	1		7	1	101
Hazardous	1								4		2			7
Sewage Sludge									5		2			7
Federal Entities	11	7	6	2	6	4	5		16		2	3		62
Remote														
TOTALS	13	8	43	5	8	10	6	0	73	2	9	10	1	188

Incinerator Classification	Estimated PCDD/F Emissions to Air [mg I-TEQ/yr] by Province													Totals
	AB	BC	MB	NB	NF	NT	NS	NU	ON	PE	QC	SK	YK	
Municipal	1.4	6.6			117		13		2034	85	36			2293
Medical			9269	2.3		1501			9165	133		603	389	21,062
Hazardous	141								2.5		35			178.5
Sewage Sludge									82		29			111
Federal Entities	791	524	311	54	653	278	235		2709		124	87		5766
Remote														
TOTALS	933	531	9580	56	770	1779	248	0	13,993	218	224	690	389	29,411

To update the PCDD/F emission inventory for incineration facilities for this study, it was necessary to establish which facilities were operating, how much waste they burn annually, select an appropriate emission factor for each facility, and provide an estimate of the total emissions to compare to the 2000 numbers. The 2005 estimates are shown in the table below.

Table 2 Summary of Incinerators and PCDD/F Emissions 2005

Incinerator Classification	Number Identified	Waste Quantity [Mg/year]	Releases of PCDD/F [mg I-TEQ/year]		
			Air	Residues	Total
Large Municipal	7	762,793	60	4,139	4,198
Medical	42	8,082	3,142	81	3,222
Hazardous	9	204,418	257	610	867
Sewage Sludge	6	172,525	46	1,501	1,547
Federal Entities	30	1,087	159	9	168
Remote and Federal Lands	22	3,320	34	14	47
Totals	116	1,152,225	3,697	6,353	10,051

In 2000, the only emissions considered were those to the atmosphere. Added to the inventory for 2005 is a estimate of the PCDD/F released in residues. The number of operating incinerators in 2005, 116, is significantly fewer than those listed in the 2000 inventory, 188. The actual number of incinerators listed in the report is 119. The latter number includes three hazardous waste incinerators which either did not operate as a separate system in 2005 or for which no definitive data could be gathered. The Belledune facility was not operating in 2005, but is commissioned and can operate. The car bottom furnace at MRR can only be operated in conjunction with the other furnace on site and emissions were assumed to be combined. Lastly, no throughput data is available on the Steacy facility. The 2006 review identified incinerators that have been added to the inventory since 2000 or were missed from that inventory. These include three hazardous waste incinerators that were not included in 2000 and 22 incinerators at new resource development sites.

The closure of older facilities, combined with adjustments in the estimating procedures, produces a revised estimate for annual PCDD/F emissions to the air that is just 16% of the 2000 number, less than 4 gm I-TEQ per year. The biggest reductions occurred in the medical waste category where the 2005 estimate is 15% of the earlier number. Given the PCDD/F emission factor used for earlier estimates of the sewage sludge incinerator emissions, the closure of the Toronto facility reduced air emissions for this category by over 50%. Similar reductions are evident in the large MSW incinerator category. A significant number of incinerators operated by federal entities have been closed leaving just 30 incinerators in this category and their emissions are estimated to have been reduced to less than 3% of the previous number. Hazardous waste incinerators operating in the country have increased from 7 to 12 in the listing, although most of the additional units are not new, just ones that were overlooked in the previous inventory. Emissions to the atmosphere for this category have risen by over 40% to an estimated 0.26 g/year.

The addition of an estimate for the PCDD/F in residue streams adds approximately 6.4 g/year to the total PCDD/F releases from incinerators in Canada. This number does not include the contribution of residues streams from the hazardous waste sector because disposal volumes for these units were not available, not was there any information on the amount of residue they produced. All the residue emissions are estimated on the basis of default factors and would benefit from confirmation by site specific testing.

The total emissions from incinerators in 2005, including the portion assigned to the residue streams, is estimated to be approximately one third of that identified for the air emissions only in the 2000 inventory.

Findings and Conclusions

During the course of the study, 22 incinerators were identified as having been installed at remote mining and exploration camps to address the need for safe waste disposal in areas where landfilling is not a practical waste management option. These units, some servicing relatively large camps, dispose of considerable amounts of waste on a daily basis. Another group of new incinerators installations were identified at various industrial and commercial interests in Alberta, but it was not ascertained whether this trend has occurred in other provinces. Most of these new units are batch type incinerators designed with a primary and secondary chamber the latter being equipped with a temperature controlled secondary burner. None are equipped with HRSGs and few have been installed with APC equipment. Regardless of the lack of APC equipment on these units, limited test data suggests that their emissions could meet the CWS standard. Good combustion control in these units coupled with an afterburner that ensures that minimal quantities of products of incomplete combustion are released, and stack temperatures well in excess of the *de novo* synthesis window explain this performance.

Commercial waste incinerators, those burning MSW and medical waste, have been upgraded to meet the CWS. Most of this occurred shortly after the Standard was adopted, and consistent monitoring data shows most of these facilities to be recording emission concentrations that are below the 32 pg I-TEQ/Rm^3 @ 11% O_2 level of quantification standard defined by Environment Canada as satisfactorily proving virtual elimination for that source. Large commercial hazardous waste incinerators did not meet the CWS standard as early as the MSW incinerators. Three of the 6 major hazardous waste incinerators listed in a September 2004 report had test data below the CWS target. This review has shown that there is uncertainty in the reported PCDD/F values but even assuming the worst case, the commercial MSW and medical waste incinerators are still below the CWS standard. If the reported data were assumed to be subject to a positive bias, the hazardous waste incinerator performance might be satisfactory to meet the CWS.

The sampling and analysis methods used in Canada are comparable to those used in Europe. The latter methods were recently updated by the European Normalisation Commission and can be assumed to reflect the best available techniques for ensuring representative emission

concentrations are reported. The European sampling methods provide an alternative way of determining the level of quantification in a sample based upon reviewing the congener data provided by the analytical laboratory. With this approach the contribution of specific congeners is included or omitted depending upon the quantity determined in the analysis and the calculation of the I-TEQ values is determined on two different distributions. This clearly shows the potential impact of using detection limit/quantification limit values in the equivalency calculation and overcomes some of the inconsistencies with the way the results are presented.

Similar regulatory standards are applied to incinerators in most jurisdictions. These standards are applied regardless of the waste the incinerator is burning, or the size of the incinerator, with the exception of some low level cut-offs. Further exceptions to this finding were found in the United States of America where different types of incinerators are subject to different standard, and in Japan where a sliding scale of allowable emissions based upon size is applied. In the United States, the standards were set on the basis of the MACT protocol where the best 12% of the existing population were used to set the standard. In Japan, there appears to be a recognition of the cost effectiveness of adding more sophisticated controls to larger facilities.

Canada's CWS PCDD/F standards are the most stringent in any national legislation.

It does not appear that any country has moved towards adoption of the WHO_{98} TEF factors in their national legislation; however, given the uncertainty in PCDD/F measurements, and the limited impact that the revised TEFs would have on the total WHO_{98}-TEQ value for most operating facilities, its implementation should have little repercussion on operating facilities.

Large facilities in Canada are required to routinely monitor the stack emissions of PCDD/F according to the CWS. Such monitoring appears to be required annually, a practice that is in line with the requirements of the US EPA, but less frequent than the twice yearly testing required in the European Union. Provinces have the option to allow testing frequency to be changed after a considerable period of reported concentrations below the 32 pg I-TEQ/Rm^3 LOQ level defined by Environment Canada. The CWS requires that this value be determined using detection level values for congeners that are not quantified during the analytical procedure. The CWS would appear to imply that small facilities are those burning less than 26 Mg per year. These units are required to "make determined efforts" to achieve the CWS targets, and, if possible, they are to prove that they indeed to meet these standards by a single round of testing.

This study has identified that a major limitation in the data available from many of the "non-commercial" facilities is the lack of consistency in defining how much waste is charged to the furnace. This leads many facilities to fall into a situation where they try to rationalize their status as a small facility on the basis of that the facilities are used infrequently, even though the incinerator's rated capacity would suggest that the facility could burn considerably more than 26 Mg/yr or 500 kg/week or 70 kg/day.

Typically, small batch incinerators, designated by their hourly burn capacity, will accept

between 70 and 210 kg of waste per batch, operate for 2 -3 hours on each batch, and can be cycled anywhere from 3 to 6 times per day. This suggests that these systems could process 26 Mg/yr if the smallest unit was run once daily throughout the year but the same unit could process up to 156 Mg/yr if run at the maximum frequency. Considering the smallest unit is rated at 50 lb or 22 kg/hr burn rate, it is clear that many of these incinerators have the potential to exceed the "small" incinerator designation in the CWS.

If this rationale is accepted, most incinerators in the country thus have the capacity to exceed the "small" incinerator designation. That means that the CWS suggests that they must all be tested annually. Given the capacity of the testing industry, the remote locations of many of these facilities, and the cost of completing such testing, it is unlikely that such testing will be completed. Thus, there is a need to reconsider the requirements under CWS with respect to the size of the incinerators.

Recommendations

The implementation of the Canada-wide Standards for PCDD/F from incinerators has been effective in reducing emissions from large facilities, and has forced the closure of many smaller facilities that could not be viably upgraded to meet the standards. Furthermore, this study has shown that the CWS PCDD/F emission standard sets the world's most stringent emission target therefore:

It is recommended that no further adjustment to the CWS PCDD/F numerical emission standards is necessary.

To clearly enunciate the requirements defined by the standard, given the definition of waste incineration:

> It is recommended that any system that thermally treats wastes for the purpose of disposal be subject to the Canada-wide Standards for PCDD/F.

While new thermal destruction technologies are being developed and employed in various countries, their application in Canada will require that they meet the CWS for PCDD/F. To avoid any debates about the applicability of new technologies to meet these standards:

> It is recommended that any new thermal destruction technology only be approved if the proponent can demonstrate that the system will meet the emission standard, either through the application of a suitable air pollution control system, or by submitting validated test data from a full scale facility operating in another jurisdiction. Full scale facilities are typically deemed to be in commercial operation, that is they are not large scale pilot facilities, or even proof of concept demonstration units.

This study has identified a group of existing and new incinerators for which the monitoring requirements of the existing CWS standard are not viable. As such there are a number of steps that could be taken to address these systems.

There is evidence that most small incinerator operators do not routinely record waste loads to their furnaces and thus the total waste processed in a year is poorly defined. Since some steps should be taken to estimate the annual emissions from such facilities:

> It is recommended that waste throughput used for annual emission calculations for any small batch incinerator should be based upon the design rated capacity of the specific incinerator.
>
> Furthermore, it is recommended that the number of batches assumed to be charged to the unit be based upon 24 divided by twice the manufacturer's cycle time for the unit in hours.

In any of the above recommendations the document identified that when defining capacity for any installation is should be in the basis of all incinerators installed on a site:

> It is recommended that, for the purposes of defining the steps that an operator must take to ensure that the facility meets all the requirements of the CWS for PCDD/F, the total installed incineration capacity on a given property be used.

This will result in new installations comprised of numerous small incinerators not being able to avoid the provisions of the CWS by claiming the units were below the 26 Mg/year threshold.

Large incinerators, who provide a service based upon a tipping fee, should be using their annual test data and the annual waste throughput to calculate annual PCDD/F emissions. However, there is currently limited information available from most facilities with respect to PCDD/F in solid residues that are transferred for disposal so:

> It is recommended that PCDD/F in solid residues should be included in the annual emission estimates from all incinerators. Procedures and suitable default factors should be developed to aid in these submissions.

While large facilities are routinely tested in most jurisdictions, the same is not the case for smaller incinerators. Indeed, even though the determined efforts clause of the CWS suggests that a one time proof of effectiveness should be completed for the smaller facilities, this has not been accomplished. Such testing would impose a large financial burden on small facilities. However, the limited test data presented for new equipment shows that modern two stage systems are capable of meeting the CWS. To encourage the use of good incineration practices that will assist the operator in meeting the standards:

It is recommended that jurisdictions explore opportunities to employ up to date incineration equipment to replace existing systems that would otherwise need to be upgraded with complex air pollution control systems to meet the CWS.

Furthermore, it is recommended that jurisdictions allow such equipment to be operated without the annual testing requirements provided the operator takes appropriate measures to ensure good operation and provides adequate records of such operation.

Coupled with these recommendations are a series of implementation recommendations.

Currently available data suggests that new incinerators are capable to meeting the CWS standards when operated according to the manufacturer's instructions.

It is recommended that any manufacturer selling a batch incinerator in Canada obtain third party certification that the unit meets the CWS for PCDD/F when burning the type of waste intended for a specific installation.

To facilitate such certification

It is recommended that a multi-stakeholder committee consisting of regulators, manufacturers, and testing companies be convened to commence the development of a certification procedure for batch incineration equipment.

Such systems should be equipped with certain monitoring equipment to ensure proper operation is maintained. As a way of implementing such measures:

It is recommended that equipment that achieves certification can only be sold with a monitoring package capable of recording pertinent operating parameters that ensure the system is being used in the manner it was intended to be used.

Furthermore, it is recommended that all installations using a certified incinerator shall install weigh scales to record the charge weight of each load charged to the incinerator.

The monitoring package should be connected to a computer which will continuously log data from temperature probes, differential pressure meters and auxiliary fuel flow. The data from this system will be made available to environmental inspectors who will be able to check the performance of the system. Thus:

It is recommended that the computer monitoring equipment be integrated with all the operating controls of the facility in a manner that would facilitate remote access to the data to enable the manufacturer to assist the operator with trouble shooting the operation of the unit.

Furthermore, it is recommended that arrangements be made so the appropriate regulatory or jurisdictional authority can access the data remotely for the purposes of monitoring the operation.

The operators of such equipment must understand their roles in ensuring appropriate performance and thus it is recommended that:

Operators be trained, either through an appropriate site specific training programs or through a certification program provided by a qualified body, on the operation of the unit.

Operators be instructed to distinguish between broad categories of waste, say packaging versus food waste, and be given clear instructions on how much of each component it is suitable to charge the furnace with on each load.

The provisions for equipment certification that avoid the need for annual testing, and the suggestion that certain systems do not need APC systems to meet the CWS only applies to systems that vent directly to the atmosphere at temperatures in excess of $600^{O}C$. Systems equipped with heat recovery boilers have the potential to have higher emissions due to the gases spending time in the *de novo* synthesis temperature window.

It is recommended that any owner contemplating the installation of a boiler on a waste incinerator be required to install an APC system to remove PCDD/F from the exhaust gas stream.

Newer, simpler systems have become available and can be used to limit emissions while not unduly increasing the complexity of the system.

Existing incinerators should be required to prove that they are meeting the CWS for PCDD/F. To that end several recommendations address the small system still operating in the country. Many of these incinerators have produced little data to enable their emissions to be estimated. Indeed, annual waste throughput data was not available for most of these systems. Therefore:

It is recommended that all facilities install scales and start recording the amount of waste charged to their incinerator along with the date and time of the start and completion of each operating cycle.

Electronic records should be collected to facilitate analysis of annual throughput.

Since most of these systems are small, batch incinerators, for which the cost of annual testing may be prohibitive, if it is deemed appropriate to allow new batch installations without PCDD/F testing requirements, existing small batch incinerators should meet similar requirements. Thus:

It is recommended that these facilities be required to install temperature, pressure and auxiliary fuel flow monitoring equipment to confirm the incinerator is operated appropriately.

Furthermore, it is recommended that all records, monitoring data and reports required shall be maintained at the site for a minimum period of at least two (2) years from the date of their creation in a hard copy format and as an electronic record and shall be made available for inspection by regulatory staff.

While the PCDD/F inventory was updated for this study, keeping it up to date requires some information from the operating facilities. To improve the inventory:

It is recommended that all facilities be required to file, with the appropriate regulatory authority, their annual waste throughput data, by the end of March in the following year starting in March 2008. This filing should include details on the quantity and disposition of residues discharged from the facility.

As noted earlier, a recommendation was included to encourage the development of more data on residue quality and volumes so the inventory can be updated to include the contribution of the residues. Lastly, when the throughput and residue data become available:

It is recommended that the PCDD/F inventory developed as part of this study be updated in 2008 by the incorporation of waste throughput and residue generation data along with the results of the residue testing programs.

Based upon the results of this update:

It is recommended that suitable default factors for air emissions and PCDD/F in residues be developed to aid in preparing the annual emission estimates from all incinerators.

1.0 INTRODUCTION

Under the *Canadian Environmental Protection Act*[1], the federal *Toxic Substances Management Policy (TSMP)* and the CCME *Policy for the Management of Toxic Substances*, dioxins and furans [PCDD/F] were designated as Tract 1 substances and scheduled for virtual elimination from the Canadian environment. To achieve this goal the incidental release of PCDD/F in emissions from various combustion systems was targetted for action. During the development of the Canada Wide Standard for PCDD/F, that culminated in the adoption by the Ministers in 2001, a number of source categories were considered for specific recommendations. Among the sources was incineration for which specific air emission standards were adopted.

Under the adopted CWS standard, all new or expanded incineration facilities were required to meet a numeric target and confirm that this had been achieved through one time testing following start-up. Existing large incineration facilities were required to meet numeric standards by 2006, and to prove they met the standard by undertaking an annual testing program. Existing small incinerators, defined as those incinerating less than <26 tonnes per year, were to undertake determined efforts to reduce PCDD/F emissions through the application of technically and economically feasible in-plant changes or additions to the emission control systems that would produce on-going reductions in emissions. For the small facilities subject to the "determined efforts" definition contained in the Standard, it is suggested that the effectiveness of these efforts should be evaluated through one time testing following implementation of the measures.

The Ministers included a requirement that progress towards meeting the CWS objectives be reviewed after 5 years. This report forms part of the materials being prepared for that review.

1.1 Scope of Report

When the Request for Proposals for this review was issued it called for a number of aspects of incineration to be addressed:

- updating the national inventory of incinerator sources and their emissions;
- reviewing methods employed by operators to meet the requirements of CWS;
- assessing the implications of improved air emission control strategies on residue streams;
- comparing emission standards currently applied in Canada to those in other jurisdictions, including assessing the application of alternative ways of expressing emission criteria; and,
- considering the implications of the implementation of alternative thermal processes for waste destruction, including the potential effect of these systems on the release of PCDD/F to the environment.

[1] CEPA, 1999. Canadian Environmental Protection Act, 1999. 1999, c. 33 [Assented to September 14, 1999] Available at http://laws.justice.gc.ca/en/C-15.31/

A preliminary review of the progress made on the Canada Wide Standard for PCDD/F was conducted for CCME in 2005[2]. That report made a number of recommendations that were incorporated into the scope of this study. The study team noted that they had not been able to correlate the 2000 PCDD/F inventory estimates with data available in the 2004 NPRI listings. They suggested that there was a need to make the link between the two lists more transparent and at the same time evaluate the quality of the inventory data. Furthermore, the study team suggested that their examination of the literature indicated that emissions were not reported in a consistent manner so it was difficult to compare literature data to available emission information.

To provide the background for the emission estimates derived in this report, incinerator technologies and air pollution control equipment capabilities are reviewed. As an extension of the technology descriptions, typical test data from various facilities are reviewed and discussed with respect to the current understanding of the formation of PCDD/F in combustion processes. Such data can be interpolated to provide better estimates of emissions from incinerators installed in the last five years. Moreover, to improve the transparency of the emission estimates derived in the report, a discussion of all aspects of emission inventory development is provided and the inventory is based upon recommendations for calculating the appropriate factors.

1.2 Nomenclature

As pointed out in the 2005 review, part of the problem many people have when reviewing data on PCDD/F emissions is that the data are not expressed in a conventional concentration manner. This is because the term PCDD/F refers to many organic species.

The polychlorinated dibenzo-p-dioxins [PCDD], the polychlorinated dibenzofurans [PCDF] and the polychlorinated biphenyls [PCB], the three organic species of particular interest in this report, are similar in nature. Their general molecular structure consists of two rings of six carbon atoms (benzene rings, as shown in Figure 1-1) bound by oxygen atom(s) (shown as O in the figure) with chlorine or hydrogen atoms attached in the numbered positions. There are 75 different configurations for the chlorine atoms associated with PCDDs, each of which is known as an isomer or congener. They are found in 8 groups, defined as homologues or congener groups in the US EPA[3]. Homologues are divided based upon the number of chlorine atoms present on the rings (1, 2, 3, 4, 5, 6, 7 or 8). Similarly, there are 135 PCDF congeners also divided into 8 homologues.

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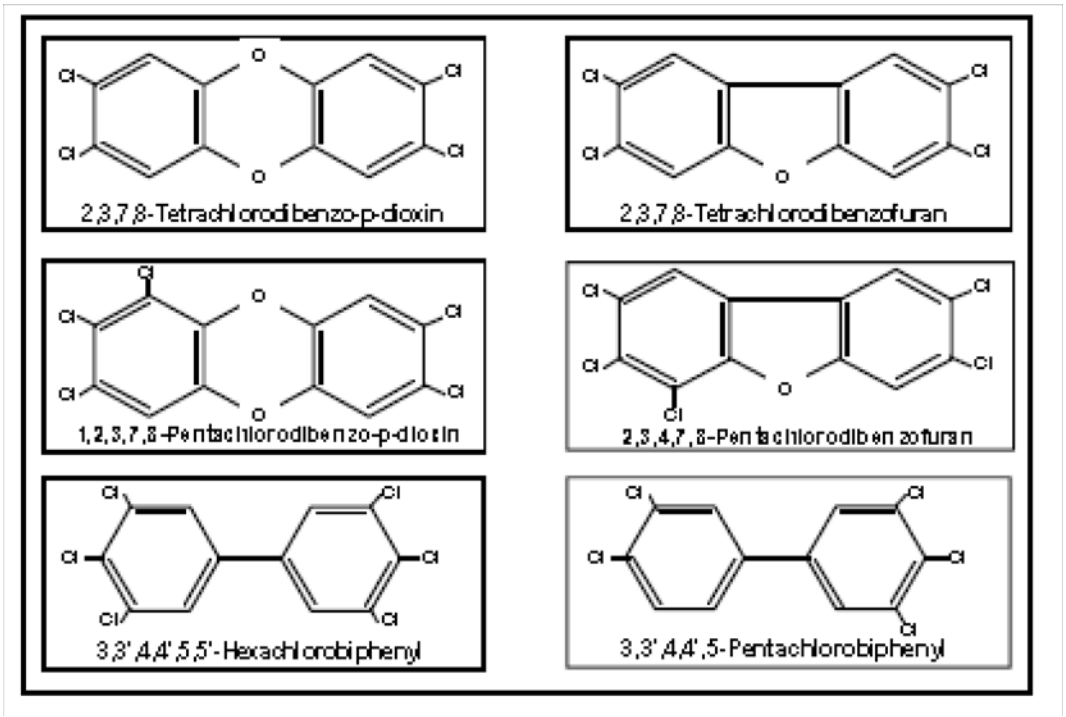
[2] Jacques Whitford, 2005. Dioxins and Furans Canada-Wide Standards – Emission Inventory Update and Review of Technical Pollution Prevention Options. A report to the Canadian Council of Ministers of the Environment.

[3] US EPA, 2005. The Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States: The Year 2000 Update (External Review Draft, March 2005; EPA/600/p-03/002A) http://www.epa.gov/ncea/pdfs/dioxin/2k-update/

Figure 1.1 Schematic Diagrams of PCDD, PCDF and PCBs



Polychlorinated biphenyls [PCBs] are more complicated than PCDD/Fs. There are 209 PCB congeners, of which only 13 were thought to be similar to dioxins: those with four or more lateral chlorine atoms with one or no substitution in the ortho position[4]. These compounds are sometimes referred to as coplanar, meaning that the two benzene rings are on the same plane giving the molecule a flat structure.

For all these chemicals, the physical/chemical properties of each isomer varies according to the degree and position of chlorine substitution.

As can be appreciated trying to document, let alone track and set limits for 210 PCDD/F isomers and 13 specific PCB congeners would be exceedingly difficult. Indeed, during the NITEP PEI studies conducted for Environment Canada, the results for the PCDD/Fs were merely reported as the homologue values, with the sum of the homologues being the data that was published for PCDD/F emissions. PCBs were reported as the sum of all PCB homologues measured during that testing. It was not until after that study, conducted in 1984, that the concept of assessing PCDD/F emissions on the basis of toxicity was adopted[5]. This approach has become known as the TEQ or toxic equivalence method, based upon applying toxic equivalency factors [TEFs] that relate the toxicity of each isomer to that of the most toxic dioxin congener, namely 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). This concept was initially applied for PCDD/F congeners, and only more recently has it been extended to include PCBs. The most common TEF values used throughout the 1990s were the International factors (I-TEF)[6]. The sum of the PCDD/F emissions expressed in this manner are designated in the literature as I-TEQ values. For the most part, all concentrations referred to in this report are expressed in this manner, as designated by the inclusion of I-TEQ in the definition of mass, ie. pg I-TEQ/g.

Other conventions related to describing emissions, namely the inclusion of diluent factors and different temperatures standards, or the use alternative toxic equivalency schemes are introduced in the appropriate sections of this report.

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[4] Ahlborg, VG; Becking, GC; Birnbaum, LS; et al. (1994) Toxic equivalency factors for dioxin-like PCBs. Chemosphere 28(6):1049-1067.

[5] US EPA, (1989a) Interim procedures for estimating risks associated with exposures to mixtures of chlorinated dibenzo-p-dioxins and -dibenzofurans (CDDs and CDFs) and 1989 update. Washington, DC: Risk Assessment Forum. EPA/625/3-89/016.

[6] Kutz, FW, Barnes, DG, Bottimore, DP, Greim, H, Bretthauser, EW. 1990. The international toxicity equivalency factor (I-TEF) method of risk assessment for complex mixtures of dioxins and related compounds. Chemosphere, 20, 751–757.

1.3 Report Structure

This report is organized into the following chapters:

Chapter 2 – PCDD/F Formation provides a brief outline of the current understanding of the formation of PCDD/F as a means of explaining why the main way of controlling their release is generally to apply good combustion practices.

Chapter 3 – Incineration Processes summarizes the types of incinerator systems used in Canada and how each attempts to address the requirement for providing good combustion control.

Chapter 4 – Air Emission Control Strategies provides a discussion of air pollution control (APC) systems with an emphasis on the methods used to control the release of PCDD/F present in the gases leaving the combustion portion of the facility.

Chapter 5 – PCDD/F Sampling Methods reviews the sampling methods used by different jurisdictions to determine the amount of PCDD/F being emitted in the exhaust gas stream.

Chapter 6 – Reporting Measurement Results discusses how different jurisdictions express PCDD/F measurement results and identifies conversion procedures to allow comparison of results.

Chapter 7 – PCDD/F Emission Regulations provides a summary of the PCDD/F emissions limits that are in place in Australia, European Union, Japan, New Zealand, and the United States.

Chapter 8 – Emission Data provides a summary of the available emission data for incinerators operating in Canada in four main categories (large MSW incinerators, medical waste incinerators, hazardous waste incinerators, and sewage sludge categories) and also provides limited data on small batch incinerators.

Chapter 9 – Alternative Equivalency Factors provides a discussion of alternatives to the I-TEQ equivalency factors and examines the effect of using an alternative equivalency factor on Canadian incinerator emission measurement results.

Chapter 10 – Findings and Conclusions provides a summary of the main findings and conclusions of this report.

Chapter 11 – Recommendations provides recommendations based on the findings and conclusions of this report.

2.0 PCDD/F FORMATION

PCDD/F releases from combustion processes is generally considered to be unintentional. That is, the process is not designed to create these compounds and their presence is indicative of either their lack of destruction in the combustion process, or their formation by some mechanisms operating in the furnace. This chapter provides a brief outline of the current understanding of their formation as a means of explaining why the main way of controlling their release is generally to apply good combustion practices. A detailed discussion of PCDD/F formation is included in a CCME commissioned report on waste management pollution prevention alternatives[7]. That document provides the following summary of the issues surrounding formation and control:

> The formation of PCDD/F as trace by-products of combustion processes has been studied extensively since the mid-1980's with much of the research being conducted on municipal solid waste incinerators. This study has determined that formation is a highly complex phenomena involving multiple gas and solid phase reactions between minute quantities of reactants. Two main theories regarding the mechanism of formation of PCDD/F during combustion processes have been developed. These theories should not be regarded as being mutually exclusive from one another since they may act in combination during the combustion of any carbonaceous material.
>
> The *de novo* synthesis theory is considered the major mechanism by which PCDD/F are formed in thermal industrial processes. This theory suggests that PCDD/F is formed in the presence of fly ash containing chemically unrelated unburnt aromatics and metal catalysts. Gas phase chlorine is believed to form metal chlorides on the surface of the fly ash. The metal chlorides subsequently react with the carbon structures on the fly ash. This is followed by metal-catalyzed oxidation/gasification of the fly ash surface, which releases various chlorinated organic compounds including PCDD/F, chlorophenols, chlorobenzenes, and aliphatics. These reactions must occur in the presence of oxygen and catalysts formed from transition or heavy metals. Moreover, researchers found that temperatures in the range between 250^{O}C and 450^{O}C were most likely to result in higher PCDD/F generation. For many incinerators, this temperature range is only found in the post furnace region, typically the waste heat boiler or in electrostatic precipitators (ESP). *De novo* synthesis experiments suggest that more furan than dioxin congeners are formed (ie., PCDF:PCDD >1.0) along with other chlorinated organic compounds (eg., PCBs, chlorobenzenes, chlorophenols, chlorinated polycyclic aromatics).
>
> Researchers have concluded that the basic set of conditions required for *de novo* synthesis of PCDD/F are a solid matrix containing carbon structures, organic or inorganic chlorine, copper or iron ions, an oxidizing atmosphere, and an optimal temperature range of 250 to

[7] Chandler, A.J., 2002. Technical Pollution Prevention Options for Incinerators A Report Prepared for The Canadian Council of Ministers of the Environment Inc. by A. J. Chandler & Associates Ltd. Willowdale ON. September 2002

450^{O}C.

The Precursor Theory suggests simply that the various chemically-related chlorinated aromatics undergo condensation reactions on fly ash surfaces in the presence of metal catalysts. Thus, two precursor molecules are coupled to form a dioxin or furan structure. In this theory, the precursor compounds must have a structural resemblance to dioxin and furan molecules. The optimal temperature range for dioxin and furan formation over which the precursor theory operates is the same as that observed for de novo synthesis (i.e., 250 to 450°C). Therefore, formation of PCDD/F from precursors must also occur in the post-combustion zones of thermal processes. This temperature range is often considered the "window of opportunity" for catalytic formation of PCDD/F on surfaces of fly ash particles.

Both the *de novo* and precursor theories have been validated in laboratory studies; however, the relevance of each theory to actual combustion scenarios in the field has not been well established. The main difference between these two theories relates to the carbon source. It is likely that further research may blur the distinction between these two theories, such that the carbon source in PCDD/F formation is derived both from condensation of gas phase organics and volatilization of fly ash-derived organics, with the relative attribution dependent on facility and process-specific variables. Thus, the two theories are not necessarily mutually exclusive. The formation of PCDD/F in thermal processes is undoubtedly the result of a complex set of competing chemical reactions.

Regardless of which theory or theories best explains how PCDD/F are formed during thermal processes, certain conditions that act in combination to increase the potential for PCDD/F formation have been well characterized in the scientific literature, particularly those studies conducted with municipal solid waste incinerators. These conditions include:

- incomplete combustion of a fuel
- an oxidizing atmosphere
- presence of a chlorine source
- fly ash surfaces (carbon source)
- fly ash with degenerated graphitic structures (more ordered carbon atom arrangements are less prone to decomposition reactions)
- presence of catalytic metals (especially copper, but iron, manganese and zinc are also indicated as potential catalysts for PCDD/F formation)
- temperature/time history of at least 1 second at less than 600^{O}C (optimal temperature range lies between 250 and 450^{O}C)

From this it follows that good combustion, which reduces the concentration of products of incomplete combustion, both the gaseous and solid forms, must be the foundation of any measures to reduce PCDD/F emissions from incinerators. The other attributes relate

to the conditions and substances found in the incinerator and, after good combustion control has been employed, little can be done to change these situations.

On the basis of this list, some have suggested that controlling the amount of chlorine in the system might influence the generation of PCDD/F. Consistent analysis of the available data indicates that changing the amount of chlorine in waste streams does not have a discernible impact on PCDD/F emissions from waste incinerators. Therefore, it is unlikely that interventions to reduce the amount of chlorine in waste will produce any appreciable effect on PCDD/F emissions.

From the foregoing it can be seen that good combustion is necessary to ensure low PCDD/F emissions. For engineers and scientists the phrase "good combustion" has some meaning, but what are the implications for regulators or members of the public trying to grapple with the potential performance of new incinerators? Moreover, with many infrastructure projects becoming a public/private partnership, how do politicians and financiers judge the suitability of a particular design for their specific requirements?

2.1 Combustion Control Principles

Combustion control must compensate for:

- the natural variability in fuel quality; and,
- the controlling factors that govern the rate of chemical reactions.

Sewage sludge and liquid hazardous wastes are more homogeneous than MSW and medical waste stream, thereby it easier to control combustion in incinerators used for their disposal. However, variability in the fuel still must be addressed. Incinerator operators understand the need to keep the operation at a steady level to achieve the best performance. Each component of a waste stream has its inherent energy content and this must be matched with sufficient oxygen to ensure proper combustion. Because the mix of components can change, some means must be provided to allow the system to handle this variability. Ensuring that the waste is well mixed before it is charged to the furnace is the first step. The remaining variability in the fuel must then be handled by a well designed furnace.

Typically combustion control systems compensate for the fuel variability. Two stage starved air systems and kiln systems generally rely upon maintaining a large quantity of fuel in the kiln to damp out the variability in the waste quality whereas conventional mass burn MSW incinerators must respond to the heat release by adjusting the air flow. By sensing the rate of heat release in the furnace and adjusting the supply of combustion air the controls compensate for especially high or low heat-release rates. Alternatively, some designers adjust the fuel feed rates to compensate for the calorific value variability.

The importance of the control steps cannot be over-emphasized because the thermal destruction

of organics is not a simple process. Many intermediate steps are involved in the oxidation of long chain hydrocarbon materials to the products of complete combustion namely carbon dioxide (CO_2) and water. Generally, it is agreed that the reaction occurring in the fuel bed is one of gasification, with the waste being exposed to air while being heated. The amount of air added under the bed of material and the degree of agitation of the bed controls the rate of gas generation. The gases that leave the bed are rich in carbon monoxide and hydrogen and contain many unburned hydrocarbons. When provided with additional air these gases will burn readily. This additional air is normally referred to as overfire air and is supplied above the bed. The degree to which the combustion process is completed is a function of how well the air and the gases are mixed. The amount of carbon dioxide generated defines the extent of combustion completion and is generally referred to as the level of combustion efficiency. Complete combustion will result in the generation of CO_2 and water vapour only but this is rarely the case as some traces of organic materials can usually be found in incinerator exhaust streams.

Carbon monoxide (CO) is the most refractory, or difficult to oxidize, species in the oxidative chain from hydrocarbon to carbon dioxide and water. The oxidation of CO to CO_2 is accomplished much faster in the presence of hydrogen. Miller and Fisk[8] suggest the dominant reaction in the chain is:

$$CO + OH \rightarrow CO_2 + H$$

The concentration of hydroxyl radicals is thus very important in the reaction. However, the reaction between hydroxyl radicals and hydrocarbons is faster than that between CO and OH and it is necessary to consume all the hydrocarbons in the system before the system can maximize the conversion of CO to CO_2. Thus high levels of CO are generally correlated with higher levels of residual hydrocarbons illustrating the rate-limiting steps in the reaction.

If excessive air is present in the furnace, the combustion temperature and the concentration of hydroxyl radicals are reduced. In turn, the organics react with the OH radicals and the CO oxidation does not occur. Conversely, insufficient air can lead to pockets of fuel rich gas that lack sufficient oxygen to oxidize the CO. It is possible to establish an appropriate range for the concentration of oxygen in any system. Operation in this zone minimizes the release of CO and thus also minimizes trace organic releases. The establishment of this range is most important because, once determined for a system, it can be used to ensure that the system is operating at its most efficient level.

Good combustion conditions leading to reduced organic emissions are those that:

- ensure complete mixing of the fuel and the air;
- maintain high temperatures in the presence of sufficient oxygen; and,

[8] Miller, J.A. and G.A. Fisk, 1987. Combustion Chemistry. C&EN Aug. 31, 1987; pp22-48.

- prevent the formation of quench zones or low temperature pathways that would allow partially-reacted solids or gases to exit from the combustion chamber.

These design conditions must be combined with good operating conditions to ensure that the performance is maintained and organic constituents are reduced to the basic elements. As noted by McKay[9] it is particularly important to prevent the generation of soot in the system, because soot consists of carbon, and as discussed in the previous section, carbon in the flyash of the incinerator will lead to PCDD/F formation.

While combustion control is generally designed to address the destruction of organic compounds, adjusting combustion conditions can also influence the downstream partitioning of inorganic materials in the incinerator. Higher temperatures in the furnace influence the nature of the compounds formed in the furnace and whether these compounds are volatilized or transported in solid phase with the exhaust gases. Higher temperatures and more complete combustion result in trace metals being found further down the system, particularly in the APC residue stream. Such conditions were noted during the NITEP MSW system testing at PEI in the mid-80's[10]. Of course, since trace metal emissions must be also be controlled, the air pollution control systems, discussed later in this report, must fulfill various roles. While no further discussion of the relationships between combustion and trace metals emissions is contained in this report, the reader is referred to other documents for a detailed discussion on those contaminants[11].

The conditions that lead to a reduction in organic emissions also can cause an increase in the generation of NO_x. The formation of NO_x is attributed to two mechanisms: the oxidation of the fuel nitrogen to NO_x; and the combination of nitrogen and oxygen in combustion air at high temperatures, the thermal NO_x portion. The conversion of fuel nitrogen to NO_x is dependent upon the local oxygen availability to volatile species, the amount of fuel-bound nitrogen and the chemical structure. The thermal NO_x reaction is strongly temperature dependent because it is formed by the combination of radicals of the two species. It has been shown that the conversion of fuel nitrogen can range from 5% to 50% controlled largely by the extent of mixing and the content of oxygen.

Part of the previous discussion indicated that if *de novo* synthesis is to occur several conditions must be satisfied, not the least of which is having the gas and particulate participating in the

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[9] McKay, Gordon, 2002. Dioxin characterisation, formation and minimisation during municipal solid waste (MSW) incineration: review. Chemical Engineering Journal 86 (2002) 343–368. Available at: http://www.seas.columbia.edu/earth/wtert/sofos/mckay_dioxin-formation_2002.pdf.

[10] NITEP, 1986. "The National Incinerator Testing & Evaluation Program, (NITEP), Air Pollution Control Technology". Environment Canada, Report EPS 3/UP/2, September.

[11] Chandler, A.J., 2003. Background Study on the Incineration of Hazardous Waste. Final Draft of A Report to ENVIRONMENT CANADA to complete Contract Number K2237-2-0006. Prepared by A.J. Chandler & Associates Ltd. Toronto. March

reaction spend sufficient time in the temperature range conducive to such synthesis. Typically heat recovery steam generators [HRSG], or boilers, are used at MSW incinerator facilities to convert the energy in the waste to useful forms of energy for district heating or electricity production. Temperatures in such devices are in the appropriate range to encourage the synthesis reactions. Thus one would expect that, given the same combustion efficiency in an MSW incinerators and a sewage sludge incinerator, the PCDD/F emissions from the MSW incinerator might be higher given that HRSG devices are more likely to be used in MSW facilities than on sewage sludge incinerators. Similarly, boilers are not typically installed in hazardous waste incinerators or biomedical waste incinerators.

While much of the research emphasis has been focussed on defining the conditions conducive to minimising emissions of PCDD/F through the stack, the mechanisms discussed above also have implications for solid residue streams generated by combustion equipment. Obviously, ash from the grate of solid fuel combustion device will be exposed to temperatures in excess of that conducive to formation, indeed temperatures in the range where any PCDD/F will be destroyed. Rapid quenching of ash discharged from the grates should minimise the potential for any PCDD/F in that waste stream. On the other hand, residues from heat recovery systems, which operate in the critical temperature zone may be expected to have some PCDD/F present, but the amount will likely vary with the temperature regime where the ash was collected, and the time the ash was in the gas stream at these temperatures. This suggests that the PCDD/F formation processes related to *de novo* synthesis or precursors may be inhibited if the gasses leaving the system are rapidly quenched to below the optimal temperature ranges.

Of course, the corollary is also true. If PCDD/F materials are exposed to elevated temperatures in the absence of oxygen the PCDD/F will be destroyed. Based upon his research Hagenmaier[12] developed the heat soak technology in Germany. By heating the flyash in an atmosphere with little or no oxygen PCDD/F are destroyed. This approach is now being successfully used for PCDD/PCDF decontamination of flyash and other residues mainly in Europe and Japan.

[12] Hagenmaier, H., M. Kraft, H. Brunner, and R. Haag, "Catalytic Effects of Fly Ash from Waste Incinerator Facilities on the Formation and Decomposition of Polychlorinated Dibenzo-p-dioxins and Polychlorinated Dibenzofurans", Environmental Science and Technology 21, pp. 1080 – 1084, 1987

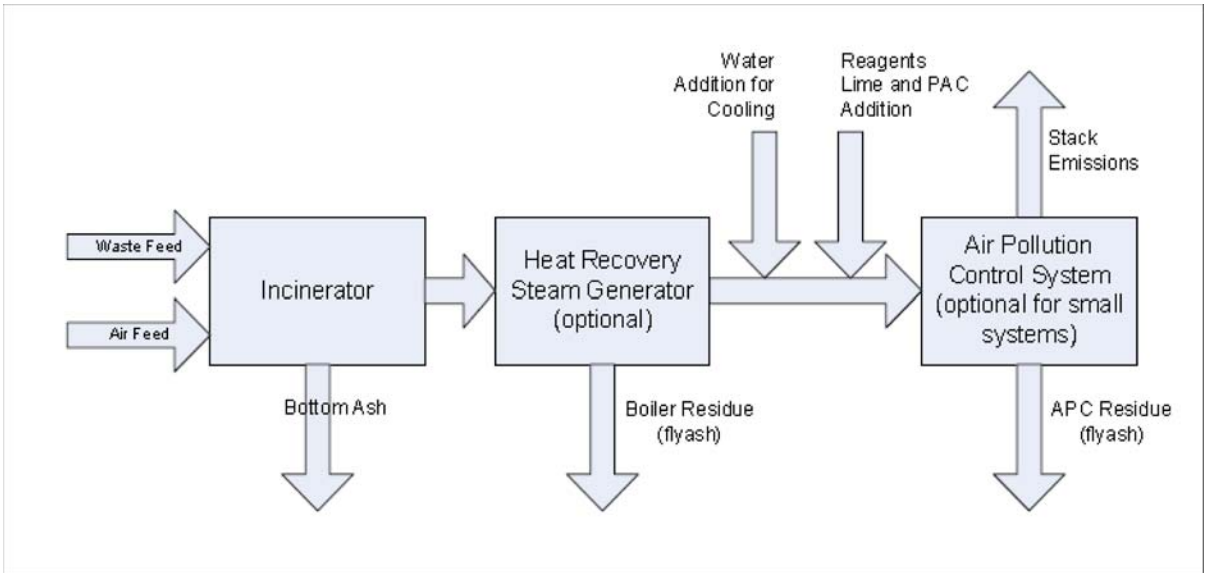
3.0 INCINERATION PROCESSES

3.1 Introduction

The previous chapter identifies incinerator operating characteristics that are anticipated to give rise to inadvertent production of PCDD/F. To understand how these factors might relate to PCDDD/F emissions this chapter summarizes the types of incinerator systems used in Canada and how each attempts to address the requirement of providing good combustion control. With the likelihood that some PCDD/F may be released even from the best operating incinerators, air pollution control systems can be employed as the last option to minimize the release of PCDD/F to the atmosphere. The available air pollution control systems are discussed in the next chapter.

Figure 3.1 is a generalized schematic of an incineration system. Not all components shown in the diagram are installed in every facility. The dotted lines indicate components of the system that could be considered optional in some incinerator installations.

Figure 3.1 Generalized Schematic of an Incineration System



Regardless of the waste being destroyed, all incinerators have a zone where the waste is ignited and mixed with air to promote combustion. Most incinerators provide additional air to complete the combustion process. After the waste has been oxidized in the furnace, residues, generally referred to as bottom ash, must be removed from the furnace. The energy available in the hot gas stream generated by combustion may be recovered in a heat recovery steam generator [HRSG] or boiler thereby creating steam that can be used to produce electricity or for process or space heating.

If an air pollution control system is installed to treat the hot gases leaving the incinerator, the gas treatment system includes some means of reducing the gas temperature before the control devices. This reduces the size of the required control equipment because the gas volume is reduced. While an HRSG installed in the system will reduce the gas temperatures, if there is no boiler typically a rapid quench system will be used to achieve the desired gas temperatures. As noted in the previous chapter, such quenching will limit the potential for *de novo* synthesis because the gases do not remain in the critical temperature range for sufficient time to allow the reactions to proceed. Lacking either an HRSG or a boiler, gases can be released directly to the atmosphere, typically as high temperature.

Solid residues deposit in HRSG units, or are collected in air pollution control systems. These streams are generally referred to as fly ash because they have travelled suspended in the exhaust gases. Again, because time is required for the synthesis reactions that produce PCDD/F, the quantity of PCDD/F present in the fly ash streams can vary depending upon where the fly ash is removed from the system.

The 2006 CWS Incineration review task encompasses incinerators designed to dispose of:

- municipal solid waste [MSW];
- biomedical waste materials;
- sewage sludge; and,
- hazardous waste.

These wastes having different physical and chemical characteristics and incinerators need to be purpose built to handle the specific materials. Thus, an incinerator designed for sewage sludge is unlikely to provide satisfactory operation for the disposal of liquid hazardous waste materials, or even municipal solid waste. Similarly, MSW cannot be charged to a liquid hazardous waste incinerator, or a multiple hearth sewage sludge incinerator.

For any specific furnace there is a limitation on the amount of material that can be charged to the system. The charging rate is limited by the system's design heat release rate which in turn is governed by the ability of the specific furnace to supply and mix sufficient air to ensure all the waste is burned in the most effective way possible. As noted in the previous chapter, too high a heat release rate makes it unlikely that combustion processes can be completed; too low a heat release rate usually leads to insufficient temperatures in the combustion system and the

production of products of incomplete combustion. In designing the system, the manufacturer seeks to provide good combustion control to minimize the potential for PCDD/F formation.

It should be recognized that for a given waste type different design variants can be employed. Different designs of incinerators are limited in both the minimum and maximum amount of waste they can be fed, thus some designs are preferred for small installations and some are required for large installations. The suitability both for the type of waste, and the amount of waste that will be destroyed, dictates most incinerator selections as these factors have a direct impact on the capital cost of the equipment and thus the per tonne disposal costs.

The design variants discussed in this document are somewhat generic in nature, that is they can be employed for different types of wastes, provided they are designed for the specific waste that will be charged to the furnace. In this way fixed grate furnaces are employed for medical wastes, certain types of hazardous wastes, and general MSW disposal in small batch type systems. Similarly, fluidized bed furnaces can be used for sewage sludge disposal, hazardous waste disposal and MSW disposal. Rotary kiln furnaces are frequently employed for hazardous waste destruction but also form an integral part of one manufacturer's MSW incinerator offering. Specific furnace types, such as the mass burn European furnaces used for MSW disposal, seldom see duty for other materials. The discussion that follows deals with incinerator designs by fuel types as a convenient way to differentiate between the designs.

Table 3-1 provides a summary of the types of incinerators available in the marketplace, the types of wastes they typically handle, and the range of capacities that are available. Specific details are provided on the pages following the table.

Table 3.1 Summary of Incinerator Types

Description		Applicable Waste Type Handled				
General	Sub-Category	MSW	Hazardous	Sewage Sludge	Medical	Fume
Mass Burn		100 - 700 Mg/d				
Modular	Starved Air	5 - 120 Mg/d	45 - 3,500 kg/hr		45 - 3,500 kg/hr	
	Excess Air	10 - 100 Mg/d	45 - 3,500 kg/hr		45 - 3,500 kg/hr	
Rotary Kiln		50 - 300 Mg/d	60 - 150 x 10^6 Btu/hr		45 - 3,500 kg/hr	
Fluidized Bed		50 - 150 Mg/d	As Req'd	5 - 65 Mg dry/d		
RDF	Stoker	30 - 450 Mg/d				
	Semi-Suspension	400 - 1000 Mg/d				
Liquid Injection			< 5.7 m^3/hr			
Multi-hearth				0.5 - 6 Mg dry/d		
Multi-chamber	Retort	10 - 350 kg/hr			10 - 350 kg/hr	
	In-line	225 - 900 kg/hr			225 - 900 kg/hr	
Catalytic	Fume					As Req'd

3.2 Municipal Solid Waste Incinerators

MSW incinerator facilities typically contain several process sections:

- a waste receiving and storage area;
- a waste feed system to charge the incinerator;
- a combustion system;
- a boiler to convert the heat of combustion to usable energy;
- an air pollution control [APC] system; and,
- an ash handling system.

The first five of these processes all have the potential to influence the operation of the facility and the quality and quantity of air emissions and solid residues released from the facility. Processing the waste to remove non-combustible materials will reduce the volume of residues generated. Processed fuel, generally termed refuse derived fuel or RDF, is normally burned in furnaces that are configured differently from those used to burn MSW and both types of furnaces have their own operating characteristics and emissions patterns.

3.2.1 Available MSW Combustion Alternatives

There are at least 18 major incinerator system manufacturers with operating MSW incinerator systems in the world. While each system has some unique features, combustion systems can be divided into two broad categories based upon the fuel characteristics:

- mass-burning - the 'as-received' MSW is fed directly into the furnace and burned on a grate or hearth without any pretreatment such as size reduction, shredding, or material separation prior to burning.

- refuse-derived-fuel (RDF) - a prepared fuel of a more homogeneous nature which is sold to outside customers or burned in an on-site "dedicated" incinerator.

Mass burning was adopted in Europe at the turn of the century and has continued to evolve over the past 25 years. While these systems do not require pre-treatment of the waste fed to the furnace, removal of over-sized material (appliances and furniture, etc.) and mixing of the waste before feeding are critical to smooth operation of these facilities. Mass burning is a well established technology. Two types of mass burn systems are available:

- the European or large system; and,
- the modular type system.

The RDF process involves the separation of certain materials from the waste to improve the combustion characteristics of the fuel. Various levels of processing are possible but they all involve the same basic operations. The MSW is usually shredded thereby reducing the size of the

material; sorted to remove non-combustibles; and burned in semi-suspension or suspension fired furnaces. Ferrous metals may be recovered using magnetic separators; and, glass, grit and sand may be removed by screening. Further processing can be used to remove certain plastics and aluminum materials if desirable. Air classifiers or rotary drums may also be used to further process the fuel product by removing additional non-combustible materials. During processing the material is thoroughly mixed improving its homogeneity.

There is no unique answer as to which incineration method is better. The choice of system is typically based upon the amount of waste that must be disposed, or the age of the facility. In Canada, no RDF facilities are still in operation. The last RDF facility, the SWARU plant in Hamilton, Ontario closed in 2002. Mass burn European furnaces are operated in Quebec City and Vancouver, British Columbia. Starved air modular incinerators are installed in Charlottetown, Prince Edward Island and Brampton, Ontario. The furnaces at Levis, Quebec and Ile de la Madeleine are defined as step grate furnaces.

3.2.1.1 MASS BURNING SYSTEMS

EUROPEAN TYPE SYSTEMS

The European systems have proven to be rugged as well as reliable and have been constructed in sizes ranging from 100 Mg per day (Mg/d) to 750 Mg/d. Mass burning technology can be applied in almost all situations; however, it does not compete well with other incineration systems at design capacities below 300 Mg/d because of the high capital cost per Mg of waste burned daily.

The European mass burning incinerator can be either of the refractory lined or the water-wall design. In a refractory lined furnace, combustion temperatures are regulated by using high excess air rates (100 to 200 percent excess air). In a water-wall furnace, the combustion temperature is maintained by circulating water in closely-spaced tubes located on the furnace walls. Most waterwall furnaces operate at a lower excess air rate, in the order of 80%. This results in a reduction of both the furnace volume and the size of the air pollution control equipment.

The basic combustion process in European mass burn furnaces consists of layered burning of the waste on the grate that forms the bottom of the furnace and transports the waste material through the furnace. The fuel passes through various temperature regimes while on the grate. The initial grate section is used to dry the waste; radiant heat from the furnace, combined with under-fire air drives off the water. Once the material is dry it begins to pyrolyse prior to burning. The pyrolysis and combustion process at this stage consumes the waste but generates significant quantities of hydrogen, carbon monoxide and unburned hydrocarbons. Additional air is required to complete the conversion of these materials to carbon dioxide and water vapour. This air is supplied above the material on the grate, and is commonly called over-fire air. The last section of the grate completes the reaction driving the balance of the combustibles from the bed material. Sufficient time must be allowed for this last stage of combustion to go to completion and maintain high combustion efficiency. Material leaving the burnout section of the grate passes through a

quench tank before being dewatered and conveyed to an ash storage bunker.

Generally the grate manufacturers provide the grate system and design the furnace configuration above the grate. When combined with their proprietary air control systems, the grate systems can meet guarantees of the appropriate level of combustion for the waste being burned. The HRSG or energy recovery system downstream of the furnace can be supplied by any one of several boiler manufacturers.

Differences in grate and furnace design or operating philosophy are based upon the manufacturer's experience. The efficiency of the grate system, as defined by consumption of carbon, depends upon its ability to provide combustion air to all the waste. This requires that the waste be mixed while on the grate thereby exposing fresh surfaces for burning. While the grates can vary in configuration they are generally divided into three categories:

- Rocking grates with alternate rows being mechanically pivoted or rocked to produce an upward and forward motion, advancing and agitating the waste.

- Reciprocating grates consisting of sections stacked above each other with each pair consisting of a fixes portion and one that slides horizontally. Waste tumbles off the fixed portion and is agitated and mixed as it moves along the grate.

- Travelling grates are formed of a continuous metal-belt conveyor or interlocking linkages and move along the longitudinal axis of the furnace. Several belts can be stages through the furnace bottom, and while the waste is not agitated while on the belt it is when transferred from one belt to the next.

Maintaining uniform conditions reduces the possibilities of operational problems caused by ash slagging or corrosion in the combustion zone. The manufacturers achieve stable operation by controlling:

- bed coverage: trying to maintain a uniform distribution of waste on the grate;
- combustion air flow: adjusting the initial combustion zone air to match the burning characteristics of the solids; and,
- the relationship between the grate and the gas going to the upper part of the furnace and the location of over-fire air ports: developing good mixing of gases above the bed and enhancing the combustion effectiveness.

The furnace configuration plays an important role in the ease with which combustion can be controlled and the quality of the ash leaving the grate. The path that the combustion gases take after they leave the burning waste is also important in ensuring uniform and complete combustion.

As the gases leaving the grate move through the throat of the furnace, additional air must be

added to complete the combustion process. The design of the furnace throat is an important aspect in ensuring proper mixing of this air and thus controlling the concentration of organic contaminants in the flue gas and the APC residues. Over-fire air must be well mixed and have limited potential for short-circuiting or creating temperature depression if low emissions are to be achieved. The throat causes a flow constriction, thereby enhancing turbulence and providing the best location to ensure the complete mixing of the over-fire air and the combustion products.

The balance of under-fire to over-fire air, the waste nature and the control of the system can influence the way the material burns and affect both ash quality and the air emissions. Air control systems provide varying flows of air to different regions of the grate and to different areas of the zone above the grates. Typically, 60 to 80% of the air added to the furnace comes from the under-fire system. With limited over-fire air, its addition must be carefully controlled to achieve the desired mixing. The location and configuration of the over-fire air ports is made more critical by the variations in the waste and the need to follow the steam demand in energy from waste [EFW] plants. Controlling steam production can be accomplished in several ways. The philosophies of two different manufacturers illustrate how these can vary.

- Von Roll (Quebec City) monitors the steam production rate and controls the ram feeder frequency and the amount of primary air to the middle region of the grate, the pyrolysis region, to maintain the correct steam rate. Von Roll also monitors the furnace temperatures in the radiant region to control the secondary airflow rates. If the temperature drops, the secondary air can be reduced to restore temperatures to the correct level.

- Martin (Vancouver) uses O_2 levels in the flue gas to control the refuse ram feeder rate and the grate speed, thus controlling the MSW feed rate. A second control loop monitors steam rate and adjusts the under-fire air to control the steam production rate.

Both of these combustion control philosophies are also aimed at maintaining low organic emission rates from the furnace. These conditions can influence the trace metal partitioning between the furnace and the APC system because they not only can change the temperature regimes on the bed and volatilize materials that might otherwise not become volatile but also local velocities that can influence the amount of material entrained into the gas stream.

MODULAR INCINERATION SYSTEMS

Smaller mass burn incinerators are typically of the modular design, being factory built and installed in the field. Typical modular incinerators for MSW applications range in capacity from 10 to 100 Mg per day. Smaller sized modular incinerators are used for medical and hazardous waste disposal, with the smallest modular incinerators being skid mounted transportable systems that can be used in remote areas. The later can be in the 35 - 90 kg/hr size.

The modular incinerator, also referred to as the controlled-air incinerator, makes use of a two-stage combustion process. Typically modular incinerators consist of a primary chamber and a secondary combustion chamber. They are classified as either excess-air or starved-air (sub-stoichiometric) on the basis of the primary chamber operating mode. The difference in these two modes of operation are summarized below:

a) **Starved-Air Incinerator** - The primary chamber of this incinerator is run without sufficient air to complete the burning process (below the stoichiometric requirement). Typically 30 to 80% of the stoichiometric requirement is provided. Without sufficient air, pyrolysis gases are formed in the primary chamber. Excess air is provided in the secondary chamber section of the incinerator to complete the combustion process.

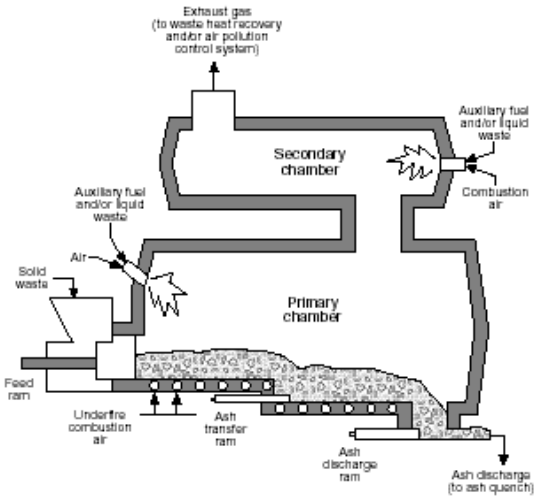
b) **Excess-Air Incinerator** - The primary chamber in these units has more than the stoichiometric requirement of air. Typically 60-200% excess air is supplied to these units and this promotes almost complete combustion in the primary chamber (in the order of 90-95%). Gas-phase combustion is completed in the secondary chamber where additional air is added on an as-required basis.

Of the two types of controlled-air incinerators, the starved-air unit (See Figure 3.2) appears to be the more widely used. The success of the starved-air design has been due, in large part, to its ability to reduce the entrainment of particulate matter in the flue gas. This has been attributed to:

1. minimizing the disturbance of the fuel bed by limiting the number of grates;
2. maintaining a slow rate of volatilization by reducing air flow; and,
3. consuming any liberated particles in the secondary chamber.

Most starved air modular systems (the Charlottetown facility and the Brampton facility are two typical examples) feature a stepped series of solid hearths with limited air injection points. This is different from European mass-burn and excess air modular units that feature air introduction through the grate and numerous moving grate sections. Larger modular incinerators used for continuous operation are equipped with a hopper/ram assembly or double ram system to allow waste to be charged to the furnace on a periodic basis, typically every 6 - 8 minutes. The waste is moved through the furnace by transfer rams placed along the stepped bottom of the furnace. To

Figure 3.2 Schematic of Fixed Hearth, Two Stage Incinerator (from US EPA)



maintain combustion control with variable waste materials these furnaces retain a large mass of partially burned material at all times. The controlled-air concept provides faster response to temperature fluctuations because upper chamber temperature is controlled by varying the over-fire air addition rate rather than the more complicated systems employed in large conventional mass burning units.

The large mass of material in the furnace, minimal disturbance of the bed, and low under-fire air addition rates in the starved air system generally result in poorer carbon conversion, higher ash quantities and lower energy recovery typically 55-60% compared to 65-70% for mass burning. The latest generation of starved-air units have included provision for a burn-out hearth area where extra air is supplied below the waste on the final hearth. This has reduced the ash volume and lowered the unburned carbon levels to below 6%, as demonstrated during the 1992 start-up of the Brampton facility.

Modular incineration systems have a lower capital cost per daily Mg of waste burned compared to mass burning operations. Starved air systems can have lower excess air requirements than mass burn units thereby reducing the size of APC equipment.

Controlled-air incinerators are manufactured by several vendors including Basic (Wainwright), Consumat (PEI, Brampton), Morse Boulger, and Simonds. These units are supplied as standard models but can be modified to suit the specific needs of a customer. Many manufacturers also supply equipment to medical care facilities for the disposal of biomedical wastes.

OTHER MASS BURN VARIANTS

Several other mass burning technologies are in limited use throughout the world. Among these technologies are variations of the rotary kiln. See Figure 3.2.

Systems categorized in this class consist of a rotary kiln and an afterburner. Rotary kilns are the basic processing component in the cement and lime processing industries as well as providing the enclosure for the destruction of solid hazardous waste materials.

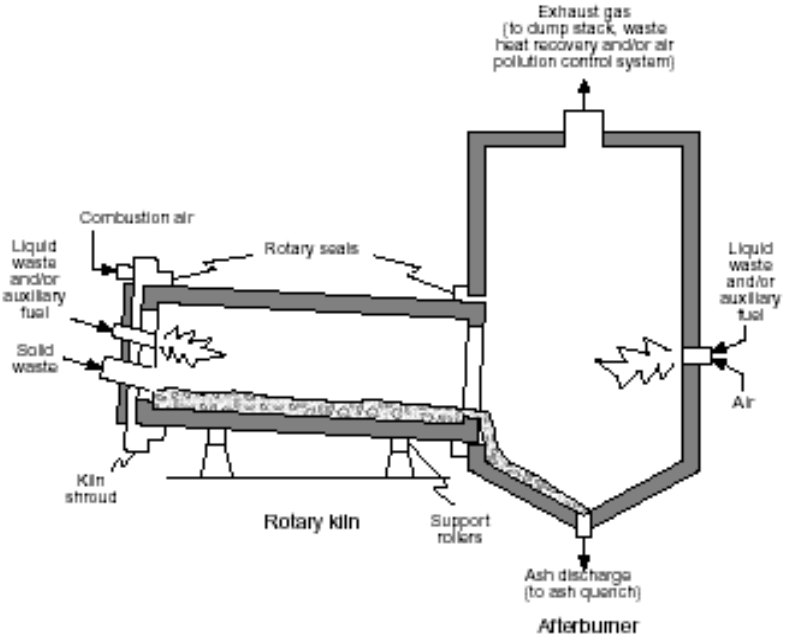
The rotary kiln is a long cylindrical, refractory-lined, steel shell that rotates around its longitudinal axis during operation. To allow it to rotate, the kiln is fabricated with reinforced steel bands on the outside of the cylinder and these rings ride on steel rollers. Kilns are typically rotated by a gear train that engages a spur gear affixed to the circumference of the shell.

Most kilns for waste combustion applications are 4.5 to 6 metres in diameter to facilitate their factory fabrication and shipment to site. Their length can range from twice to ten times their diameter depending upon the specific application. The refractory lining for the shell is acid resistant brick. Normally the inside of the kiln is smooth, however, some designs incorporate vanes or paddles to encourage solids mixing along the kiln length. The long axis of the kiln is normally slightly inclined to the horizontal. Typically, this incline, referred to as the "rake", is in the range of 2^{O} to 4^{O}. Rotational speeds range from 0.5 to 2 revolutions per minute, again depending upon the nature of the wastes being handled. It is important to realize that the combination of the rake and the rotational speed combine to determine the residence time of the solids in the system and the amount of mixing provided for wastes and combustion air in the furnace. Mixing also serves to transfer heat between the waste, the flames and the refractory.

Rotary kilns used for MSW processing can be of waterwall or refractory wall design and can also include ignition grates similar to the grate in a European mass burn system. Systems in current operation include the Volund rotary furnace, and the Westinghouse/O'Connor rotary kiln. The difference between these system is that the Westinghouse unit is a water-wall lined kiln with air and water tubes laid longitudinally in the kiln. The Volund is a refractory lined kiln.

There are no rotary kiln incinerators used for MSW in Canada, but the hazardous waste incinerators at the Swan Hills Treatment Center are of this design.

Figure 3.3 Schematic of Rotary Kiln Incinerator (from US EPA)



3.2.1.2 REFUSE DERIVED FUEL SYSTEMS

Unlike the mass burn systems, Refuse Derived Fuel(RDF) systems fire a waste that has had its physical characteristics altered. The furnaces then handle this waste by pneumatically injecting it into the combustion chamber. The fuel is then fired in suspension, on a stoker grate or in a fluidised bed incinerator.

SEMI-SUSPENSION BURNING SYSTEMS

While semi-suspension furnace are used to burn wood waste or coal, operating experience with MSW has been relatively limited. The most recent installations of this type are in Hartford, Connecticut and Detroit, Michigan. There are no installations of this type in Canada. In these furnaces, the fuel is injected into the furnace through wall ports. Once in the furnace it ignites, and burns while falling to the grate. The bottom of the furnace is generally equipped with a travelling screen type grate system where final burn-out occurs.

RDF systems are designed to have heavier materials burn on the grate. The major design consideration with these systems is to ensure that the fuel is injected in such a manner that it builds an even bed across the grate. This is analogous to the desire for uniform bed characteristics in the mass burn system. To accomplished this, the designers ensure heavier materials travel

further across the furnace before they fall to the grate, and they design the injection system to spread the injected material across the grate.

This technology typically offers higher energy recovery efficiency, lower excess air requirements and lower capital cost (per daily Mg) as compared to mass burning systems. In spite of these advantages, semi-suspension burning is generally not economical for plant sizes below 400 t/d.

Data from the Hartford facility indicate that the combustion characteristics of these furnaces promotes increased entrainment of particulate matter from the furnace through the boiler and into the APC system. This behaviour has the potential to increase carbon monoxide levels and regulatory requirements for carbon monoxide are less stringent than for other types of furnaces.

STOKER FIRED SYSTEMS

Stoker fired boilers are common in the utility industry. Their adaptation to burning MSW or combined MSW and coal was a development that benefitted both the utilities by supplying fuel and the municipalities looking for MSW disposal options. This older technology was employed for the SWARU facility in Hamilton before it closed in 2002.

In stoker fired systems the RDF injected onto the clean part of the grate. The distribution across the grate is controlled by the distribution air nozzle. Unlike older semi-suspension grate systems where the under-fire air is supplied by one plenum, the typical spreader stoker has several plenums so air distribution can be matched to the waste pattern on the grate. Over-fire air introduction into these systems is accomplished through a tangential entry system. This is similar in concept to the manufacturers' utility boiler designs.

OTHER RDF VARIANTS - FLUIDISED BED

The fluidised bed reactor is capable of destroying a wide range of wastes including sewage sludge, petroleum waste and paper industry waste. These units have been adapted to fire RDF materials and are used extensively in Japan for MSW. They are more likely to be used for hazardous waste or sewage sludge in North America and a detailed description of the technology is provided later in this chapter.

3.3 Hazardous Waste Incineration Equipment

There are a number of different types of incinerators that can be used for disposing of hazardous wastes. The type of incinerator selected depends upon the nature of the waste being disposed. For instance, solid hazardous waste cannot be destroyed in a liquid injection furnace, but liquid wastes can be injected into dedicated zones of systems that handle solid waste. Liquids can be disposed in a wide range of systems from the liquid injection furnace to boilers or industrial furnaces where the energy can be recycled into new products.

The majority of the operating commercial hazardous waste disposal systems are based upon one of the following technologies:

- rotary kilns;
- liquid injection incinerators;
- fluidised bed incinerators; and,
- fixed hearth incinerators.

The disposal of hazardous waste in industrial furnaces forms a significant portion of the available disposal capacity in the United States, but not in Canada. Cement manufacturing is a highly energy intensive industry with a heavy product that has resulted in cement plants being spaced about 300 km apart over the more densely populated portions of the US. The US EPA noted[13] that in 1994 there were 111 operating cement manufacturing facilities in the US. About 30 separate sites were burning hazardous waste derived fuel at that time.

Similar applications could include lightweight aggregate kilns [LWAK] and lime kilns. The US EPA[14] designates twelve different types of industrial furnaces for potential hazardous waste disposal in that country. These include on-site boilers which convert fuel energy to thermal energy either for process heating or electrical energy. Boilers, as defined by the USEPA, 40 CFR Part 266, SubPart H, are enclosed devices that use controlled flame combustion to recover and export at least 75 percent of the energy off-site in the form of steam, heated fluid, or heated gases. By definition, boilers burning hazardous wastes in the U.S. must have a combustion chamber and primary energy recovery system of integral design to ensure that the energy recovered is in excess of 60 percent of the input.

The main hazardous waste incinerators in Canada are rotary kiln and liquid injection furnaces. Their general configuration of the system, the input waste characteristics and operating parameters are described below.

3.3.1 Rotary Kilns

The general diagram and description of this type of incinerator was provided earlier.

Solids and gasses move in the same direction in most rotary kilns used for solid hazardous waste disposal. When the wastes and auxiliary fuel are introduced in the same end of the kiln, the waste is ignited quickly and the products of combustion are provided the maximum residence

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[13] US EPA, 1995. Technical Support Document for HWC MACT Standards, Volume 1: Description of Source Categories. Prepared by U.S. EPA's Office of Solid Waste Management Division, technical support by Energy and Environmental Research Corporation (EER) and EERGC under EPA Contracts 68-D2-0164, and 68-W7-0029.

[14] US EPA, 1991. Boiler and Industrial Furnace regulations regarding hazardous waste disposal. 40 CRF Part 266, Subpart H, 56FR7134, February 21, 1991.

time in the rotary section of the furnace. Solids are fed on either a continuous or semi-continuous basis using various feed mechanisms. Batch feeding is achieved through an air lock to control the excess air in the kiln. Liquids are introduced either in batch form in containers, or atomized through the direct burner or an auxiliary waste fuel lance that introduces the waste into the main burner flame. Atomizing is provided by air or steam in dual fluid nozzles. While most wastes do not require pre-treatment for disposal in hazardous waste incinerators, some operators mix liquid and solid wastes to provide a means of balancing the heat input and neutralizing corrosive wastes prior to feeding to the kiln. Waste feeds are controlled so that waste occupies no more than 20% of the kiln volume.

Direct impingement of the main flame on the waste starts the destruction process. Heat is also transferred to the waste from the bulk gasses and the refractory walls. As in most combustion processes, volatilisation, partial combustion and gasification reactions contribute to the destruction of the waste.

Hazardous waste rotary kiln systems are typically sized for 60 million Btu/hr heat input, but can be as large as 150 million Btu/hr. Solids retention times in the kiln range from 0.5 to 1.5 hours, while gasses are retained for approximately 2 seconds in most systems. Typical gas temperatures in the kiln exceed 870^{O}C, while the solids attain temperatures in excess of 650^{O}C. Combustion air is provided through ports on the face of the kiln, and through leakage through the rotary seals. The resulting excess air levels range from 50 to 200%.

The nature of rotary kilns means that their seals are the weak point for emissions. High rates of volatilisation can cause pressure increases in the kiln which lead to gasses escaping through the seals. Thus, the introduction of highly combustible or explosive wastes needs to be carefully controlled, or the rate of mixing must be reduced to minimise the exposure of fresh surfaces. Inorganic materials, including ash, slag and other incombustible items that remain when the waste reaches the end of the kiln are discharged into a water filled quench tank. The water acts as a seal preventing the entry of air into the kiln. The rate of discharge of ash residue must be controlled so large, hot masses do not drop into the quench tank and create steam explosions that increase the pressure in the kiln.

Gasses leaving the rotary kiln are routed to a secondary refractory lined combustion chamber or afterburner to complete the destruction of volatile gas phase unburned materials leaving the kiln. This is essentially a liquid injection furnace. Temperatures on the order of 1200^{O}C with 100 to 200% excess air, turbulent flow mixing and a gas residence time of 1 to 3 seconds ensure suitable performance from the afterburner. Temperatures are maintained through the use of auxiliary fuel, normally a pumpable liquid hazardous waste. Since slagging can be a concern at the high temperatures achieved in the afterburner, some facilities employ hot cyclones positioned between the kiln and the afterburner to remove entrained particulate matter.

The preceding describes the basic rotary kiln installation however several variants are employed in specialized applications. The fast rotary kiln is operated at greater than 20 rotations per minute

to increase mixing of the waste and the gasses. Starved air operation, where the kiln is run sub-stoichiometric, reduces flue gas volumes and auxiliary fuel requirements. Oxygen assisted kilns involve the introduction of oxygen into the system to reduce the amount of air required and hence the auxiliary fuel requirements. Slagging kilns, operated at temperatures exceeding the ash melting point of the inorganics are designed to generate a molten ash. Slagging kilns, such as the installation at Swan Hills, typically have lower particulate emission rates and produce solid residues that are less susceptible to leaching of toxic metals. With their higher operating temperatures, slagging kilns produce higher NO_x emissions and experience reduced refractory operating life, but are suited to the destruction of salt laden wastes and can increase organic destruction efficiency.

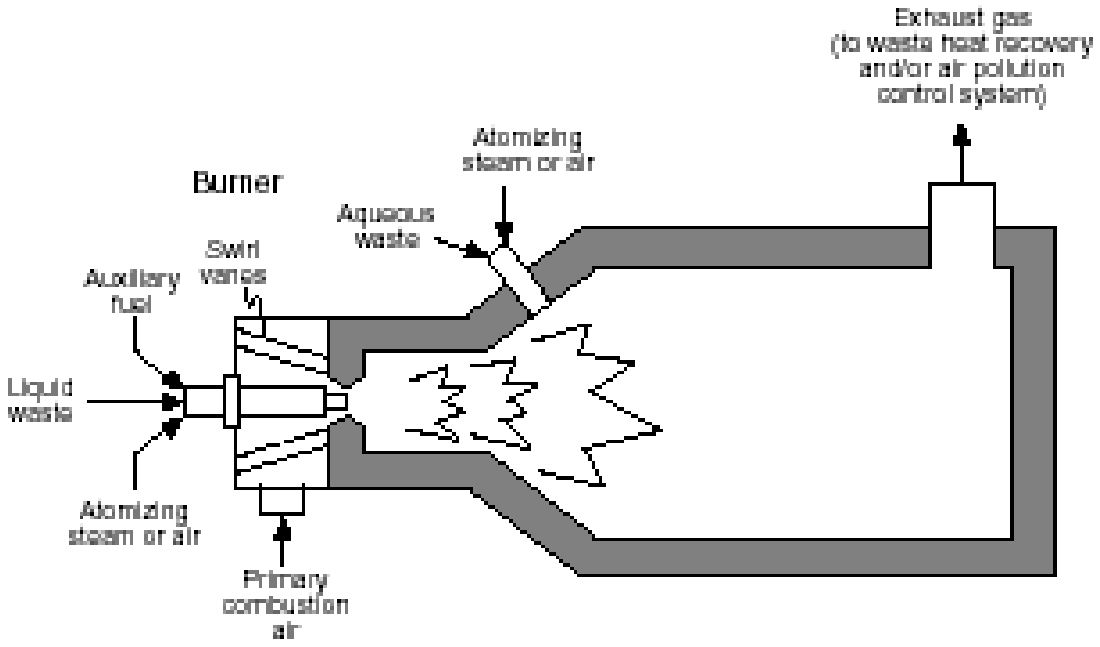
Rotary kilns are used to volatilize organics from contaminated soils at the two Bennett facilities, one operating in Quebec and the New Brunswick facility that has not been commissioned yet. In both these systems, a fossil fuel afterburner is used to destroy the vapour phase organics liberated from the soils.

3.3.2 Liquid Injection Incinerators

Liquid injection incinerators are the simplest of all the systems used for hazardous waste disposal. Typically they consist of a combustion chamber equipped with a waste burner, air supply and auxiliary fuel systems. As noted in the discussion of rotary kiln systems, the afterburner on hazardous waste rotary kiln systems is a liquid injection furnace usually operating with limited range of hazardous waste feed materials. In either applications liquid injection furnaces are fitted with an air pollution control system. More complex liquid injection systems have numerous waste feed ports designed to handle different types of waste ranging from high specific heat solvents or oil type materials to lean aqueous based wastes. The major limitation on liquid wastes is that they must be atomised to promote efficient combustion so the viscosity of the material is limited to less than 10,000 SSU and sludges or materials with high solids contents must be screened prior to being fed to the burner.

Atomisation is the key to the successful operation of a liquid hazardous waste incinerator. Dual fluid nozzles utilizing air or steam or mechanical systems that rely on pressure atomisation or rotary cup systems, provide a fine mist with droplets of 40μm or less in size. The droplets of waste have a large surface area to promote rapid vaporisation and lead to the formation of a highly combustible mixture of waste and air in the furnace.

Figure 3.4 Schematic of Liquid Waste Incinerator (from US EPA)



Typical liquid injection combustion chamber residence times range from 0.5 to 2 seconds and temperatures of 700 to 1700^{O}C ensure maximum destruction of the waste. Liquid waste feed rates can be as high as 5.7 m^3/hour. One critical performance criteria for these furnaces is that they should always be operated near their design input heat release rate. The design of the burner and the furnace require high levels of internal turbulence and any reduction in input can lead to short circuiting or cold zones in the furnace that will increase the release of products of incomplete combustion. Over the years the input to the furnace as Clean Harbors' Corunna facility has been increased and emissions of trace organics have decreased clearly indicating that there was an optimal operating point for the furnace.

Liquid injection systems are operated by Clean Harbors at both the Corunna and Mercier facilities, and downstream of the rotary kilns in the Swan Hills Treatment Facility.

3.3.3 Fluidized Bed Incinerators

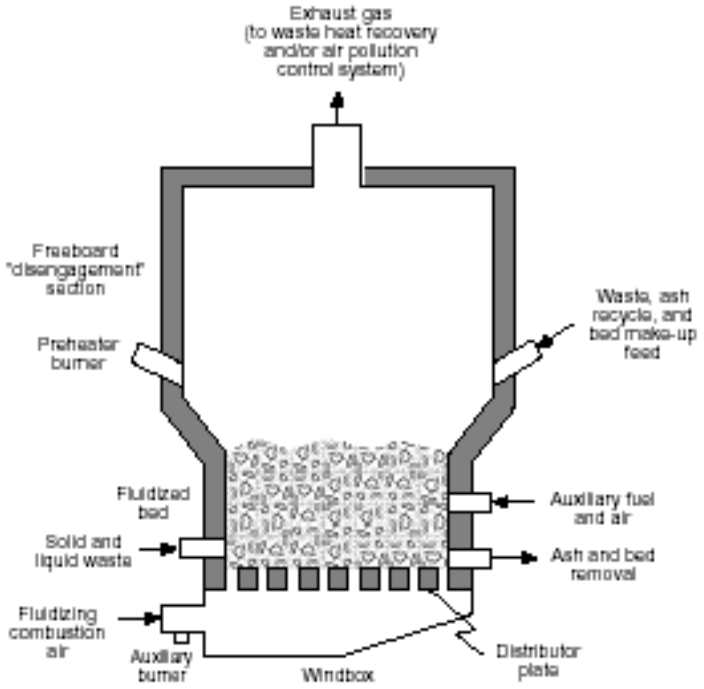
As noted earlier, the fluidized bed reactor is capable of destroying a wide range of wastes. While fluidised bed systems are used for hazardous waste disposal in the chemical industry in Europe, they have more limited use, generally for sewage sludge, in North America. In Canada a good example are the sewage sludge incinerators in the Lakeview plant near Toronto. See Figure 3.5.

Waste preparation/feed systems for these incinerators are divided in accordance with the types of

wastes being handled: liquid or solids. It is not uncommon to see these streams split to accommodate wet or dry solids and viscous and non-viscous fluids in separate injection systems. For solids handling typically the waste is shredded, separated into light and heavy fractions with the lighter materials fed to the furnace. For liquids, holding tanks and recirculating pump systems are used to feed a uniform waste stream through nozzles into the bed. The alkali containing bed materials in a fluidised bed reactor act as acid gas control reagents making these systems efficient for treating wastes containing sulphur or halogens as they reduce the load on the APC systems.

The reactor usually consists of a vertical refractory lined steel vessel containing a bed of granular material such as silica sand, limestone, alumina, or ceramic material. The bed material is supported by a refractory lined grid. This grid is perforated to allow air to be injected below the bed material using diffusers located under the grid. The air passing through the grid expands the bed by 80 to 100% causing it to become fluidised. Wastes can be injected into the bed pneumatically, mechanically or by gravity. The constant moving action of the fluidised bed causes quick uniform mixing of wastes and bed material, resulting in good combustion

Figure 3.5 Schematic of Fluidized Bed Incinerator (from US EPA)



conditions, and relatively high heat transfer rates. Furthermore, the moving and the heat of the bed serve to increase the burnout of material and only minimal amounts of bottom ash are generated.

A typical fluidised bed reactor has a height to diameter ratio of 1.25:1 with the expanded bed

occupying about 20% of the height. The bed material functions as a heat sink capable of absorbing large amounts of heat generated during the combustion process. Bed temperatures are typically maintained in the range of 760°C to 870°C which is lower than the operating temperatures of other types of systems. These lower gas temperatures and lower excess air requirements minimize the formation of nitrogen oxides.

Fluidised bed systems may require auxiliary burners located either above or below the bed to maintain bed temperature, however other options are available to maximize thermal efficiency. The reactor can be operated either as a cold windbox in which the fluidising air is injected directly into the reactor or as a hot windbox in which the air is preheated in a heat exchanger or recuperator prior to injection depending upon the nature of the waste and the need to supply additional heat.

Because of its simple design concept, the fluidised bed reactor has a low capital cost, a relatively long service life and low maintenance costs. In addition, this unit can tolerate large fluctuations in both waste composition and the rate of feed due to the high thermal inertia of the bed material, typically in the order of 596,000 kJ/m^3 (16,000 Btu/ft^3).

Some of the potential problems and special considerations of the fluidised bed incinerator include the build up and removal of residual material from the bed, the formation of eutectic mixtures that fuse in the furnace, and bed degradation. Furthermore, the systems require particulate removal devices in the gas stream because internal velocities, needed to fluidise the bed, entrain ash and carry it out of the bed.

3.3.4 Fixed Hearth Incinerators

The fixed hearth incinerator, also referred to as the controlled-air incinerator, makes use of the two-stage combustion process discussed earlier. It usually consists of a primary chamber, followed by a secondary combustion chamber. These units typically handle solid hazardous wastes, but as with other hazardous waste variants, they can be equipped with liquid injection afterburners.

A Consumat 2-stage incinerator is operated by Cameco at the Port Hope, Ontario refinery to dispose of materials contaminated with radionuclides and a similar type system has recently been installed by OPG at the Tiverton, Ontario site. Several fixed hearth furnaces are used for metal recovery operations at facilities in Ontario (MRR and Gary Steacy). These furnaces essentially use fossil fuels to heat the charge of contaminated metal thereby volatilizing trace organics that are present on the metal. The organics released are destroyed in an afterburner. In the case of the radionuclide contaminated wastes, the radioactivity is concentrated in the bottom ash and residues produced by the process.

3.4 Sewage Sludge Incinerators

Sewage sludge incinerators in Canada are typically either multi-hearth or fluidised bed systems, although in the US some sewage sludge is disposed in electric infra-red furnaces. As can be appreciated, sewage sludge typically has a high moisture content so any system must drive off the water before combustion of the solids can occur. It is possible to co-fire sewage sludge with MSW however careful blending of the two streams is required so the moisture levels do not present problems during combustion.

This section will only address multi-hearth incinerators since the application of fluidised bed systems has been covered above.

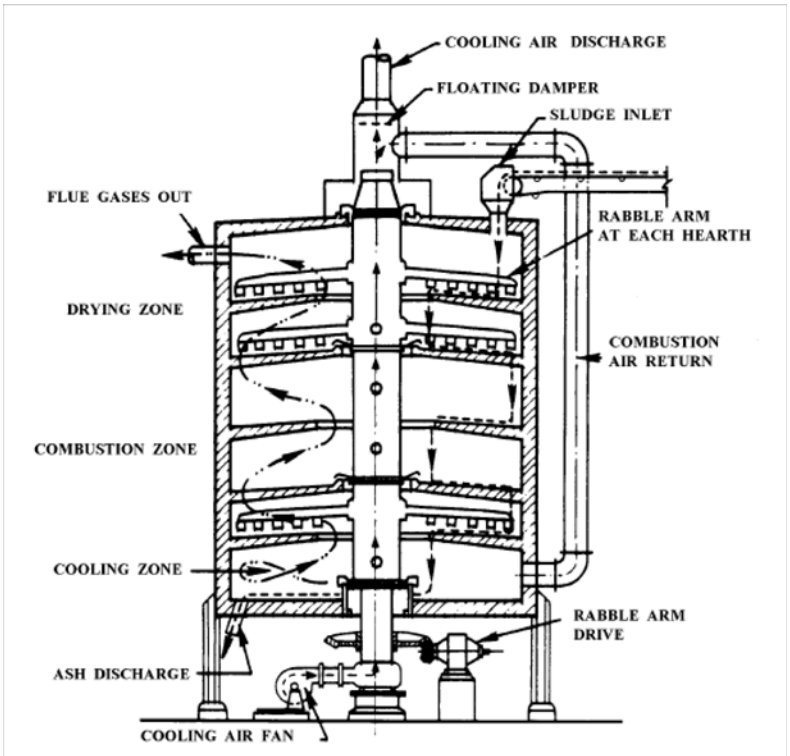
3.4.1 Multi-hearth Incinerators

As the name implies, the multi-hearth incinerator contains many hearths as can be seen in Figure 3.6. The basic multiple hearth furnace (MHF) is a vertically oriented cylinder constructed of steel and lined with refractory. Inside the cylinder are a series of horizontal refractory hearths with a center hole. A hollow cast iron rotating shaft runs through the center hole with fixed rabble arms for each hearth. Cooling air is introduced into the shaft. Each rabble arm is equipped with a number of teeth, approximately 6 inches in length, and spaced about 10 inches apart. The teeth are shaped to rake the sludge in a spiral motion, alternating in direction from the outside in, to the inside out, between hearths. Typically, the upper and lower hearths are fitted with four rabble arms, and the middle hearths are fitted with two. Burners, providing auxiliary heat, are located in the sidewalls near the hearths.

Partially dewatered sludge is fed onto the perimeter of the top hearth. The rabble arms move the sludge toward the center of the furnace. Holes near the center of the hearth allow the sludge to drop to the next hearth where the material is raked outwards to holes where it falls to the next hearth. The rabble motion breaks up solid material allowing better surface contact with heat and oxygen. A sludge depth of about 1 inch is maintained in each hearth at the design sludge flow rate. Scum, oils, grease, hair, waxes, fats, and other materials that will float, can be fed to one or more hearths of the incinerator.

Ambient air is first ducted through the central shaft and its associated rabble arms. A portion is then taken from the top of the shaft and recirculated into the lowermost hearth as preheated combustion air. The combustion air flows upward through the drop holes in the hearths, countercurrent to the flow of the sludge, before being exhausted from the top hearth.

Figure 3.6 Typical Multi-Hearth Incinerator from US EPA AP-42[15]



The multiple hearth furnace is generally divided into three combustion zones. The upper hearths provide drying at 425 and 760^{O}C. Combustion occurs in the middle hearths as the temperature is increased to about 925^{O}C. The third zone, made up of the lowermost hearth(s), is the cooling zone. In some applications, afterburners are used to reduce odours and unburned hydrocarbons. To reduce complaints about odour and poor combustion performance, some multi-hearth furnaces have been converted to provide additional fume destruction in the area formerly used by the top two hearths. By moving the feed point to the third hearth from the top and installing a fossil fired burner in the area of the second hearth, the upper part of the furnace is used to destroy materials leaving the upper bed.

Under normal operating condition, 50 to 100% excess air is added to an MHF. These relatively high rates of excess air are necessary to compensate for normal variations in both the organic characteristics of the sludge feed and the sludge feed rate. Too low an excess air level allows only partial oxidation of the carbon to occur, increasing emissions of carbon monoxide, soot, and hydrocarbons. Too much excess air increases entrainment of particulate matter and causes high auxiliary fuel consumption.

[15] US EPA, 1995. Compilation of Air Emission Factors. Chapter 2.2 Sewage Sludge Incineration. AP-42. Available at http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s02.pdf

3.5 Biomedical Waste Incinerators

Traditionally, medical waste incinerators were installed in hospitals and designed to handle on-site waste disposal. Some systems date back 40 years to a time when they were used to dispose of tissue and pathological wastes that were not suitable for disposal in landfills. Over the years the older units, designed for low calorific value materials, were used to burn the increasing amounts of plastics found in hospital waste streams. This caused deteriorating performance and in some cases forced the closure of facilities. In some parts of the country the distributed network of small incinerators has been replaced by central facilities designed to handle the "must burn" portion of the medical waste streams. Other types of medical waste are then treated with autoclaves and shredding before the waste is disposed in landfills. The centralized facilities operated in New Brunswick and Ontario are two stage incinerators as described under the MSW category, equipped with air pollution control systems to remove acid gases, PCDD/F and mercury along with other contaminants. In other provinces the older facilities may still exist and it is appropriate to review these types of incinerators in this section.

In a 1992 report to the California Air Resources Board[16] it is noted that the most common types of medical waste incinerators are starved air modular units such as those discussed in the MSW section; rotary kiln units discussed in both MSW and hazardous waste discussions; and, excess air multi-chamber batch incinerators. The multi-chamber incinerators of two different types[17] were supplied:

- Retort incinerators; and,
- In-line incinerators.

3.5.1 Retort Furnaces

Typically a compact cubic shape, this furnace has multiple internal baffles installed to guide the combustion gases through 90^{O} turns in both horizontal and vertical directions. As the gas stream turns any entrained ash drops out of the flow stream. The primary chamber of the retort has an elevated grate where the waste sits, and an ash pit below the grate. For applications with medical waste the grate was solid to prevent the leakage of materials into the ash pit. In these circumstances air was circulated under the solid grate. the Figure 3.7 provides a cross-section of a typical retort furnace.

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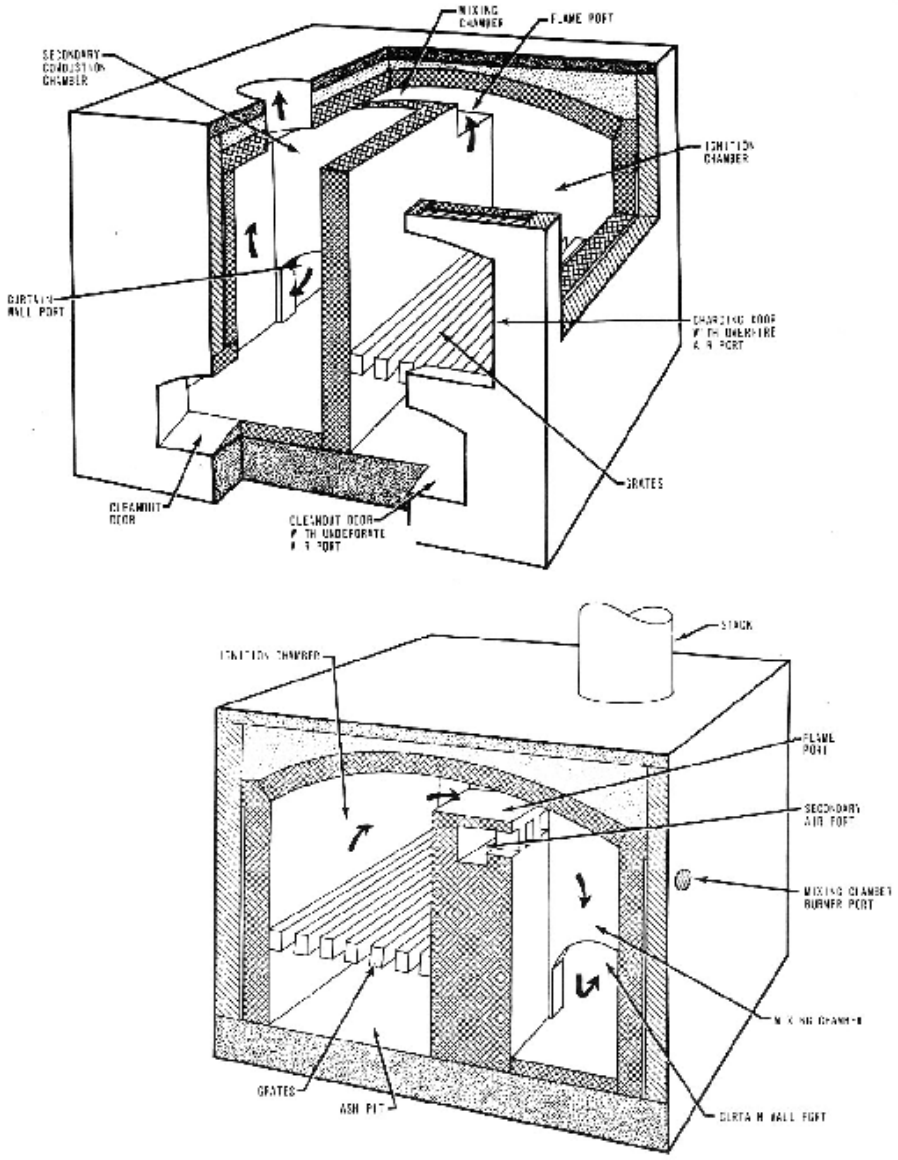
[16] CARB, 1992. Survey of Medical Waste Incinerators and Emissions Control. Contract No. A832-155 Final Report. January, California Environmental Protection Agency, Air Resources Board, Research Division. Available at http://www.arb.ca.gov/research/abstracts/a832-155.htm#Vol

[17] Ontario MOE, 1988. Guidance for Incinerator Design and Operation. Volume 1, General. ISBN 0-7729-4232-3.

Figure 3.7 Retort Incinerator from AP-40[18]



Both the primary and mixing chamber in the retort furnace are typically equipped with auxiliary fuel burners to provide sufficient energy to raise temperatures in the furnace. When the waste has sufficient calorific value to achieve the appropriate temperatures in the primary chamber the primary burner only runs on start-up. The mixing chamber, or secondary burner will likely run throughout the cycle to maintain the desired operating temperatures.

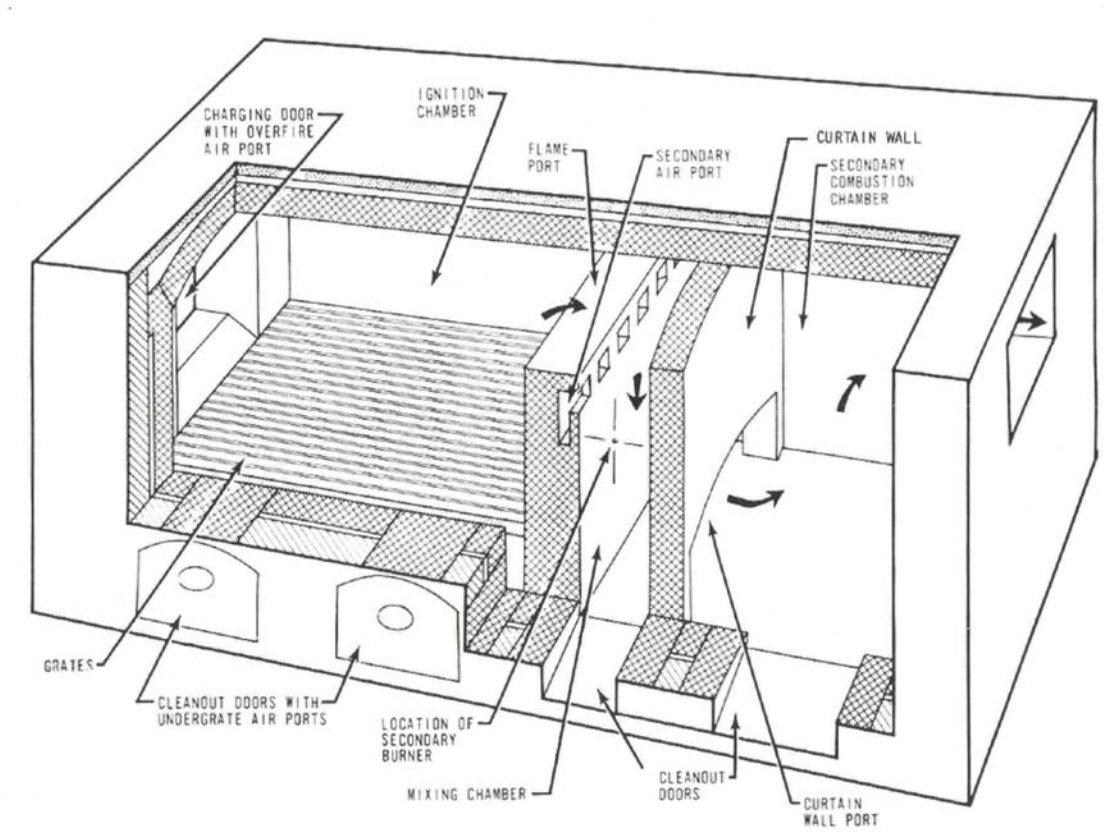
[18] Danielson, J., 1973. Air Pollution Engineering Manual, County of Los Angeles, Air Pollution Control District. AP-40 May.

Retort furnaces were normally used in either batch or semi-continuous mode in the capacity range of 10 to 350 kg/h. They were designed to operate with low calorific value wastes, and because they rely upon natural draft for air input to the system, they are unable to adequately treat high calorific waste because sufficient air is unlikely to enter the combustion chamber. Over the years the seals on the furnaces deteriorate and uncontrolled leakage can start to occur. This forces the furnace to operate with higher levels of excess air making it difficult for the system to achieve the desired temperature regimes and thus also leading to emission problems.

3.5.2 In-Line Furnaces

In-line furnaces are internally similar to the retort furnace but they are laid out so the gas flows axially from one end of the furnace to the other. Baffles and openings still cause the gas to change flow direction and auxiliary burners are still installed in these systems. Figure 3.8 shows a typical in-line furnace also taken from AP-40.

Figure 3.8 Typical In-Line Furnace from AP-40.



In-line incinerators ranged in size from 225 to 900 kg/h and were occasionally equipped with automatic charging and ash removal systems.

Typically these furnaces operated with 200% excess air with over half this quantity entering the

furnace as a result of leakage. In operation the design called for 70% of the air to be provided as overfire air, 10% as underfire air, and 20% in the mixing chamber.

Multiple chamber incinerators were used for pathological waste, crematory furnaces and other specialized furnaces such as metal barrel reclamation. In both pathological and crematory applications hot hearth arrangements were employed with the flue gases being circulated under the hearth to cause it to heat up thereby aiding in the volatilisation of the wastes.

As noted for the retort furnaces, the major problems with multiple chamber incinerators is their design heat release rate and the potential for uncontrolled leakage. Both can result in incomplete combustion and elevated emission levels. Frequently, black smoke can be observed from the stack of these systems when operation is sub-standard.

3.6 Other Systems

While the majority of incinerators operating in Canada can be classified into one of the categories discussed in the previous pages, there are other potential variants that might not appear to readily fit in these categories.

Canadian incinerators, designed and built by two different manufacturer's, Westland and Eco Waste Solutions, are two chamber furnaces designed with controlled air addition and an afterburner to ensure good performance. In the list of incinerators discussed later in this document they are referred to as "two stage c/w afterburner" or [2 Stage AB]. In these systems, a fossil fuelled burner is used to initiate the combustion of the garbage and quickly bring the furnace to the appropriate operating temperature. At this point, the burner shuts-off. This ensures that the process occurs at a relatively slow pace and promotes a more efficient oxidation. Oxygen flows through specially designed ducts and is controlled to maintain the internal temperature conditions between 650 and 850^{o}C. Measures are taken to limit the primary chamber temperatures, in one case an automatically operated sprinkler system is activated to lower temperatures. The air intake can also be closed. Another safety mechanism automatically shuts-off the system should the primary chamber temperature reach a high limit setting.

The gases and unburnt particles of matter flow through the secondary chamber where a selected internal temperature is maintained by the use of auxiliary burners. In many instances, the gases and particles act as fuel and are sufficient to maintain the appropriate secondary temperature, so the burners automatically adjust to use the optimal amount of fuel required to maintain the desired temperature. The oxygen intake to the secondary chamber can also be used to control the temperature. Both systems use patented configurations for the addition of air to the secondary chamber. These are designed to force the gases into a swirling pattern, promoting a complete mix and total oxidation. The retention time in the secondary chamber can be adjusted, based upon the size of the chamber given the rated input of the incinerator. Typically retention times are in the order of one to two seconds.

After this stage, the combustion is considered completed and the remaining harmless gases escape to the atmosphere through the stack. In one of these systems, a carbon monoxide probe can be installed in the stack and linked to the control computer. This parameter can therefore be continuously monitored.

There are excess air incinerators, either rectangular boxes or round cylinders, with afterburners installed in various locations in Canada. The afterburners could simply be in a portion of the stack, or they could be separate chambers installed behind or above the primary chamber. In most cases these systems are operated in a batch mode, loaded with waste, ignited with an auxiliary burner and then let burn until the waste is reduced to ash. The afterburner should operate throughout the whole cycle.

During the review of incinerators on Federal lands, the Canadian Armed Forces identified that they have a number of Smart Ash 100 barrel burners. These are essentially 200 l oil drums fitted with lids and air injection systems. The waste is loaded into the barrel and ignited. The fan is then turned on to force air into the barrel in a cyclonic flow pattern and additional air is added in a specially designed exhaust system. The additional air acts as overfire air ensuring destruction of the majority of the organic materials that might be present in the gas stream. These batch incinerators hold up to 200 l of waste, typically oily rags etc., and are designed to burn these materials at a rate of 22 kg/h. As noted in the Compass report[19] these units typically run for 45 minutes to 1 hour, several times a week at various Canadian Forces Bases.

All the incinerators listed above are essentially closed chambers with air being supplied either through natural draft in the case of some multi-chamber incinerators, or by forced and induced draft fans. As such all these incinerators have some type of stack to exhaust the combustion gases from the process. Many of these units can be fitted with air pollution control equipment to decrease the potential emissions of PCDD/F. A discussion of potential air pollution control options, by incinerator application category is provided in the next section of this chapter.

There are a class of waste combustion devices that are not addressed in this report, but are sometimes included when emissions from MSW combustion are discussed. These are pit burners, or conical burners. The highest preponderance of these units are found in Newfoundland and Labrador where, because of the nature of the terrain, landfills cannot be readily established. Most small remote communities are situated on rocky outcrops and have few areas suitable for a landfill. Moreover, the local animals in these areas could present problems should raw waste be disposed in landfills. For both volume reduction and to control vermin many of these communities burn waste in large concrete pits. The waste is ignited and air is blown into the pit to assist with combustion. The top of the pit is generally covered by a roof to keep precipitation out of the pit. The area between the top of the pit wall and the roof is open to the atmosphere

[19] Compass Environmental Inc., 2006. Assessment of Select Federally Owned Waste incinerators. A report prepared for Waste Management Division of Environment Canada, Ottawa. March.

although in many locations wire mesh is placed around the pit opening to capture large pieces of unburnt paper etc. These units have no stack.

A second type of waste burner, the conical burner consisting of a fixed hearth inside a steel shell is used in many remote localities in Newfoundland. The steel structure, either cylindircal with a converging cone on top, or conical shape from the ground up, is equipped with openings around the base to allow air to enter and feed the fire. Air feed rates are controlled in a very rudimentary manner and the system amount to little more than large barrel burners.

Newfoundland is attempting to reduce the use of these burners by encouraging replacement with more appropriate technology, but there are economic barriers to such plans. Currently these facilities are included in the NPRI PCDD/F inventory as MSW incinerators. The presence of these burners was recognized during the developement of the firs CSW PCDD/F incinerator standard and these systems were specifically excluded from consideration because the province developed a separate plan to address this practice. That plan is scheduled to result in the closure of these facilities by 2010.

Barrel burning, waste burning in open barrels in the backyards of rural residences, can be a significant source of PCDD/F emissions to the atmosphere according to the US EPA. Since these sources cannot be readily identified, and clearly are not associated with a municipality or a business, they are not currently included in the NPRI inventory.

3.7 Process Summary and PCDD/F Generation Potential

The previous chapter notes that PCDD/F formation from combustion processes is a function of both the quality of the combustion and the temperature regime in the system. Assuming combustion is well controlled in a system, the major generation of PCDD/F will likely take place after the gases leave the furnace. If stack gases come in contact with flyash at temperatures in the 250 - 450^{O}C range for any length of time residual carbon in the flyash can form PCDD/F. Such situations are most likely to occur in systems equipped with HRSGs. Thus *de novo* synthesis reactions can be expected to be the predominant source of PCDD/F emissions from the large incinerators MSW incinerators in Vancouver, Wainwright, Brampton, Quebec City and Prince Edward Island. As can be seen from the PCDD/F emission inventory provided later in this document, these are the only facilities with HRSGs.

Chemical reactions are typically driven by concentration effects so the more flyash present, the higher one might expect emissions to be. The amount of particulate matter entrained in the exhaust gas stream is a function of furnace design. Two-stage combustion systems in facilities such as Prince Edward Island and Brampton would be expected to have lower flyash levels. This could reduce the rate of *de novo* synthesis at these facilities. Older mass burn type systems, with poor combustion and high particulate matter carryover typically had very high PCDD/F emissions. Quebec City was modified in the 1990s to improve combustion and reduce emissions.

At that time, an advanced air pollution control system was installed on the system to reduce emissions.

At the opposite end of the incinerator spectrum in Canada are the remaining multi-chamber furnaces installed in government research facilities or hospitals. Data from the 1980s suggested that these types of incinerators had only a limited capability to control air addition which can lead to poor combustion conditions. Couple this with the changes in the waste streams, evolving from low heating value wastes with high moisture content to a stream with a high percentage of plastics with their high heating values, these units have the greatest potential for poor combustion performance and high emissions. Moreover, few of these systems have been equipped with air pollution control equipment. Thus one would be justified in applying a reasonably large emission factor to these facilities.

There are incinerators at government and other research facilities that could still be managing the waste streams they were installed to treat. Animal and plant wastes from research activities will have changed little over the years, provided the operators are not using the systems as a general disposal method. Thus, if a specific incinerator is still being used in the manner originally envisioned, ie the nature of the waste has not changed over the intervening years, and the unit has been maintained, careful consideration should be given to the unit's function and continued operation. However, given the limitations of these systems, should conditions have changed, clearly testing would be in order to ascertain whether it has outlived its useful life.

The new generation of batch fired, modular incinerators have been tested and, as shown later in this document, have low emissions of PCDD/F. This is no doubt due to the fact that combustion is well controlled and the gases leave the incinerator at temperatures in excess of 900^{O}C. This affords little opportunity for the inadvertent formation of PCDD/F through the *de novo* synthesis process. Unfortunately, as will be seen later, while these units should operate well in theory, practice can leave something to be desired. Operators must be trained to operate these units and the instructions should be followed to ensure optimal performance.

Hazardous waste incinerators would generally be considered to have good combustion control. In most cases the temperature regime after the furnace is not conducive to PCDD/F generation by *de novo* synthesis reactions. Given some of the variability in the wastes these systems handle, they do require air pollution control systems to meet standards on a consistent basis. Fluidised bed sewage sludge incinerators have good combustion control although there is significant carryover of flyash from the furnace. Temperature regimes in these systems could play a role in the quantity of PCDD/F generated. Multi-hearth incinerators can be expected to have a higher emission factor than will fluidised bed furnaces.

Later in this report the potential emissions from each operating incinerator in Canada are estimated based upon system design parameters and emission test data from comparable facilities. Of course, the influence of APC systems on emissions must be incorporated in the estimates. Such systems are discussed in the next chapter.

4.0 AIR EMISSION CONTROL STRATEGIES

Significant improvements were made in the air emission control systems of MSW incinerators after 1984. In some cases these facilities started to adopt the types of air pollution control [APC] systems used on European hazardous waste incinerators. Since then there have continued to be advances in the types of APC systems used for both MSW and Hazardous Waste incinerators. The convergence of these systems is evident in the EU Directive of 2000 that set emission standards for all incinerators in Europe at the same level.

Early APC systems on hazardous waste facilities had wet scrubber systems installed downstream of a primary particulate control system, usually an electrostatic precipitator [ESP]. The effluent from the wet scrubber was injected into the hot stack gases ahead of the APC system to reduce the temperature of the flue gasses.

Alternative APC systems developed in the late 1980s offered the particulate removal capabilities of a fabric filter with acid gas neutralizing provided by lime injected into the gas stream. These systems did not create wastewater effluents and were thus considered more convenient to operate. As it became necessary to improve the removal of certain contaminants, (PCDD/F and mercury), forms of activated carbon were added to the list of reagents used in the APC systems.

A brief discussion of APC systems is presented in this chapter. The emphasis is on methods used to control the release of PCDD/Fs present in the gases leaving the combustion portion of the facility.

4.1 Post-Combustion Control

Post-combustion control, the use of air pollution control [APC] systems, to remove unwanted contaminants such as trace metals and various acid gases from the gas stream exiting the facility is employed on most new large incinerators. The NITEP program[20] showed that trace organics can be reduced through the use of such systems. The three key aspects of APC systems are reagent addition, temperature control, and particulate removal.

APC systems rely upon both physical and chemical unit processes involving different solids removal and chemical conversion steps to effect control of unwanted emissions. These processes are combined to achieve the desired flue gas quality at an acceptable capital and operating cost. Different types of systems can change the quantity of residues resulting from the flue gas clean-up, thereby influencing the costs for residue disposal.

The integration of air pollution control systems into a particular facility involves making a

[20] NITEP, 1986. "The National Incinerator Testing & Evaluation Program, (NITEP), Air Pollution Control Technology". Environment Canada, Report EPS 3/UP/2, September.

number of choices about how particular functions will be accomplished. These are shown schematically in Figure 4.1 based upon a publication by Fläkt[21]. A more detailed discussion is presented in the previously referenced Hazardous Waste Background study report[22].

Fläkt's APC categories loosely align to standard operating practices in various facilities in Canada. The Dry system typically includes an evaporative cooling tower [ECT] to cool the gas stream, dry reagent addition followed by particulate control with the latter preferably being by fabric filter but ESPs have been employed. The Wet-Dry system introduces the reagents as a wet slurry thereby combining the function of the ECT and reagent addition. This system is employed at the Corunna Hazardous Waste incinerator. The Wet system employs wet scrubbers in systems such as that mentioned elsewhere in this report with effluent used to cool the gasses into the ESP, the scrubber with reagent addition, some type of moisture removal system and likely a fabric filter at the back of the system for final particulate matter control.

The Dry system is employed at Quebec City, Brampton and Vancouver to name three MSW installations. The Wet-Dry system is employed at Clean Harbours Corunna in the hazardous waste facility whereas Swan Hills has a variation of the Wet system. Other wet systems include the Brampton medical waste incinerator. These systems, while forming the basic control equipment to control particulates, trace metals and acid gases, are frequently augmented with special reagents or equipment to enhance the removal of particular contaminants. These post-date the original Fläkt assessment, and involve either the injection of carbon into the gas stream at some point before the final particulate control device, or passing the gas through a carbon bed filter to remove unwanted contaminants. It is the augmented systems that will be elaborated upon in the following pages.

Table 4.1 provides Fläkt's generalized comparison between the basic alternatives. The order of use of different components is governed by the selection of the process steps. The table should not be used for selection purposes but rather to give relative comparisons between different options. Note, however, that Fläkt's recognized the need to treat the effluent from wet scrubbers. The heat potential category relates to the desire to use available heat for other purposes and here, the wet scrubber offers the best potential; however, if NO_x control is to be used, some of this potential may not be realized.

The addition of carbon systems adds complexity and cost to any of the alternatives evaluated in the table, and if the carbon filter is used adds to the pressure drop in the APC system and thus energy costs. Organics removal would go to extremely high if carbon were added to the system.

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[21] Fläkt, 1991. Cleaning Flue Gases in Energy from Waste Plants. A sales document from Fläkt, Sweden.

[22] Chandler, A.J., 2003. Background Study on the Incineration of Hazardous Waste. Final Draft of A Report to ENVIRONMENT CANADA to complete Contract Number K2237-2-0006. Prepared by A.J. Chandler & Associates Ltd. Toronto. March

Figure 4.1 Comparison of Air Pollution Control System Options (adapted from Flakt, 1991)

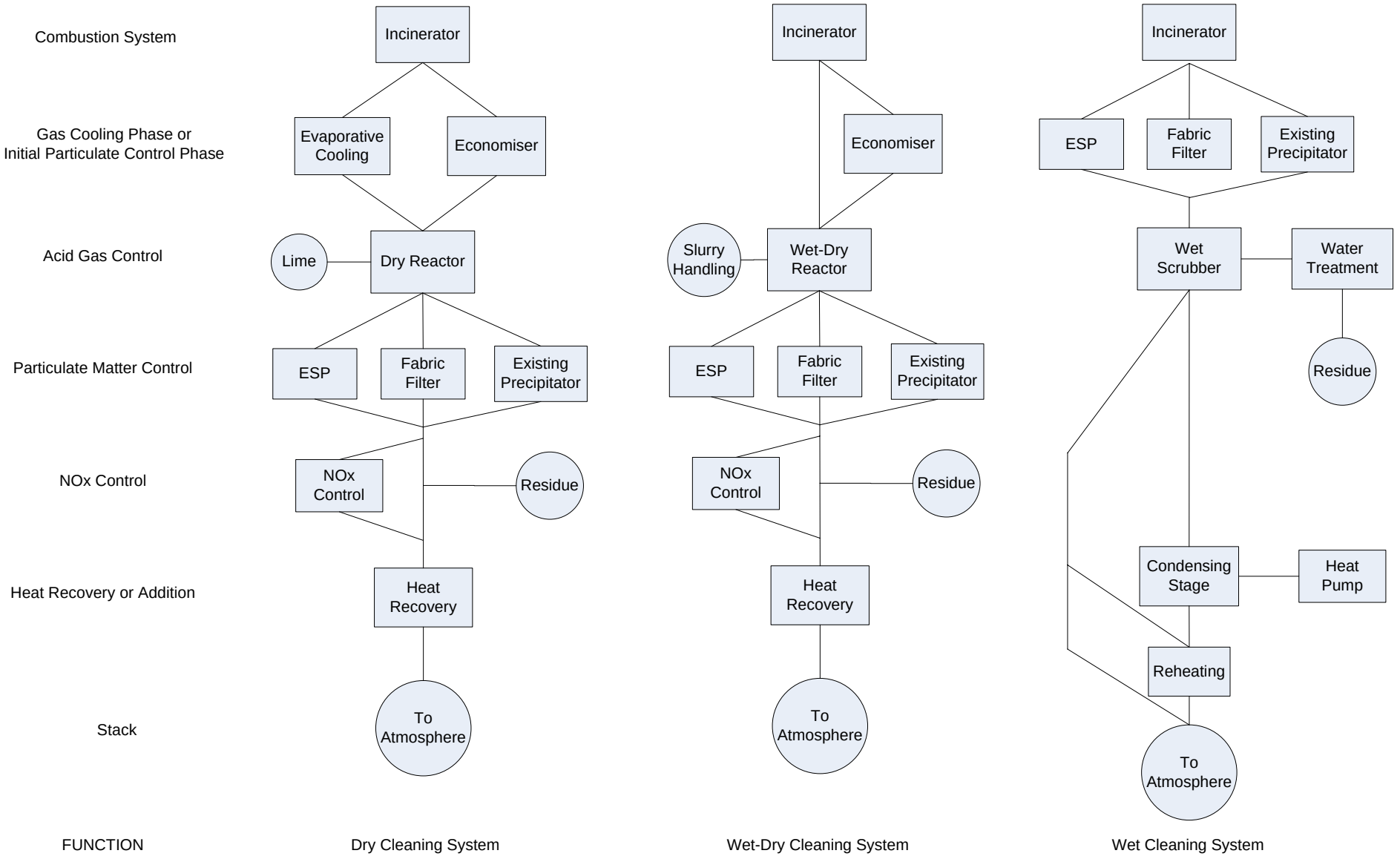

Table 4.1 Comparison of Operating Features of Various APC Alternatives (after Fläkt, 1991)

CLEANING PRINCIPLE	DRY	WET-DRY	WET
INVESTMENT COSTS	low	medium	usually high
OPERATING COSTS			
lime consumption	medium	low	low
soda consumption	none	none	medium (if use special SO_x stage)
energy consumption	low	medium	medium
maintenance requirements	very low	low	medium
COLLECTION EFFICIENCY			
dust	very high	very high	high
HCl and HF	very high	very high	very high
SO_x	medium	medium	high (with special stage)
NO_x (without special add-on stage)	low	low	none
heavy metals	very high	very high	medium
hydrocarbons	very high	very high	medium
HEAT RECOVERY POTENTIAL	high	medium	very high

4.2 PCDD/F Control Alternatives

The introduction of a finely divided reagent into the gas to control acid emissions provides an additional benefit in the removal of trace metallic and trace organic species. Volatile metals and organics demonstrate a high affinity for surface sorption and providing a large surface area in the form of fine particles in the acid gas control system increases the probability of surface reactions. This is illustrated by reduced emissions of volatile species from modern APC systems. Some limitations exist. If the particulate matter is controlled by an ESP, fine particles are more likely to escape and emission rates for volatile compounds can be relatively higher than in comparable fabric filter installations. The removal efficiency of ESP equipped systems can also be reduced if particle characteristics change. Furthermore, the adsorption effects are temperature dependant and regardless of the particulate matter control device, higher temperatures reduce the volatile substance capture efficiency. Lastly, in some dry injection systems, the recycling of the fabric filter dust to the venturi reactor, to increase SO_2 removal efficiencies and lower reagent costs, can result in an increase in the concentration of salts and trace species in the residue stream. This increase leads to different residue behaviour and can change the costs of residue disposal.

Operating experiences at most commercial incineration facilities has suggested that even with advanced acid gas and particulate control systems, further control is necessary to achieve the desired levels of PCDD/F emissions.

A good particulate matter control device can reduce the emissions of trace metals and trace organics. As noted above, lime offers numerous sites for surface sorbtion reactions that allow these materials to be trapped and removed with the particulate matter. In a similar manner a common reagent used for mercury control, carbon, provides excellent PCDD/F control.

Several different technologies can provide the required removal efficiency for organic contaminants in the flue gas stream. Carbon based systems are effective for PCDD/F control. The two main variants of this technology are PAC injection into the gas stream and carbon bed filters known commercially as activated char reactors [ACR] or adsorbers. Recently a new carbon system, the ADIOX process, has been developed in Europe. This system has been applied in many European wet cleaning systems where the scrubber elements have been replaced by carbon impregnated polypropylene elements. Another control measure, the catalytic reactor, destroys the PCDD/F molecules.

4.2.1 Activated Carbon Bed Filters

One European manufacturer developed a fixed activated carbon bed scrubber that could be installed at the end of the APC system to polish the gases and remove trace organics and mercury. The activated char adsorber consists of a vertical chamber with a bed depth of typically 0.5 to 1 meter. The flue gas flows through the ACR horizontally at a velocity of typically between 0.1 and 0.2 m/s. The activated char slowly migrates from the top to the bottom of the reactor at a rate of about 0.15 m every 6 –12 hours. The size of an ACR can be determined by the its

maximum width of 6 meters and the maximum permissible flue gas velocity of 0.2 m/s. The height should not exceed about 20 meters, thus several modules might be required in parallel. ACR's require operating temperatures between 120 and 150 °C to avoid condensation.

ACR systems have the highest known removal efficiency for dioxins and furans (> 99.9%) as well as for many other pollutants and are commonly used in Europe (Austria, Germany, Holland), Asia (Japan, Korea) and Australia as a final flue gas polishing stage for waste incinerators, iron ore sintering plants and other industrial installations with high pollutant emissions. Numerous adsorbents such as activated char made from brown coal or lignite, activated carbon made from bituminous or hard coal, activated charcoal made from wood or coconut shells, or Aktinert made from activated char or carbon and lime or limestone are used. The main criterion for selecting an appropriate adsorbent are availability and cost. The spent adsorbent including the adsorbed dioxins and furans needs to be safely disposed, preferably by incineration.

The major disadvantage of the carbon filter system is the capital investment and operating costs associated as well as the need for proper disposal of the spent adsorbent. Concerns have also arisen over the potential for fires in these systems should organic loads in the carbon get too high. The latter should not pose a problem with incinerator installations where the char can be fed to the furnace.

The most recent application of carbon bed filters in Canada is at the Medical Waste Management in Brampton. This facility utilizes a totally factory assembled and skid mounted APC system, manufactured by EMCOTEK. This unit consists of a high temperature water wall inlet and quench tower followed by a condenser/spray tower, two rotary atomizer modules for particulate removal, a proprietary three stage MistFree polypropylene acid absorber and demister system, followed by a steam re-heat system to raise gas temperature to 50^{O}C before introducing the gas to a carbon bed filter/HEPA system for mercury and PCDD/F polishing. The filter module consists of a granular carbon bed filter followed by a particulate air filter to ensure that any carbon dislodged from the granular bed is not discharged through the stack. Approximately 2250 kg of 4x6 mesh granular carbon are contained in the bed built for the MWM facility. The carbon is sandwiched between two perforated steel plates allowing flow to move upwards through the bed of carbon. This carbon needs to be replaced periodically depending upon the amount of Hg and PCDD/F removed from the stack gases. The gases are moved through the APC system by an ID fan with variable frequency drive designed to maintain draft on the incinerator. This system performs very effectively, the results in annual testing at the MWM facility are consistently below the LOQ.

4.2.2 PAC Injection Systems

While producing a lower removal efficiency, the injection of powdered activated carbon into the gas stream is a less expense method of controlling PCDD/F emissions. Such a system has been defined as an entrained flow adsorber. This usually consists of a baghouse with an activated carbon injection system upstream. PCDD/F is removed via adsorption onto the injected activated

carbon. The bulk of the adsorption takes place while the adsorbent is entrained in the flue gas flowing towards the baghouse. The filter cake formed on the bags provides an additional barrier for the flue gas to pass through thereby providing additional adsorption.

The major disadvantages of entrained flow reactors are associated with the consumption of activated carbon as well as the inevitable disposal problem of the residues. Entrained flow reactors are widely used in waste incinerators, steel plants, and numerous other industrial applications throughout Asia, Europe and North America. Even though entrained flow reactors are less costly than ACRs the investment and operating costs are significant.

Heath [23] reports that PAC injection provided PCDD/PCDF removal efficiencies of 77-80% at an ESP equipped facility. This is similar to the performance reported in ASME sponsored work at Davis County. Licata[24] reports on the Wurzburg tests and notes that PCDD/PCDF emissions were reduced 200 fold. Data received by the US EPA [25] led the Agency to conclude that an additional 50 percent or greater reduction of PCDD/PCDF emissions can be achieved with carbon injection in MSW facilities. In the Heeren facility in Roosendaal, The Netherlands, PAC experiments have shown 99.9% PCDD/PCDF reduction[26].

Quebec City, Vancouver and Brampton EFW facilities all use PAC injection as mercury and PCDD/F control techniques. This technique is also employed at the Corunna hazardous waste facility and on one of the two incinerator trains at the Swan Hills Treatment Facility.

4.2.3 Catalytic Destruction

PCDD/PCDF are organic compounds that can be destroyed by oxidation, producing CO_2 and water vapour, however trace amounts of HCl are also generated. Normally such oxidation takes place at high temperatures to take advantage of faster reaction times. Of course, raising the gas temperature requires the expenditure of energy making this approach impractical for large MSW incinerator installations. To overcome this limitation, catalysts such as platinum and oxides of vanadium and titanium which promote thermal oxidation at low temperatures can be employed.

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[23] Heath, Patrick B., 1995. Design and Installation of Powdered Activated Carbon Storage and Injection Systems for Municipal Solid Waste Incinerators. Proceedings of the 88th Annual AWMA Meeting. Paper 95-RP-147B.01. San Antonio, Texas. June.

[24] Licata, A., M. Babu, and L-P Nethe, 1994. An Economic Alternative to Controlling Acid Gases, Mercury, and Dioxins from MWC's. Proceedings of the 87th Annual AWMA Meeting. Paper 94-MP-17.06. Cincinnati, Ohio. June.

[25] U.S. Environmental Protection Agency, 1995BID.

[26] Unsworth, J.F., Dioxin removal by CRI's Shell Denox system, Heeren Waste Incineration trials, Roosendaal, The Netherlands, CRI Catalyst Co. UK Ltd., Woking, GU21 5BH, UK. As quoted in Andersson et al.

These catalysts can be employed in selective catalytic reduction (SCR) NO_x control systems where a catalyst is used to increase the low temperature reaction of ammonia and oxides of nitrogen to create nitrogen and water vapour. The addition of these catalysts promotes oxidation at lower temperatures than would normally be required for organic compounds. Using these metals in a selective catalytic reduction process for NO_x control and operating the catalyst in the 230 to 310°C range provides very effective removal of PCDD/PCDF. Even at temperatures as low as 165°C, 50% destruction of PCDD/PCDF is anticipated. The higher the temperature the greater the organic destruction. The systems have become known as SCR DeDiox technology.

Catalysts are not inexpensive and their life is not infinite, however, the simplicity of the operating system is such that only limited maintenance is required. Catalytic reduction of organics is most practical when it can be combined with NO_x reduction because of the high cost of constructing and operating such equipment. However, catalytic reduction of PCDD/PCDF ensures that the materials are destroyed, not just transferred to another media such as APC residues which ultimately must be disposed.

Since the SCR DeDiox technology has no moving parts and is essentially a piece of expanded duct, the investment as well as the operating costs are the lowest of all the alternatives. This is mostly influenced by the fact that the technology doesn't require any additives such as adsorbent and the PCDD/F are destroyed residue free. More than 10 years of full scale commercial operating experience is available for a wide array of applications in numerous different industries.

The only SCR DeDiox installation in the Canada is installed at the Algonquin Power EFW incinerator site in Brampton, ON. Treating approximately 35 Rm^3/s @ 11% O_2 of stack gases, the system operates at 235°C. Prior to the installation of this equipment, the upper confidence limit of all the PCDD/F emission concentration measurements conducted at site over a 9 year period was 280 pg TEQ/Rm^3 @ 11% O_2. During commissioning testing in November 2001 the facility recorded three PCDD/F emission concentration values well below the EnvCan LOQ of 32 pg TEQ/Rm^3 @ 11% O_2. This translates to removal efficiencies in excess of 88%. Since that time the facility has converted to using PAC to remove mercury from the stack gases and subsequent annual emission testing suggests that the PCDD/F removal efficiency, based upon pre-expansion levels, are on the order of 99.5%. As noted elsewhere in this document, the testing method is not capable of reliably reporting PCDD/F concentration values below the LOQ, nor has the inlet to the SCR DeDiox system been measured concurrently, so it is not possible to state the absolute removal efficiency achieved at the site. Also notable is the lack of other volatile organic species in the stack testing results. The quantity of most trace organics collected in sampling trains before the SCR waste installed were measurable, whereas after the SCR went into operation, these substances are not detectable in the laboratory. The PCDD/F emissions from the facility have been reduced significantly. Furthermore, the material was destroyed, not transferred to another media, so PCDD/F removed in the system no longer exists.

Catalytic reactions can be employed in different ways as demonstrated by one of the fabric filter

manufacturers.[27] They created a catalytic filter system. The system employs both surface filtration and catalysis to remove particulate matter from the gas stream while oxidizing the PCDD/F to the more common chemicals. The system consists of an ePTFE membrane filter with a catalytic needle punched felt substrate made from ePTFE fibres containing PCDD/F destroying catalyst. The GORE-TEX membrane captures sub-micron particle and does not allow them to pass through the catalytic felt. Bonte et al. report that the performance of this filter system was demonstrated on the Belgium IVRO MSW incinerator with destruction efficiencies on the order of 99.5%.

Many have questioned whether catalytic systems merely adsorbed the PCDD/F. Bonte et al. quote data from Weber[28] and Xu[29] that show little if any PCDD/F is adsorbed onto the catalyst however they note that these tests did not include the effect of particulate matter and thus they undertook tests on the filter material from IVRO to see if the particulate adsorbed PCDD/F. These tests showed that the particulate phase PCDD/F in the gas stream ahead of the filter and in the fabric filter dust were equivalent. The filter itself appeared to retain less than 0.01% of the PCDD/F present in the raw gas stream.

4.2.4 Other Removal Techniques

Companies and researchers continue to look for new approaches to air pollution control systems. One such product is supplied by Götaverken Miljö of Sweden. In the early 1990s during the start-up of the new Amsterdam MSW incinerator researchers noticed that the PCDD/F emissions were not consistent under different operating conditions. Further study showed that the plastic materials used in the system absorbed PCDD/F under some conditions and under other conditions the contaminants were released from the plastic back into the gas stream. The researchers hypothesized that this effect, which they likened to a flywheel storing and releasing energy, could be the reason that the performance of the facility was not at expected levels. This is now recognized to be a "memory effect" that is a function of temperature, concentration and the nature of the plastic materials. In wet scrubbing systems the packing materials are frequently constructed of plastic thus there was a need to reduce the memory effect.

Originally developed at the KfK in Germany[30], Götaverken Miljö markets a new material for the packing that has carbon particles homogeneously embedded in polypropylene. They called this

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[27] Bonte, J.L., K.J. Kritsky, M.A. Plinke, M. Wilken. 2001. Catalytic Destruction of PCDD/F in Fabric Filter: Experience at a Municipal Waste Incinerator in Belgium. IT3 '01 Conference, Philidephia, PA. May, 2001.

[28] Weber, R. et al. 2000. Dioxin Destruction Efficiency of Catalytic Filters - Evaluation of Laboratory and Comparison to Field Operation" Organohalogen Compounds, 45, 2000, pp. 427-430. As cited in Bonte et al.

[29] Xu, Z. 2000. Catalytic Destruction of PCDD/F: Latoratory Test and Performance in a Medical Waste Incinerator. Organohalogen Compounds, 45, 2000, pp. 419-422. As cited in Bonte et al.

[30] Andersson, S., Kreisz, S., Hunsinger, H. (2002) *Organohalogen Compounds* 58: 157-160.

material Adiox[31]. The plastic still absorbs the PCDD/F but these contaminants diffuse through the polypropylene to the carbon particles where they are irreversibly adsorbed to the carbon. The plastic acts as a barrier for the carbon ensuring that it is not contaminated by other materials such as mercury.

The ADIOX material has been installed in a number of applications including a scrubber at a Dow facility in Canada. The initial application in an incineration facility was in the Thisted EFW in Sweden. In 2001, the packing in the wet scrubbers was replaced with Adiox packing. Initial removal efficiencies were in excess of 90% with inlet concentrations in the 6 - 10 ng/Nm^3. Testing at 3, 6 and 9 months showed the gas phase removal efficiency values consistently in the range of 65 - 75%. After 12 months the total removal efficiency was still in the 80% range. After the first year of operation a baghouse and PAC addition were installed ahead of the scrubber. The Adiox did not release PCDD/F at the lower input concentration as evidenced by emission concentrations in the 45 pg/Nm^3 range. These results were from a wet scrubber with a saturated gas stream so water on the packing would interfere with the transfer efficiency. In 2004 a dry Adiox absorber was installed at another Swedish incinerator. Gas treatment in this system consists of an ESP, two wet scrubbers, reheater and a bag house filter. The Adiox dry scrubber was installed in the gas stream between the reheater and the baghouse and operated at temperatures in the 60 - 80^{O}C range. Efficiencies in excess of 97.5% were recorded in various tests, with the highest efficiencies, >99%, being recorded at the highest temperatures. The manufacturer suggests this occurs because the diffusion reactions occur faster at the higher temperatures.

The dry scrubber can be designed to operate at approximately 20^{O}C above the dew point. The scrubber can be housed in a tower of between 0.5 and 7 m in diameter and 4 to 15 m high depending upon the operating conditions and desired emission concentration.

The manufacturer has not determined how long the packing material will last. Various documents on the web site suggest it will be at least a few years before it might need to be replaced. Disposal of the existing packing could be done in the incinerator were the absorber is installed however feed rates would need to be controlled to ensure that the thermal capacity of the system is not compromised.

[31] http://www.gmab.se/documents/Andersson_DryAdiox_Dioxin2005_CD2218_000.pdf

5.0 PCDD/F SAMPLING METHODS

5.1 Introduction

Measurements of PCDD/F concentrations in the exhaust gas streams of combustion sytems were required during research needed to develop both the understanding of the mechanisms discussed in Chapter 2 and the Air Pollution Control systems discussed in Chapter 4. Indeed early NITEP work[32] included an evaluation of the newly developed ASME Modified Method 5 protocol for sampling and analysis of PCDD/F in incinerator stacks. Since 1984 sampling methods have been revised to ensure that the quality of the reported results, and to meet the increasing demands posed by lower and lower emission concentrations.

The methods employed in different jurisdictions are reviewed in this chapter. While there are several sampling procedures employed for collecting PCDD/F and PCB contaminants in stack samples, the methods currently incorporated in North American and European regulations and permits are similar. Gas being exhausted is sampled by extracting a portion of the flow stream isokinetically; filtering the extract to concentrate the species of interest; and, recovering the concentrated sample from the sampling system so the laboratory analysis can be completed using HRGC/HRMS techniques are the basic steps in all methods. Being similar, they should produce similar results if the methods are employed by trained samplers and chemists who take care with their tasks.

Even if testers provide reliable measurement results, the methods have limitations. In the analytical laboratory the ability to measure the quantity of PCDD/F present in the sample is limited by the instrumentation. Converting the analytically determined quantity to an emission concentration requires that both the sample volume and the stack gas flow be quantified. There are limitations in these measurements as well. When all the measurement factors are combined they introduce some uncertainty in the reported results.

Both the concept of the detection/quantitation limit and the concept of uncertainty in the reported results are presented in this chapter. Since these concepts are based upon statistical analysis of data, a more intensive treatment of the is provided in an appendix to the report.

Regardless of the sampling method employed, traditional stack sampling procedures present limitations both to researchers and operators of combustion equipment. The sampling methods are labour and equipment intensive, requiring a minimum of 4 hours sampling time to extract sufficient sample from the stack. Typically a minimum of 2 people must undertake this task, but it one is attempting to ensure that operating conditions are appropriate during the testing continuous emission monitoring equipment is also operated by another person at the same time. After the sample is collected, it must be recovered from the sampling train, this usually takes at

[32] NITEP, 1986. "The National Incinerator Testing & Evaluation Program, (NITEP), Air Pollution Control Technology". Environment Canada, Report EPS 3/UP/2, September.

least 1 hour and typically sampling teams dedicate one person to this task. The sample is delivered to the laboratory and analysis requires 6 - 8 weeks under normal conditions. Analytical costs can be as high as $1500/sample, putting the cost of the average sampling campaign at nearly $30,000. So, $10,000 per result and 90 days of time are required. This can be viewed as unsatisfactory because people want to be ensured that the system operates properly all the time. To provide that assurance, the continuous operating data is typically monitored, and indeed regulations require that facilities be operated within the operating range they were tested at. Typically the other parameters monitored for this purpose include: temperatures, flows, pressures, reagent feed rates, waste feed rates, and combustion gas concentrations.

Some longer term sampling systems have been developed in an attempt to provide more assurance that continuous operation is satisfactory. By monitoring for a longer period, with an in-situ system, labour is reduced and analytical costs are controlled. Two such methods are discussed in this chapter.

For the researcher, access to instantaneous measurements of PCDD/F concentrations would be ideal, however given the quantitation limits existing analysers this is not possible. Researchers are thus looking into employing surrogates that reflect PCDD/F emissions but can be measured on a continuous basis[33]. While these techniques are not appropriate for regulatory testing, they are reviewed in this chapter to illustrate developments in the field.

5.2 Regulatory Methods

Measurements are required to determine the concentration of PCDD/F and dioxin-like PCBs in the exhaust gas stream of an incinerator are typically defined in regulations.

In North America the method employed is referred to as US EPA Method 23[34]. Method 23 forms the basis of the Environment Canada methods which were developed subsequent to the 1984 NITEP PEI study to formalize a sampling and analysis procedure for PCDD/F and semi-volatile organic species in Canada. Employing the Environment Canada methods provides quantification of PCBs, chlorobenzenes, chlorophenols and poly aromatic hydrocarbons as well as PCDD/F. This is unlikely the analytical method used in the United States as part of Method 23 which only provides PCDD/F data. The Environment Canada modifications involve different train spiking and sample handling procedures when the sample is returned to the laboratory. Typically, stack sampling consultants in Canada still refer to the PCDD/F sampling method as Method 23. The

[33] US EPA, 2004. The Use of Surrogate Compounds as Indicators of PCDD/F in Combustor Stack Gases. An report by Paul Lemieux. Available at: http://www.epa.gov/appcdwww/aptb/EPA-600-R-04-024.pdf

[34] US EPA Method 23 - Determination of Polychlorinated Dibenzo-p-dioxins and Polychlorinated Dibenzofurans from Municipal Waste Combustors. 02/91 FR Copy. Available at: http://www.epa.gov/ttn/emc/promgate/m-23.pdf

same method is employed in both Australia and New Zealand.

Quass et al.[35] note that EN 1948[36] is the European standard guideline for sampling and analysing PCDD/F emissions from waste incinerators. It is stated that EN 1948 is the basis for national standard guidelines for the determination of the dioxin emissions in many European countries, (e.g. CSN EN 1948; DIN EN 1948 and VDI of 3499 etc.). VDI 3499 sheets 1 to 3 are the German standard guideline for the determination of dioxin emissions from stationary sources, and provides two measurement procedures: Part A the application of DIN EN 1948 for PCDD/F-emissions at levels of about 0.1 ng I-TEQ/m³; and, in Part B the method is modified for PCDD/F concentrations in excess of 0.1 ng I-TEQ/m³ . While using the method for PCDD/F determinations has been validated, the method had not been validated for PCB by October 2005.

Calling upon the work of Quass et.al. the following material provides a comparative description of the various procedures mentioned above. The following is divided into 3 sections:

- sample collection and recovery;
- sample extraction and clean-up; and,
- identification and quantification of samples.

5.2.1 Sample Collection Alternatives

European Methods as Endorsed by CEN

The standard procedures used for PCDD/F sampling in Europe are covered by EN 1948-2006. EN 1948, provided in 3 volumes, was published in a revised version in May 2006. The method includes directions for sampling, extraction and clean-up, and identification and quantification in separate sections; Volume 1 deals with sampling.

This guideline was developed and validated for the measurement of PCDD/F emissions in the range of 0.1 ng I-TEQ/m³ with dust loading up to 15 mg/m³. PCB concentrations, according to Quass et al., should be in the range of 0.01 ng WHO TEQ PCB/m³ based upon information in a fourth volume of the standard which is still in draft status.

EN 1948 suggests that 3 different sampling methods can be used. As is standard for all methods,

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[35] Quass, Ulrich, Christine Kube, Stefan Haep, Alfons Buekens, Bernard De Caevel, Catherine Lambert, 2005. Preparatory work for new dioxin measurement requirements for the European metal industry. Final Report Reference ENV.G.2/ATA/2004/0070 October 2005. Intended for European Commission DG Environment. Available at: http://europa.eu.int/comm/environment/ippc/pdf/dioxins_final_rep.pdf

[36] EN 1948-1, -2 and -3. 2006. Stationary source emissions – Determination of the mass concentration of PCDDs/PCDFs. European Standard approved by CEN on 2006-1-23. Obtained through ANSI from SIS.

the sample gas is taken at a flow rate that matches the velocity in the stack, thus capturing particulate matter in a representative manner. All sampling methods require that surfaces in contact with the sample gas be manufactured from glass.

The first method listed is known as the **Filter/Condenser** Method. The sample gas passes through a particulate matter removal device maintained at a temperature between the dew point and 125°C. The removal device can take several forms from a filter, to a cyclone/filter arrangement or even a packed glass wool filter. After the particulate matter is removed, the sample gas is cooled down to below 20°C. The gaseous PCDD/F compounds are collected either in absorption solutions (impinger) or on a solid adsorbent. The total PCDD/F content is determined as the sum of the contents in the following compartments:

- Glass tube of the probe (if used)
- Particle filter (and packed glass wool filter or cyclone)
- Condensate
- Impinger solution and/or solid adsorbent
- Rinsing solution (used for cleaning of all glass surfaces)

The second method, known as the **Dilution** method involves collecting the gas through a heated probe followed by rapid cooling of the gas stream to below 40°C. Cooling is accomplished in a mixing channel by diluting the gas with dried and filtered air. The dilution prevents the temperature from falling below the dew point of water. A combination of a particle filter and solid adsorbent is used to separate and accumulate the PCDD/F contained in the sample gas.

Compartments for the analysis are

- Particle filter;
- Solid adsorbent; and,
- Rinsing solution.

To ensure that the dilution air cannot contaminate the sample, this air is passed through a filter and solid adsorbent before being combined with the sample gas. This portion of the train is renewed for each test and, should the sample results be unsatisfactory, the dilution air filter unit has to be analysed to check for possible contamination of the sample by the dilution air.

The third method, known as the **cooled probe** method, involves collecting the sample gas using a water-cooled probe. The sample gas temperature at the exit of the probe, must be below 20 °C. Any condensate formed in the probe is collected and the majority of the particles in the gas stream collect in the condensate. The gaseous PCDD/Fs from the sample gas are accumulated on solid adsorbents or in impingers. A particle filter is installed before the final sorption step to collect small particles or aerosols.

Compartments for the analysis are:

- Condensate;
- Impinger and/or solid adsorbent and filter;
- Rinsing solution.

Regardless of the sampling method employed, the procedures require that a field blank be used to ensure that contamination does not enter the system during transport, handling and recovery, and return of the equipment to the laboratory. Blanks should not exceed 10% of the regulatory limit. The sampling trains are spiked with $^{13}C_{12}$-labelled standard substances (PCDD/Fs and/or PCBs). As a second quality control standard, the recovery rate of each standard substance must be greater than 50%, calculated on the basis of the extraction standard.

Specific Methods used in Germany for High Concentrations or High Dust Loads

The German standard VDI 3499 is also provided in three parts, sheet 1-3[37]. The three parts of VDI 3499 describe the three different sampling methods outlined above in the discussion of EN 1948. Each sheet (1, 2 or 3) is divided into two parts: "A" covering sampling and analysis identical to the EN-1948 procedures; and, "B" a modified measurement procedure for PCDD/F emissions on systems anticipated to exceed 0.1 ng I-TEQ/m³ or to have dust loads greater than 15 mg/m^3. Part B procedures are described in the following paragraphs.

Part B provides modifications for cases with high PCDD/F emission concentrations, emissions with high dust loading, emissions containing tarry particles or for measurements of uncontrolled exhaust gas streams.

As a precaution, the standard notes that separate sampling trains must be used for high and low ranges of emission concentrations. This is to avoid the potential for memory effects. A sampling train previously used in a PCDD/F emission concentration range much higher than 0.1 ng I-TEQ/m³ must not be used in the lower concentration range of <0.1 ng I-TEQ/m³.

In cases where there is a high dust loading an additional particulate matter filter has to be installed in the sampling train. For the dilution method and dust concentrations above 100 mg/m^3, the method recommends a WB50 filter be added to the system. For the filter/condenser method used in situations where the dust concentration is >20mg/m³ the method recommends a packed quartz wool filter.

Furthermore, the methods recommend that the mass of the $^{13}C_{12}$ labelled standard substances (sampling, extraction and injection standards) be adapted to the expected PCDD/F emission

[37] VDI 3499, A Standard Guideline for the Determination of PCDD/F emissions from stationary sources. Sheet 1-3; 2003;

concentration and that the sampling time be adapted to the measurement task (up to 8 hours).

North American Procedures

The North American standard, Method 23, was referenced in the introduction to this section of the report. In this case the sampling train is configured with glass nozzle and probe, a glass fibre filter and a solid adsorbent (XAD2) housed in a glass cartridge.

Compared to EN 1948 this sampling method could be thought of as a simplified filter/condenser method. The sample gas is brought to a temperature of ≥120 °C in the probe and filter and then it is further cooled in the condenser. The temperature of the sample gas should then not exceed 20°C. The gaseous PCDD/F are collected on a solid adsorbent. The condensate is collected after the adsorption stage exclusively for the determination of the moisture. The relatively complex liquid-liquid extraction of the condensate, as intended in EN 1948 and VDI 3499, is not required.

Compartments for the analysis are:

- Particulate filter (glass fibre filter);
- Solid adsorbent (XAD2);
- Rinsing solution.

Quass et al. suggest that Method 23 is suitable to determine PCDD/F concentrations from 0.2 to 0.4 ng I-TEQ/m³ in the flue gas; however, this method is routinely used in Canada for concentrations considerably below this level. While it is suggested that the guideline should be good for dust loadings up to 20 mg/m^3, the train can be modified with the addition of a cyclone before the filter if it is to be used for raw gas sampling at higher concentrations.

While there is no information in Method 23 on using the method for the collection of other organic components, like PCB or PAH, the Environment Canada sampling and analysis procedures[38] provide for such analyses.

In the Environment Canada approach, the train consists of 4 impingers, filled with empty/ethylene glycol/empty/silica gel respectively. Recovery of the samples include cleaning and rinsing the nozzle/probe assembly and retaining the rinsings. Removing the filter from the housing and saving. All the sampling train ahead of the filter is then cleaned and rinsed with the rinsings being combined with those from the probe. The XAD-2 trap and the cooling jacket are sealed and returned to laboratory for sample recovery through extraction. The contents of the 1st

[38] Environment Canada, 1989. Reference Method for Source Testing: Measurement of Releases of Selected Semi-Volatile Organic Compounds from Stationary Sources, Department of the Environment, Report EPS 1/RM/2, June. and: A Method for the Analysis of Polychlorinated Dibenzo-Para-Dioxins (PCDD), Polychlorinated Dibenzofurans (PCDF) and Polychlorinated Biphenyls (PCB) in Samples from the Incineration of PCB Waste, Department of the Environment, Report EPS 1/RM/3, June.

three impingers are combined as another sample. Rinsings from the impingers are combined in a 2nd impinger sample.

Summary of Sample Collection Procedures

Table 5.1 summarizes the regulatory requirements for sampling PCDD/F's in Europe and in those jurisdictions that have adopted US EPA Method 23 as the basis of testing.

Table 5.1 Comparison of Regulatory Sampling Methods

Standard	Range of PCDD/F [ng ITEQ/Nm^3]	Basis of Sampling	Temperature [^{O}C]	Samples Created	PCB Validated
EN 1948	<0.1 Note: dust concentration <15 mg/Nm^3	Filter/ Condensor	20	5	no
		Dilution	40	3	no
		Cooled Probe	20	3	no
VDI 3499	>0.1 Note: Dust >20 mg/Nm^3	as above but particulate filter added to train - quartz glass or WB50			no
Method 23	0.2 - 0.4 Note: Dust <20 mg/Nm^3	Simplified filter/ condensor method	20	3	validated with Env Canada Method
	Dust >20 mg/Nm^3	as above but add cyclone		4	as above

5.2.2 Sample Extraction and Clean up

In all the regulatory methods, the samples must be returned to the laboratory for analysis. This section discusses the various procedures used by the different methods. Each of the regulatory methods outlined were published with detailed laboratory analysis procedures. While similar, it is appropriate to review the methods as the sample extraction and clean up procedures influence the limits of detection of the methods. Generally, the laboratory analysis procedures require a two part process:

- extracting the PCDD/F and other organics from the collection matrix;
- cleaning the extracted materials; and,
- analysing the quantity of PCDD/F and other contaminants using high resolution

gas chromatography coupled with a mass spectrometer.

The steps and cautions from the methods are outlined in the following sections.

European Methods

The extraction and clean up procedures for samples collected with EN-1948 methods are outlined in 1948-2, the second volume of the standard.

Soxhlet extraction and liquid-liquid extraction procedures are used. A cleaning procedure for the raw extract of the sample removes matrix components, which could disturb the separation process. In addition an enrichment of the PCDD/Fs and/or PCBs is achieved.

The separation of PCDD/Fs and PCBs takes place during a column chromatography clean-up, e.g. using Florisil or Alumina. In principle several clean up steps can be used, provided the procedure is validated.

In each sample the recovery rate of each standard substance of the extraction standards shall be:

- 50 – 130 % for the tetra- to hexa-chlorinated congeners
- 40 - 130 % for the hepta- to octa-chlorinated congeners.

Deviations are permissible if the contributions of the respective congeners do not exceed 10 % to the total I-TEQ (30 - 150% for the tetra- to hexa-chlorinated; 20 - 150% for the hepta- to octa-chlorinated congeners).

The recovery rate for the PCB extraction standard substances shall be 40 - 120 %.

German Clean-up Procedures

Subsequent to sampling, the VDI methods outlines clean-up and other procedures generally following those outlined in EN 1948. However, when tarry and similar components are present in the raw extracts of the samples, these are to be subjected to additional clean up methods using sulfuric acid. The sulfuric acid effects the decomposition of various organic matrix components.

In addition to the collection of PCDD/Fs the sampling device is also suitable for the determination of further organic compounds (e.g. PCB's, PAH's). However, these measurements have not been validated. Typically, the sampling methods in part B are applied to a wide range of facilities e.g. smelting plants for the recovery of copper and aluminium and iron sintering plants.
Method 23

For Method 23, the extraction steps, clean up and identification as well as the quantification of the

PCDD/F congeners are similar to EN 1948. The configuration of the $^{13}C_{12}$ labelled standard substances are slightly different than those in EN 1948 but this should not be considered significant. One major difference from the EN 1948 directions, Method 23 calls for adding approximately 2.5 to 5 more standard to the train.

To monitor extraction, clean-up and analysis of semi-volatile samples, labelled surrogates are added to the samples before extraction. One set to the solid samples before the soxhlet extraction. A second addition, the injection standards are added just prior to sample injection. The XAD-2 resin cartridge receive a field spike prior to deployment into the field. Clean-up efficiencies are determined by the addition of an alternative standard prior to the clean-up phase.
With the Environment Canada modifications to Method 23, at the laboratory, solids are extracted with dichloromethane followed by toluene. Toluene acidified with trifluoroacetic acid is used to ensure extraction of chlorophenols and PCDD/F. The combined extracts from the various parts of the train are split 5 ways prior to clean-up. One is retained for re-analysis if necessary. The remaining four are cleaned for various analyses: PCDD/F; PCB/CB; CP; and PAH.

Summary of Recovery and Clean-up Procedures

With the exceptions of the German methods to deal with tarry residues or those with high dust loadings, and the Canadian procedures that provide samples for determination of additional species, the sample recovery and clean-up procedures outlined above are reasonably similar. The caution is that these methods must be applied by qualified professionals in laboratories designed and equipped to produce high quality results on samples containing very low concentrations of the target species.

5.2.3 Identification and Quantification

Regardless of the sampling and clean-up procedures determination of PCDD/Fs and dioxin-like PCBs is based upon quantitative analysis using the isotope dilution techniques with a high resolution gas chromatograph/high resolution mass spectrometer [HRGC/HRMS] system. This technique relies upon quantifying the $^{13}C_{12}$-labelled standard substances, which are added to different steps of the overall procedure as internal standards. There are some differences between the methods outlined in the various protocols.

European Methods

For the identification of the congeners

- a HRGC/HRMS with a mass resolution of 10,000 is necessary. A resolution in the range from 5,000 to 10,000 is acceptable if the absence of interferences is well documented.
- At least two ions of the molecular isotope cluster of each chlorination shall be

recorded.

- The isotope ratio between the ions must correspond to the theoretical value of 20% (PCDD/F) and 15% (PCB).
- The retention times of the native congeners are within a time window from +3 s to 0 s compared to the signal of the corresponding $^{13}C_{12}$-labelled standard substance.
- The signal-to-noise ratio of the raw data must be at least 3:1 for the signal taken for identification.

Additionally, the identification requirements of the following important points must be fulfilled for quantification:

- The separation of all PCB congeners of interest shall be achieved by using a standard reference mixture.
- It is not possible to separate all 2,3,7,8-chlorinated PCDD/F congeners by using only one chromatography column. Multiple analysis by using different chromatography columns allows for a complete separation. Results of an individual column may be recorded. If the regulatory limit is exceeded, additional confirmation analysis is necessary.
- The recovery rates of the extraction standard substances must correspond to the requirements specified already.
- The measuring range must be linear (at least 5-point-calibration for the determination of the response factors).
- An extraction blank value is to be determined. The concentrations of all congeners should be below the limit of determination and/or factor 10 below the lowest measured concentration.

German Methods

Analytical procedures are identical to the EN 1948 method using HRGC/HRMS and isotope dilution technology.

Method 23/Environment Canada

Isotope dilution analysis procedures use the internal standard values to correct the resulting PCDD/F data for recovery. No surrogate recovery factors are applied to the results of the PAH, PCB, CB or CP data. It should be noted that at present PCB/CB and PAH/CP analyses are completed with low resolution GC/MS.

Summary of Analysis Procedures

As with the other portions of this review of methods, analytical procedures are similar in all standards. For the experienced practitioner application of the analytical procedures to produce good results requires knowledge of the equipment being used and how to determine if the

equipment is operating at the appropriate level when testing. Quality assurance, quality control procedures must be adhered to if the analyst is to ensure high quality data.

Regardless of the methods employed, the results should be comparable.

5.3.4 Minimum Detection Limits

No discussion of PCDD/F sampling and analysis would be complete without some reference to the method capability to measure low concentrations. This is sometimes referred to as the limit of quantification [LOQ]. Essentially, the aim is to establish the lower end of the analytical results that can be reliably reported.

Currently, in Canada, the LOQ for PCDD/F is defined[39] in terms of the ITEQ value for the sample. The ITEQ value, discussed in the next chapter, is calculated by summing the product of each of the individual congeners multiplied by its respective toxic equivalency factor, to provide a single number describing emission concentrations. For stack sampling data the Environment Canada LOQ value is set at 32 pg ITEQ/Rm^2 @ 11% O_2. According to the report, the LOQ was determined by assessing the variability (standard deviation) of repeated measurements of analytes at a concentration near the detection limit. In Canada, the LOQ is used as a baseline to assist in establishing the virtual elimination target.

The LOQ should not be confused with the detection limit for a sample. The definitions in EN 1948 distinguish between the two terms:

- limit of detection [LOD] - minimum value of the measurand for which the measuring system is not in the basic state, with a stated probability. Typically, the LOD is expressed as the mean analytical blank value [b_{ave}] plus three (3) times the standard deviation of the analytical blank [s_b]. The equation is thus:

$$LOD = b_{ave} + 3s_b$$

  The typical confidence level used for this expression is 99%. In EN 1948 the LOD should preferably be calculated from the analytical blank average. If this is not possible, the LOD can be calculated from the signal to noise ratio according to EN 1948 Part 3 §8.1 which states that the signal-to-noise ratio of the raw data shall be at least 3 : 1 for the native congener signal used for identification.

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- limit of quantification [LOQ] limit above which a quantification of the measurand is possible, is expressed as the mean analytical blank value plus, five to ten times the standard deviation of the analytical blank. The factor *F* depends upon the

[39] Environment Canada, 1999. Level of Quantification Determination: PCDD/PCDF and Hexachlorobenzene. A report by Analysis & Air Quality Division, Environmental Technology Centre, Environment Canada. November

accepted measurement uncertainty. The equation defining the LOQ is thus:

$$LOQ = b_{ave} + Fs_b$$

In EN 1948, the limit of quantification should preferably be calculated from the analytical blank average however, if this is not possible, the limit of quantification can be calculated from the signal to noise ratio as defined in Part 3 §8.3e, that is the signal-to-noise ratio of the native congeners shall be 10 : 1 and the signal-to-noise ratio of the $^{13}C_{12}$ labelled congeners used for quantification shall be > 20 : 1.

The EN 1948 standard defines a permissible limit of quantification [LOQ] for individual congeners as:

$$LOQ_i \leq \frac{0.5\,pg / m^3}{I - TEF_i}$$

Where LOQ_i = individual congener level of quantification and
$I\text{-}TEF_i$ = international toxicity equivalence factor for the congener

Unlike the Canadian LOQ, which is a single number defining the limit below which it can be said that PCDD/F's have been eliminated, the EN 1948 approach requires that the concentration of each congener be determined and these data be incorporated into the calculation of the ITEQ value of the sample. If the concentration of any congener is less than the value derived from the equation above, the ITEQ value for the emission concentration must be reported in two ways:

- the sum of the product of the concentration and the toxic equivalency factor for all the congeners with the mass of those below the LOQ being set equal to the LOQ; and,
- the sum of the product of the concentration and the toxic equivalency factor for all the congeners with the mass of those below the LOQ being set equal to zero.

At the LOQ, the quantity of each of the individual congeners that represent the minimum that could be quantified for a typical 5.5 m^3 sample is shown in the third column of Table 5.2. Ideally, laboratories might be able to report lower values and some do, as exemplified by the low end of the range in the fourth column of the table. However, the reality is that the LOQ calculated from the data can also be above the permissible LOQ as seen in the fourth column. If this is the case, and the overall ITEQ exceeds the applicable standard, the laboratory might be required to do more clean-up of the sample, or analyse the sample on another column to confirm the results. If the problem still exists, the other alternative is to extend the sampling time thereby increasing the volume and the congener quantity.

The EN 1948 approach suggests that the theoretical LOQ for a sample might be on the order of 7.93 pg ITEQ/m^3 if each congener was at the LOQ. Based upon the range of LOQ ITEQ values for the individual congeners in the CEN validation study the sample LOQ would be anywhere in the range of 7.1 to 60.3 pg I-TEQ/Nm^3 if all the congeners were either at the minimum or maximum

value. The congener LOQ values for any particular sample would be expected to be distributed between the extremes and the value for the sample would lie somewhere in the range or above the maxima.

The range of theoretical sample LOQ values suggests that there could be other factors that affect the results of any sampling program.

Table 5.2 Limits of Congener Quantification based upon a 5.5 m^3 sample volume

Congener	I-TEQ	LOQ [pg]	CEN Quantification Limits [pg ITEQ/m^3]
2,3,7,8-TCDD	1	2.75	0.4 to 0.5
1,2,3,7,8-PeCDD	0.5	5.5	0.3 to 0.7
1,2,3,4,7,8-HxCDD	0.1	27.5	0.3 to 2.8
1,2,3,6,7,8-HxCDD	0.1	27.5	0.2 to 2.8
1,2,3,7,8,9-HxCDD	0.1	27.5	1.0 to 2.8
1,2,3,4,6,7,8-HpCDD	0.01	275	0.2 to 6.2
OCDD	0.001	2750	0.1 to 8.8
2,3,7,8-TCDF	0.1	27.5	0.4 to 0.5
1,2,3,7,8-PeCDF	0.05	55	0.3 to 0.8
2,3,4,7,8-PeCDF	0.5	5.5	0.3 to 0.8
1,2,3,4,7,8-HxCDF	0.1	27.5	1.0 to 3.2
1,2,3,6,7,8-HxCDF	0.1	27.5	0.5 to 3.2
1,2,3,7,8,9-HxCDF	0.1	27.5	1.0 to 3.2
2,3,4,6,7,8-HxCDF	0.1	27.5	0.4 to 3.2
1,2,3,4,6,7,8-HpCDF	0.01	275	0.1 to 7.2
1,2,3,4,7,8,9-HpCDF	0.01	275	0.2 to 7.2
OCDF	0.001	2750	0.4 to 6.4

5.3.5 Measurement Uncertainty

An appendix of the EN 1948 addresses the uncertainty in measurements and serves as a starting point for this section.

There are two types of errors that can occur in any measurement system:

- Random Errors (Type A); and,
- Systematic Errors (Type B).

Typically when evaluating such errors one would look at every step of the procedure and perform a propagation of errors estimate. Only the Random Errors can be determined

experimentally. Generally the procedure would be to several parallel tests and calculate the standard deviation of the test results as a measure of the error. The Systematic Errors cannot be determined directly, they can only be estimated because the true value of a stack concentration is seldom known. Errors during sampling can occur through non-representative sampling, inhomogeneities in the sample, or contamination in the sampler. During the sample recovery, the extraction procedures, column chromatography and even sample loss can contribute to errors. Reference standards may have errors in the certified value, or dilutions can be done incorrectly. Matrix effects or interferences both contribute systematic errors during the quantification step and the integration of the signal out of the instrument can also contribute to the error. By developing an equation to describe all these factors and differentiating it for each variable would be very difficult so the next best approach is to assume all the factors are independent. This allows the squares of the estimate of each error to be summed and the overall error can be determined by taking the square root of this value.

In Annex B of EN 1948 it is concluded that the various errors include the field sampling uncertainty of 11.1% and the measurement uncertainty of 6.8% which suggest that the overall sampling procedure error is 13%. The contributions of the blank, a leak, uncertainties in the standards, and not corrected analytical systematic errors such as losses during clean-up create an uncertainty on the order of 27% for the systematic errors. Take the square root of the sum of the squares of these values produces an overall uncertainty on the order of 30% - 35% according to EN 1948.

Annex B concludes by noting that the 7% uncertainty in the analytical procedure agrees well with method inter-calibrations on round robin analysis trials. The conclusions go on to note that when combined with sample volume determinations the uncertainty within the same laboratory is on the order of 15% and between laboratories this is extended to 20 - 30%.

Uncertainty, expressed as a percentage, is one way of looking at sampling data. As noted above, when the true concentration is not known, as is the case in all stack sampling, it is impossible to determine how much the results might vary from reality. However, dual train measurements, determinations of stack concentrations based upon simultaneous sampling with two or more trains, can provide a measure of variability. Two such studies have been published:

- Annex F of EN 1948 provides an assessment of both internal and external variability of measurements conducted with the three different sampling trains listed in the protocol as part of the validation studies conducted on the methods; and,
- ASME ReMap[40] project which considered simultaneous sampling data collected

[40] Lanier, W. Steven and Charles D. Hendrix, 2001. Reference Method Accuracy and Precision (ReMAP): Phase 1. Precision of Manual Stack Emission Measurements. Prepared under the auspices of American Society of Mechanical Engineers, Research Committee on Industrial and Municipal Waste. Published as ASME Report CRTD Volume 60.

from various sources by various study teams and provides information not only on PCDD/F sampling method variability but also looks at particulate matter and data for several metal species.

Both these studies are included in the Appendix on sampling attached to this report. The results are summarized in the following paragraphs.

CEN Study Results

The results of the validation tests were submitted the CEN committee for review. The committee checked all the results to ensure that all the requirements of the Standard had been met before the statistics were calculated. The internal variability results are summarized in Table 5.3 for each of the three facilities tested with the various methods.

Out of the total of 36 possible samples from facility A, 33 samples were available for analysis at 3 different laboratories. In addition 3 cross check samples were submitted. Eighteen analytical results, including all those from one laboratory, were rejected as being outside the limits, even after the extraction limits were enlarged to a range of 10% to 180%. A total of 10 pairs remained for the calculation of variability.

Out of the total of 36 possible samples from facility B, 34 were available for analysis at 5 laboratories and 2 cross-checks were submitted. Only 11 pairs were judged suitable for the calculation.

For facility C only 4 days of testing were completed, producing 24 possible samples. All the samples were available and sent to a single laboratory. Only one pair of samples were judged to be unacceptable for calculation procedures.

By comparing the differences between test results generated by the different sampling contractors and laboratories an external variability can be determined. This provides an evaluation of the overall uncertainty attached to the results of an individual measurement.

Unfortunately, not all the test data was judged suitable for the evaluation of the external variability. The results from facility C were all analysed at one laboratory so these data were not available. At facility A, evaluation of the results determined that the sampling points were sufficiently different that these data should not be used to determine external variability. Thus, external variabilty was calculated on the basis of facility B data.

Table 5.3 Summary Internal Variability Data from Validation Tests for CEN

Facility	Method	Number of Pairs	Average [ng I-TEQ/m^3]	Internal Variability [ng I-TEQ/m^3]
A	Dilution	5	0.19	±0.12
	Filter/Cooler	5	0.04	±0.06
B	Dilution	3	0.04	±0.016
	Filter/Cooler	5	0.03	±0.014
	Cooled Probe	3	0.041	±0.011
C	Dilution	4	0.13 (0.10)*	±0.21 (±0.08)*
	Cooled Probe	4	0.13	±0.02

Note: * indicates a single outlier point removed from the calculation

The external variability, and hence the uncertainty of the measurements of PCDD/F expressed as I-TEQ determined from these data was ±0.050 ng I-TEQ/m^3 at a mean measured concentration of 0.035 ng I-TEQ/m^3. While this would suggest that negative values could be reported, in reality the range shows that the data likely does not fit a normal distribution curve. Most environmental data is log-normally distributed. That is the bulk of the data is close to the mean but a low number of high and low values are expected to be found. The variations is treated differently with log-normal distributions and the apparent anomaly would not occur. The results suggest that no conclusions on differences in emissions could be made if the results are less than 85 pg I-TEQ/m^3 because the data is within the range of the uncertainty.

The ASME Study

The ReMAP methodology involved an assessment of the external variability because the data was collected from a number of projects undertaken by different sampling teams at different facilities and typically analysed by different laboratories. Some of the data includes the results of validation studies for different methods, other data were collected as part of specific research projects being undertaken for US EPA or other entities.

The data used for the original ReMap study included 19 paired samples collected from the mid-point in the air pollution control system of an MSW incinerator[41]. These samples were not collected at the stack, rather they were collected before the ESP but after the reagent injection.

[41] Rigo, H. Gregor and A.J. Chandler, 1997. Retrofitting ESP Equipped MWCs to meet the 1995 Emission Guidelines using Sensible Heat Exchanger Cooling and Dry Reagent Injection. A presentation at the 5th North American Waste to Energy Conference. RTP, North Carolina. Proceedings published by SWANA GR-WTE 0105.

Also included in the data were 3 pairs of data, essentially simultaneous tests on a light weight aggregate kiln exhaust conducted for the US EPA by two different contractors. Subsequent to the preparation of the ReMAP report, simultaneous testing was conducted during compliance testing at another MSW incinerator in the United States. A total of 5 additional paired tests were included in a revision to the PCDD/F findings[42].

Based upon the data available and the upper 95% confidence interval on the power law function, at 32 pg ITEQ/m^3 the uncertainty is ±18.6 pg ITEQ/m^3 and this rises to ±49.5 pg ITEQ/m^3 at an average concentration of 80 pg ITEQ/m^3. As Hendrix notes in the revised documents, it is important to recognize that since the model is a regression line the model improves if it contains more data near the extremes.

Comparing the uncertainty provided by the CEN study with that at similar concentrations found in the ReMAP study suggests that the uncertainty shown by the ReMAP data is 40% of the value developed from the CEN study. Unlike the CEN study, where simultaneous sample pairs were analysed by different laboratories, each of the ReMAP studies reflects only the variability in one laboratory.

The ReMAP values suggest that at the current CWS limit for incinerators, 80 pg ITEQ/Rm^3, the uncertainty in the measured value would extend from less than the LOQ to approximately 130 pg ITEQ/Rm^3.

The relationship between concentration and precision needs to have more study, mostly by encouraging more dual train sampling at the lower emission concentrations currently being achieved by some of the MSW incinerators in Canada.

[42] Hendrix, Charles D., 2006. Updating the Models. Precision of Manual Stack Emission Measurements. Draft document submitted for review to ASME committee.

5.4 Long Term Sampling

While year over year sampling using methods outlined in the previous section shows that newly upgraded facilities routinely meet the CWS standards, there are questions about how representative the short term samples are of the annual situation. In Europe this question has been addressed by the development of 2 long term sampling systems:

- **A**dsorption **ME**thod for **SA**mpling of Dioxins and Furans [AMESA]; and,
- **D**ioxin **M**onitoring **S**ystem [DMS].

5.4.1 AMESA

AMESA is similar to the cooled probe sampling method and EPA 23. The isokinetic sample is removed from a representative point in the stack, and cooled to 70°C within the probe. It then passes through an adsorption unit, consisting of a quartz wool filter and solid adsorbent (XAD 2) where PCDD/Fs are collected. Condensate is collected behind the adsorption unit so moisture levels can be used to normalise the flow rate.

Unlike the manual sampling methods, only the contents of the the adsorption unit is analysed. The recommended protocols follow EN 1948. Quass et al. suggest that AMESA will allow the determination of the PCDD/F emission content within the range of 0.0001 - 10 ng I-TEQ/m³ with a dust load of up to 20 mg/m³. The sampling time can vary between 6 hours and 4 weeks. AMESA is installed in more than 70 waste incineration plants in Europe.

Comparative measurements between the Filter/Condenser method, the Cooled probe method and AMESA showed good results.

5.4.2 DMS (Dioxin Monitoring System)

Dioxin monitoring system DMS is based upon the dilution method of EN 1948. The sample gas is collected in isokinetic mode via a heated probe and cooled down very rapidly below 40°C with dried and filtered air in a mixing channel. A combination of particle filter (this unit consists of a fine dust filter and a 2 stage foam filter) and solid adsorbent is used to extract and accumulate the PCDD/F from the sample gas.

As with the other long term method, only the adsorption unit is analysed according to EN 1948. While Quass et al. quote the PCDD/F measurement range to be similar to the AMESA unit, it is suggested that the DMS can handle dust loadings up to 150 mg/m³. Sampling times for both units are similar. DMS is installed in various incineration plants.

Quass et al. note that Umicore Hoboken in Belgium used an AMESA system at their facility for a period of almost two years. Their conclusions at the end of the test period was that semi-

continuous sampling was not cost competitive to manual sampling due to the high initial investment required and the on-going maintenance costs.

5.5 Alternative Analysis Procedures

Undertaking PCDD/F sampling programs, even annual testing, is expensive. Long term PCDD/F sampling, as noted above, can be more expensive. Clearly, if alternatives to the existing approaches can be developed there would be a ready market. This has prompted research into the use of surrogates and immunoassay procedures.

5.5.1 Surrogate Procedures

As discussed in the US EPA report referenced at the start of this chapter, surrogates are essentially indicator species whose concentration in the stack gases correlate closely with the PCDD/F and/or the dioxin like PCB concentrations. Ideally, the compounds of most interest would be those that can be sampled on a continuous basis with instruments such as on-line GC/MS units. In flue gas from incineration processes CB (chlorobenzenes) and CP (chlorophenols) as well as PCDD/Fs are detected. Currently the analysis of low concentrations of chlorophenols relies upon a derivatization step that forms acetate derivatives that are easier to monitor on low resolution GM/MS. Chlorobenzenes on the other hand can be monitored directly and thus were the first surrogate compounds proposed. If a linear relationship exists between CB and PCDD/F it can be characterised by a correlation coefficient [r] or a coefficient of determination [r^2]. The correlations at combustion facilities have been very good.

The use of such surrogates may not be universal to all incinerator systems. The PCDD/F signatures for different combustion systems vary and with these the I-TEQ will vary. Should a system be developed to utilize CBs as surrogates for PCDD/F there will need to be significant facility specific validation tests.

It is important to recognize that Lemieux recommends that "before surrogates can be used with adequate confidence at waste combustion facilities on a routine basis, additional datasets need to be generated. It would be useful to make detailed, isomer-specific measurements of CB and CP compounds, as well as low chlorinated CDDs/Fs, during every test where PCDDs/Fs are measured."

It must be remembered that this technology cannot current be applied to regulatory testing of incinerator emissions, it is a research tool used by scientists examining the physical and chemical phenomena that govern the emissions of PCDD/F and other organics from combustion sources.

As pointed out by Gullett[43] the instrument is not sensitive enough to measure the concentrations of the targetted species after APC equipment, the technique must be employed at the exit of the furnace or boiler, before any control measures are employed.

5.5.2 Immunoassays

Surrogates, with extensive validation tests, will not provide particular simplification to the procedures required to monitor PCDD/F. They will still require extensive monitoring with elaborate analytical procedures. To simplify the analysis step of the PCDD/F determination, bioassays are available on the market.

Bioassays procedures use a dioxin specific antibody for dioxins and dioxin-similar compounds (PCB, PHAH etc.) to detect and quantify a sample. As a result bioassays directly produce an I-TEQ sum value. The extraction and the clean up are essentially simplified. It takes only 24 hours to get an analysis value. Bioassays are extremely sensitive (fg - range), so that these measurement methods are mostly used for samples with a minor PCDD/F content, e.g. feed and food samples. Indeed, in Japan, bioassay was adopted as one of measurement method in the Law Concerning Special Measures against Dioxins (Dioxins Law). One presumes that should the bioassay suggest a sample has failed to meet the limits, there would be a need to verify this conclusion by completing the detailed testing.

The Kyoto Electronics Manufacturing Co. (KEM)[44] is developing a new simplified dioxin method for the analysis of flue gas, fly ash, bottom ash, soil, sediment, air and water. In 2006, as a first step, KEM has marketed the sample preparation system and a dioxin biosensor for flue gas, flue ash and bottom ash residues in Japan. The sample preparation system involves purifying a crude extract of hexane solution and substituting it for DMSO solution in the preparation system. The resulting prepared sample can be used in not only KEM DXS-600 Dioxin Biosensor but also in various kinds of bioassay technique.

The biosensor uses a highly sensitive antibody which recognises 2,3,4,7,8-Cl_5CDF. This dioxin congener shows a close correlation to the I-TEQ of the PCDD/F in most incineration processes. The total I-TEQ is calculated from the results of the 2,3,4,7,8-Cl_5CDF-congener.

Bioassay developments are also being explored in the Netherlands by Biodetection Systems. To reduce costs associated withexisting PCDD/F and PCB analysis procedures for food and feeds that EU legislation requires be monitored, they have developed bioassay techniques that rely upon BioDetection Systems' Chemically Activated Luciferase Expression or CALUX® reporter gene bioassay. Essentially the bioassay produces a light that is proportional to concentration.

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[43] Gullett, Brian K., 2006. Comments made during a presentation at the 4th ICIPEC Conference Kyoto, Japan, September.

[44] See: http://www.kyoto-kem.com/english/products/dioxin/e_02.php

6.0 REPORTING MEASUREMENT RESULTS

6.1 Introduction

During sampling the gas and any contaminants present in the stream are extracted and passed through a collection device which concentrates the species of interest in the "sample". The sample is recovered from the sampling train and sent to the laboratory for analysis. In the laboratory the sample is processed and the result is a weight measurement for the species of interest. That weight is then used to calculate the concentration in the stack gases by dividing the weight by the volume of gas extracted. While this is very straight forward for particulate matter or even volatile organic species such as toluene, or metals such as lead or mercury, how we report PCDD/F emissions is complicated by the fact that the sampling discussed in the previous chapter results in obtaining at least 17 different values for PCDD/F alone. As noted in the Introduction there are 210 isomers of PCDD/F and 209 isomers of PCB that could be identified in the analytical procedures. Tracking these substances for the purposes of: setting limits; identifying control techniques; or, even determining the mechanisms by which they are formed, would be extremely onerous. As noted, early measurements addressed homologue totals, ie. the amount of material found at different chlorination levels. When scientists managed to identify that there were particular isomers responsible for the effects noted during exposure to PCDD/F they reasoned that, if the degree of effect caused by different isomers could be measured, it could be possible to express the amount of PCDD/F present based upon the anticipated effect of the mixture. Thus, the concept of assessing PCDD/F emissions on the basis of toxicity was adopted[45]. This approach has become known as the TEQ or toxic equivalence method, based upon applying toxic equivalency factors [TEFs] that relate the toxicity of each isomer to that of the most toxic dioxin congener, namely 2,3,7,8- tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). In this chapter, the concept of toxic equivalence and the different schemes employed are discussed.

In reviewing emission regulations from various jurisdictions it becomes evident that not all concentrations are expressed in the same manner. During the sampling procedure the gases are typically cooled, moisture is removed and then the volume of gas sampled is determined. While that volume can be related to the flow in the stack, which is determined by measuring the velocity profile across the stack along with the temperature of the stack gases, different jurisdictions have attempted to standardize such readings by defining how the results should be expressed. While temperature and pressure affect gas volumes, and are specified in most standards, concentration can also be influenced by the amount of air present in the gas stream. If more air is added, the concentration is reduced, but the mass flow rate of the pollutant of interest does not change. Thus, when setting concentration limits it is important to standardize the amount of dilution that is acceptable for the particular source. The issue of standardization is also addressed in this chapter.

[45] US EPA, (1989a) Interim procedures for estimating risks associated with exposures to mixtures of chlorinated dibenzo-p-dioxins and -dibenzofurans (CDDs and CDFs) and 1989 update. Washington, DC: Risk Assessment Forum. EPA/625/3-89/016.

6.2 Expression of PCDD/F as Toxic Equivalents

Mass is the basis for all concentration measurements as discussed above. In an attempt to simplify the standards for emissions of PCDD/F, the mass of the individual congeners identified during analysis are adjusted on the basis of their toxicity and the adjusted concentrations are summed to provide a single number of PCDD/F based upon toxicity. This concentration is frequently denoted with a reference to the way the adjustment was carried out, such as the current Canadian practice of reporting data as [mass ITEQ/Rm^3 @ 11% O_2]. The alternative adjustment factors are discussed in this section, the significance of part of the above expression after the slash is discussed in the next section.

In 1984, when the concept of assessing PCDD/F emissions on the basis of toxicity was adopted, there was no common designation, but the approach has become known as the TEQ or toxic equivalence method. As noted, the approach is based upon applying toxic equivalency factors [TEFs] that relate the toxicity of each isomer to that of the most toxic dioxin congener, namely 2,3,7,8- tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). The most common TEF values used throughout the 1990s were the International factors (I-TEF)[46]. The I-TEF factors are shown in Table 6.1. The sum of the PCDD/F emissions expressed in this manner are designated in the literature as I-TEQ values.

As studies into toxicological effects progressed, it became apparent that polychlorinated biphenyls [PCBs] also play a role in the effects that were being found. The structure of PCBs is more complicated than those for PCDD/Fs in that the molecules take different shapes. There are 209 PCB congeners, of which only 13 were thought to have dioxin-like toxicity: those with four or more lateral chlorine atoms with one or no substitution in the ortho position[47]. These compounds are sometimes referred to as coplanar, meaning that the two benzene rings are on the same plane giving the molecule a flat structure. The physical/chemical properties of each congener vary according to the degree and position of chlorine substitution.

To address the behaviour of PCBs, revised TEFs were proposed by Alhborg and his colleagues in 1994. These factors, which have become known as the TEQ-WHO_{94}, were used by scientists undertaking risk assessment evaluations, but few countries adopted them for emission characterization. The TEQ-WHO_{94} factors are provided in Table 6.1. Note that, for PCDD/F congeners, the TEFs are the same in both the ITEQ formulation and the WHO_{94} proposal.

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[46] Kutz, FW, Barnes, DG, Bottimore, DP, Greim, H, Bretthauser, EW. 1990. The international toxicity equivalency factor (I-TEF) method of risk assessment for complex mixtures of dioxins and related compounds. Chemosphere, 20, 751–757.

[47] Ahlborg, VG; Becking, GC; Birnbaum, LS; et al. (1994) Toxic equivalency factors for dioxin-like PCBs. Chemosphere 28(6):1049-1067.

In 1997 an expert group from the WHO reassessed the TEFs for PCDD/Fs and PCBs by re-evaluating toxicological effects data on a range of species, and *in vivo* biological data[48]. The group recommended revising the human-based TEFs and adopting new TEFs for fish and birds when these factors were to be used in risk assessment studies. The sum of PCDD/F and PCB emissions calculated using these recommended factors have become known as the TEQ-WHO_{98} values. The new TEFs for human/mammal health are the same as the I-TEFs for most dioxin congeners but include a higher value for 1,2,3,7,8-pentachlorodibenzo-p-dioxin and lower values for octachlorodibenzo-p-dioxin and octachlorodibenzofuran.

It has been suggested[49] that the TEF-WHO_{98} will produce a more conservative TEQ result from the analysis of samples as the values will increase by approximately 10% compared to those calculated using the I-TEFs. The US EPA[50] provide annual emission estimates for large municipal incinerators in the US (Table 3-7 in referenced report), expressed on the basis of both the I-TEQ and WHO_{98} approaches. The table suggests that the difference in the annual emissions based solely on the PCDD/F congener data is approximately a 10% increase with the WHO_{98} formulation. Another examination[51] looked at emission data from New Zealand incinerators and determined that the WHO_{98}-TEFs would produce a 4 to 14% increase in the TEQ for PCDD/F discharges. The impact a change in the formulation will have on Canadian emission levels is best determined by examining the available emission data for different types of sources and comparing the two TEQ values. This will be done later in this document.

As to how the TEF-WHO_{98} values are currently being applied, Japan have adopted the TEQ-WHO_{98} factors for use when defining body burden. Japanese documents appear to suggest that these factors will also be used when assessing incinerator emissions, however this cannot be confirmed. Similarly, Australia and New Zealand suggest they might change the basis of the

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[48] Van den Berg, M, Birnbaum, L, Bosveld, ATC, Brunström, B, Cook, P, Feeley, M, Giesy, J, Hanberg, A, Hasegawa, R, Kennedy, SW, Kubiak, T, Larsen, JC, van Leeuwen, FXR, Liem, AKD, Nolt, C, Peterson, RE, Poellinger, L, Safe, S, Schrenk, D, Tillitt, D, Tysklind, M, Younes, M, Wærn, F, Zacharewski, T. 1998. Toxic equivalency factors (TEFs) for PCBs, PCDDs, PCDFs for humans and wildlife. Environmental Health Perspectives, 106, 775–792.

[49] Van Leeuwen, F.X.R., Younes, M.M. (eds). 2000. Proceedings of the World Health Organization and International Programme on Chemical Safety consultation, 25–29 May 1998, Geneva, Switzerland: Assessment of the Health Risk of Dioxins: Re-evaluation of the Tolerable Daily Intake (TDI). In: Food Additives and Contaminants, 17, 223–240 (executive summary).

[50] US EPA, 2005. The Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States: The Year 2000 Update (External Review Draft, March 2005; EPA/600/p-03/002A)

[51] Sinclair Knight Merz Limited, 2001. Dioxin Discharges from Waste Incineration Technical Specifications for a National Environmental Standard. New Zealand, August. Available at: http://www.mfe.govt.nz/publications/hazardous/dioxin-waste-incinerators-aug01.pdf

Table 6.1 Summary of Toxicity Factors used in Different Formulations

Congener	IUPAC Number	I-TEQ	TEQ-WHO_{94}	TEQ-WHO_{98}
2,3,7,8-TCDD		1	1	1
1,2,3,7,8-PeCDD		0.5	0.5	1
1,2,3,4,7,8-HxCDD		0.1	0.1	0.1
1,2,3,6,7,8-HxCDD		0.1	0.1	0.1
1,2,3,7,8,9-HxCDD		0.1	0.1	0.1
1,2,3,4,6,7,8-HpCDD		0.01	0.01	0.01
OCDD		0.001	0.001	0.0001
2,3,7,8-TCDF		0.1	0.1	0.1
1,2,3,7,8-PeCDF		0.05	0.05	0.05
2,3,4,7,8-PeCDF		0.5	0.5	0.5
1,2,3,4,7,8-HxCDF		0.1	0.1	0.1
1,2,3,6,7,8-HxCDF		0.1	0.1	0.1
1,2,3,7,8,9-HxCDF		0.1	0.1	0.1
2,3,4,6,7,8-HxCDF		0.1	0.1	0.1
1,2,3,4,6,7,8-HpCDF		0.01	0.01	0.01
1,2,3,4,7,8,9-HpCDF		0.01	0.01	0.01
OCDF		0.001	0.001	0.0001
3,3',4,4'-TeCB	PCB-77		0.0005	0.0001
3,4,4',5-TCB	PCB-81			0.0001
2,3,3',4,4'-PeCB	PCB-105		0.0001	0.0001
2,3,4,4',5-PeCB	PCB-114		0.0005	0.0005
2,3',4,4',5-PeCB	PCB-118		0.0001	0.0001
2',3,4,4',5-PeCB	PCB-123		0.0001	0.0001
3,3',4,4',5-PeCB	PCB-126		0.1	0.1
2,3,3',4,4',5-HxCB	PCB-156		0.0005	0.0005
2,3,3',4,4',5'-HxCB	PCB-157		0.0005	0.0005
2,3',4,4',5,5'-HxCB	PCB-167		0.00001	0.00001
3,3',4,4',5,5'-HxCB	PCB-169		0.01	0.01
2,2',3,3',4,4',5-HpCB	PCB-170		0.0001	
2,2',3,4,4',5,5'-HpCB	PCB-180		0.00001	
2,3,3',4,4',5,5'-HpCB	PCB-189		0.0001	0.0001

reporting, but do not appear to have changed their regulations to reflect this. The European Union Directive on Incineration clearly notes that the I-TEQ approach is to be used. The US EPA still reference I-TEQ based factors for calculating emission concentrations. While not adopted for emissions characterization, the TEQ-WHO_{98} approach is incorporated into regulations on food and feeds in the EU[52].

The discussion of PCDD/F emission values would not be complete without referencing the emission values used for some of the US NSPS regulations. These limits are expressed on the basis of the total mass of the 17 congeners in the I-TEQ list, but without adjusting the values for the toxicity levels. This was a refinement of the homologue summation method used in the 1980s, since the total of the homologues which includes the 17 congeners is typically larger than the sum of the 17 by themselves.

Regardless of the toxic equivalency factors selected, the application of the factors is the same. Either the mass or the concentration of the individual congener is multiplied by the appropriate factor to get an adjusted value for that congener. The adjusted values are then summed to provide a single number describing the PCDD/F and/or PCB present in the sample. This number should be designated as the TEQ value.

6.3 Treatment of Low Values

When measurements of individual dioxin congeners are below the limit of quantification [LOQ], as discussed in Chapter 5, different approaches have been adopted to deal with reporting these values.

As outlined in the discussion of EN 1948, the method is clear: if the quantity of a specific congener is below the LOQ, the TEQ must be calculated in two ways: one including the specific congeners at the quantification limit and the other setting the quantity to zero.

In US EPA Method 23 it states that: "Any PCDDs or PCDFs that are reported as nondetected (below the DL) shall be counted as zero for the purpose of calculating the total concentration of PCDDs and PCDFs in the sample".

Even though Method 23 is used in New Zealand too, it has been recommended that sampling data include half of the level of detection[53] as the "measured" concentration. This is justified on

[52] COMMISSION DIRECTIVE 2006/13/EC of 3 February 2006 amending Annexes I and II to Directive 2002/32/EC of the European Parliament and of the Council on undesirable substances in animal feed as regards dioxins and dioxin-like PCBs.

[53] Sinclair Knight Merz Limited, 2001. Dioxin Discharges from Waste Incineration Technical Specifications for a National Environmental Standard. New Zealand, August. Available at:

that basis that it provides some advantages when calculating discharge TEQ concentrations. This approach ensures that a satisfactory analytical detection limit is achieved using the methods employed. Since laboratories are routinely able to achieve very low detection limits (at the pg/Sm^3 level), the contribution of LOD values to limits would be expected to be very small even if no dioxin congeners were actually quantified.

6.4 Conversion Procedures for Sampling Conditions

Emission standards are given in many different units and can be related to different diluent levels (ie. different oxygen concentrations, or CO_2 concentrations, or even excess air levels in the regulations from the province of Quebec).

In order to allow a comparison of standards it is necessary to convert values to the same basis. For this report, all Canadian emission summaries and recommendations are expressed in mass/Rm^3 @ 11% O_2, where the R or reference conditions are 101.3 kPa and 25^{O}C. The conversions can be accomplished with the following equations.

To correct for diluent concentration from a referenced value:

$$\text{Concentration @ 11\% } O_2 = \text{Concentration}_{\text{referenced}} \times [(20.9 - 11)/(20.9 - O_{2\ \text{referenced}})] \quad (1)$$

$$\text{Note: } O_{2\ \text{referenced}} = 20.9 - 1.14\ CO_2\ (\%)\ \text{dry} \quad (2)$$

To convert for excess air according to the Quebec Regulation on the Quality of the Environment c.Q-2, r.20 the following equation is applied:

$$\text{Concentration @ 50\% Excess Air [EA]} = \text{Concentration}_{\text{measured}} \times 11.30 / (N_2/O_{2\ \text{measured}}) \quad (3)$$

Where N_2 = nitrogen concentration by difference assuming stack gases are nitrogen + oxygen + carbon dioxide + carbon monoxide with volume of gases expressed as percentage of the total.

By combining equations 2 and 3, assuming that 11% oxygen is the referenced condition and that the carbon monoxide levels in the low ppm range and have no substantive effect on the results, 50% excess air values can be converted to 11% oxygen levels using the following equation:

$$\text{Concentration}_{11\%\ \text{oxygen}} = \text{Concentration}_{50\%\ EA} \times \{[100\text{-}O_2 - CO_2]/O_2\} / 11.30$$

$$\text{Concentration}_{11\%\ \text{oxygen}} = \text{Concentration}_{50\%\ EA} \times \{[100\text{-}11\text{-}(9.9/1.14)]/11\} / 11.30$$
$$= 0.646\ \text{Concentration}_{50\%EA}$$

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http://www.mfe.govt.nz/publications/hazardous/dioxin-waste-incinerators-aug01.pdf

To convert from one standard temperature to another the volume of gas must be adjusted for the effect of temperature. Since gas volume varies directly with the absolute temperature, the absolute temperature ratio is applied to perform the correction. The absolute temperature is 273.16 plus the temperature of the standard in ^{O}C. The absolute temperature for Canadian standard conditions is 298.16, and this goes on the bottom of the absolute temperature ratio.

By combining the diluent correction and the temperature correction terms it is possible to adjust the concentrations expressed in other regulations to the Canadian basis.

Standard conditions in the US are $20^{O}C$ with 7% oxygen diluent levels. The conversion is

$$\text{Concentration}_{\text{CanadianRef}} = \text{Concentration}_{\text{US}} \times (20.9-11)/(20.9-7) \times 293.16/298.16$$
$$= 0.7003 \times \text{Concentration}_{\text{US}}$$

Standard conditions in the EC, Japan, Australia and New Zealand are $0^{O}C$ with 11% oxygen diluent levels. The conversion is:

$$\text{Concentration}_{\text{CanadianRef}} = \text{Concentration}_{\text{EC}} \times 273.16/298.16$$
$$= 0.9162 \times \text{Concentration}_{\text{EC}}$$

Values are generally reported to two significant figures.

6.5 Reporting Procedures for this Report

For this report the emission data will be reported on the basis of the EN 1948 advice:

> if the concentration of any congener is less than the LOQ, two values will be reported for the site:
>
> - a total that includes the congener taken as zero; and,
> - a total that includes the congener taken at the LOQ.

Furthermore, in order to ascertain the potential impact of using the TEQ-WHO_{98} factors, the emissions will be reported both on the basis of the I-TEQ factors and the TEQ-WHO_{98} factors.

7.0 PCDD/F EMISSION REGULATIONS

7.1 Introduction

In 1988 a CCME predecessor issued a report[54] concerning the anticipated performance of municipal solid waste incinerators. Shortly thereafter a similar document related to hazardous waste incinerators was issued. While the initial report stopped short of defining a regulatory limit for emissions from MSW incinerators, based upon data available at the time, it suggested that well operated facilities should be able to limit PCDD/F emissions to 0.5 ng TEQ/Rm^3 @ 11%O_2. This number became the *de facto* standard that was applied in various Canadian jurisdictions for MSW and other incinerators. The TEF used in the calculation of this number were the same as the I-TEQ factors discussed elsewhere in this report, with the exception that the factor for 1,2,3,7,8 PeCDF was 0.01 versus the I-TEF for the same congener of 0.05.

The approach of setting emission limits based upon the performance of installed equipment was recognised as a way of forcing lower limits while ensuring that they were achievable. A guidance document issued by the OAQPS Director[55] addressed the need for consistency in the application of Best Available Control Technology [BACT] principles to MSW incinerators and made recommendations for standards on that basis. Another example of the trend was the development of the Maximum Achievable Control Technology [MACT] principle in Title III of the U.S. *Clean Air Act* which states that the EPA must consider standards based upon the demonstrated performance of the best 12% of the population[56]. This was applied when the U.S. EPA released the rules governing air emissions from many forms of incinerators as detailed later in this chapter. Ontario adopted a similar approach, designated in that case as a Performance Standard[57] with the issuance of Guideline A-7 in 1995.

This direction in lowering standards to keep pace with progressive advances in control technology suggests that, for the most part, jurisdictions have reached the lowest level practicable. The definition of any standard must relate both to the ability to achieve the performance level specified, and also to prove that it has been met. As can be appreciated from the discussion in the sampling chapter, today's sampling procedures are capable of determining

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[54] Canadian Council of Resource and Environment Ministers, 1988. Operating and Emission Guidelines for Municipal Solid Waste Incinerators.

[55] US EPA (1987). Operational Guidance on Control Technology for New and Modified Municipal Waste Combustors. A memorandum from Gerald A. Emison Director Office of Air Quality Planning and Standards (MD-1Q) RTP NC, June 26, 1987.

[56] Lee, Bryan (1991). Highlights of the *Clean Air Act* Amendments of 1990. J. Air Waste Manage. Assoc. Vol. 41, No. 1. January. pp. 16-19.

[57] MOE, 1995. GUIDELINE A-7 Combustion and Air Pollution Control Requirements for New Municipal Waste Incinerators. Legislative Authority: *Environmental Protection Act*, Part V, Section 27, and Part II, Section 9 Ontario Regulation 347, General -- Waste Management Regulation, Ontario Regulation 346, General -- Air Pollution Ontario Regulation 512/95

the presence of low levels of PCDD/F in the stack, albeit with some level of uncertainty, and as will be seen in the chapter on emission levels, currently installed equipment is capable of forcing the need for such low detection limits. The justification for pushing any emission standards lower than currently being achieved must come from a consideration of the potential damage that could be posed by such emissions and the costs associated with the reduction in these emissions.

In 2001 the emission limit for PCDD/F from incinerators in Canada was set at 0.080 ng/Rm^3 @ 11% O_2. It is important to recognize that included in the PCDD/F CWS for incineration was a definition of incineration that allows the standard to set emission limits for any thermal process. To quote from the definition contained in the standard:

> *Waste incinerator*: a device, mechanism or structure constructed primarily to thermally treat (e.g., combust or pyrolyze) a waste for the purpose of reducing its volume, destroying a hazardous chemical present in the waste, or destroying pathogens present in the waste.

The definition lists combustion and pyrolysis as examples of thermal treatment. The origin of eg is latin, *exempli gratia*, which would translate as "free example". This usage is by no means limiting suggesting that any alternative method of heating and treating waste to reduce its volume or breaking down compounds within the waste could be classified as waste incineration. As such, the PCDD/F Waste Incineration CWS would apply to any forms of thermal treatment systems.

How the current CWS standard compares to standards in other jurisdictions is the subject of this chapter.

Before embarking upon that discussion it is important to set the stage by recognizing that, with the exception of Canada, the United States, the European Union, and Japan, few countries had established PCDD/F emission limits for any combustion equipment before the acceptance of the Stockholm Convention on Persistent Organic Pollutants by the United Nations[58]. This was adopted in May 2001 and entered into force on 17 May 2004 when the 40th nation signed the document. Work had started in 1997 to develop this international binding instrument related to the need to reduce persistent organic pollutants [POPs] to protect the environment and human health.

The Stockholm Convention sets out a range of measures to reduce and, where feasible, eliminate POP releases, and Article 5, requires Parties to take measures to reduce, and where feasible, eliminate releases of unintentionally produced POPs, including dioxins, furans, HCB and dioxin-like PCBs. Article 5 also requires Parties to promote the development of and (where appropriate)

[58] At the Conference of Plenipotentiaries on the Stockholm Convention on Persistent Organic Pollutants, held 22 to23 May 2001 in Stockholm, Sweden, the Convention was adopted and opened for Signature. It remained open for signature at the United Nations Headquarters, Treaty Section, in New York, until 22 May 2002. See http://www.pops.int/ for more information.

require the use of products or processes to prevent the formation and release of unintentionally produced POPs. Included in this provision is the requirement that Best Available Techniques (BAT) and Best Environmental Practices (BEP) be applied for both new and substantially modified sources. The Convention defines "Best Available Techniques" as using the most effective and advanced techniques that can be practically adopted to *prevent or minimise* harmful emissions of by-product POPs and other environmental impacts, or *reduce* them to acceptable limits.

With this context, "Available" techniques are those techniques that can be applied by an operator to a specific facility. That is they are developed to a state that they can be employed on a facility in an economical and technically viable way. Similarly, "best environmental practices" implies the application of the most appropriate combination of environmental control measures and strategies.

This approach follows those incorporated into the CCME Incinerator Guidelines and the US EPA MACT approach for standards setting.

The effect of the Stockholm Convention has been that many countries have developed national implementation plans to address the emissions of POPs, and in those plans set out standards for PCDD/F emissions. To assist Parties, an international Expert Group was assembled to develop draft guidelines for BAT and provisional guidance on BEP information to ensure that facilities are operating in accordance with the world's best practice.

While the most frequent interpretation of the goals of the Stockholm Convention appears to be to eliminate the release of POPS to the atmosphere, there are specific references in the text of the Convention to residues and stockpiles containing POPS. In Article 6 it states that wastes containing the chemicals must be managed in a manner that protects human health and the environment. The article goes on to note in 1 d):

> "Disposed of in such a way that the persistent organic pollutant content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of persistent organic pollutants or otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option or the persistent organic pollutant content is low, taking into account international rules, standards, and guidelines, including those that may be developed pursuant to paragraph 2, and relevant global and regional regimes governing the management of hazardous wastes;"

Since part of the National Action Plan prescribed by Article 5 requires that parties "identify, characterize and address the release of" unintentional POPS it is appropriate to understand how incinerators residues fit into the inventory of PCDD/Fs in Canada.
Part V of Annex C on Unintentional POPS goes as far as to suggest that the criteria for evaluating new facilities might be that they incorporate systems to render residues inert, or at the very least

to detoxify them.

In the various jurisdictions, regulators have used a number of approaches to control PCDD/F emissions to the environment. Japan and New Zealand have passed laws to address the reduction of PCDD/F in the environment. Australia, following the guidance of the Stockholm Convention on POPs developed a comprehensive national plan for addressing these substances and out of that process confirmed emission standards for incineration sources. The European Union and all its member countries are bound by regulations that limit the amount of PCDD/F in food stuffs and feed materials and emission regulations for different categories of sources including specific incinerator regulations. The United States has developed New Source Performance Standards for a range of different combustion alternatives. The Canada Wide Standards process has sought to develop consensus guidelines that could be adopted by the various jurisdictions as a way of meeting the virtual elimination target set in the Canadian Environmental Protection Act. A detailed discussion of Canada's approach to managing unintentionally released persistent organic pollutants is available in the Canadian filing to the Stockholm Convention[59].

7.2 Japan

The basis of the Japanese emission regulations does not follow the trend in other countries with the adoption of an advanced emission control strategy, rather Japan defined a tolerable daily intake [TDI] values for PCDD/Fs in June 1999 setting the level at 4 pg TEQ_{DFP}/day/kg of body weight[60]. This was included as part of the Law Concerning Special Measures Against Dioxins (The Dioxins Law)[61].

The TEQ value specified included the contributions of co-planar PCBs as well as PCDD/F. In conjunction with the TDI, environmental quality standards were specified for the following environmental compartments:

- for the ambient air annual average: not more than 0.6 pg-TEQ_{DFP}/m^3;
- for the water annual average: not more than 1 pg-TEQ_{DFP}/L;
- for the sediment not more than 150 pg-TEQ_{DFP}/g; and,
- for the soil not more than 1,000 pg-TEQ_{DFP}/g.

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[59] Government of Canada, 2006. Canada's National Implementation Plan under the Stockholm Convention on Persistent Organic Pollutants; Ottawa, Ontario, Canada. Available at: www.ec.gc.ca/cleanair-airpur/default.asp?lang=En&n=8DDE4B39-1

[60] Government of Japan, 2003. Dioxins. Information Bulletin available at http://www.env.go.jp/en/chemi/dioxins/brochure2003.pdf

[61] Government of Japan, 1999. Law Concerning Special Measures against Dioxins (Law No. 105 of 1999. Promulgated on July 16, 1999). Available at http://www.env.go.jp/en/laws/chemi/index.html

To achieve the levels specified above, the Law also set out standards for emissions from incinerators. These target emission concentrations were classified according to capacity. The lower cut-off on the application of these standards was a hearth area in excess of 0.5 m^2 or a combustion capacity of more than 50 kg/h. Recognizing that existing facilities would need to be retro-fitted and that such facilities might not be as efficient as new facilities, three sets of standards were set: new facilities; an interim target until November 2002 for existing units and a post November 2002 standard for existing systems. Table 7.1 summarizes the existing standards.

Table 7.1 Japanese Emission Standards for Incinerators [ng TEQ_{DFP}/Nm^3]

Scale of facilities (Capacity of incineration)	**New facility** (post 1999)	**Existing Facility**
More than 4t/h	0.1	1
2t/h — 4t/h	1	5
Below 2t/h	5	10

The information bulletin on Dioxins referenced above notes that:

> "Small-scale incinerators, to which emission standards are not applied, need to be able to burn at 800°C and higher and the structure must include a thermometer and devices for supporting combustion."

These initiatives have reduced emissions from incinerators in Japan from 2200 g/annum in 2000 to an estimated 220 g/annum in 2004[62], about 63% of the total releases in the inventory. The government is targeting further reductions.

Effluent standards were also set as part of the Dioxin Law. For waste water or sludges/solutions from incinerators, post January 2003, the standard to be met was 10 pg TEQ_{DFP}/L.

It is informative to note that the government bans open burning, is closing school and other small incinerators, and is promoting the reduction of waste to reduce the need to burn waste and thereby control PCDD/F emissions from waste combustion.

7.4 Australia

The Australian government through its Environment Protection and Heritage Council issued a national action plan for addressing PCDD/F in October 2005[63]. This followed the suggested

[62] Government of Japan, 2005. Dioxins, An Updated Information Pamphlet from the Office of Dioxin Contol, Environmental Management Bureau, Ministry of the Environment, Government of Japan, Tokyo.

[63] Australia Environment Protection and Heritage Council, Oct. 2005. National Dioxins Program – National Action Plan for addressing dioxins in Australia. ISBN Web: 0 642 32397 6. Available at:

protocol of the Stockholm Convention. The action plan suggests that PCDD/F emissions in Australia are lower than many other developed countries, attributable to lower levels of industrialization than many areas of North America and Europe and measures that have been put into place since 1995 to reduce emissions and ban the use of certain chemicals. Furthermore, when the government of Australia discourages the use of high temperature incineration for the disposal of certain chemical wastes: PCBs, HCB, and organochlorine pesticides. In 1992 they developed a separate management strategy for dealing with each the three streams. PCBs were largely treated with two chemical dechlorination techniques. Pesticide residues are treated with a home grown plasma destruction system, the PLASCON system.

Like the Canadian situation, control of emission sources is a state function in Australia, although all the states are applying the 100 pg I-TEQ/Nm^3 emission limit standard for combustion equipment for new applications. The action plan suggests that governments will evaluate new proposals against the measures recommended as BAT by the Expert Committee for the Stockholm Convention.

7.5 New Zealand

Australia's decided to reject high temperature incineration in 1992 after discussions between Australian and New Zealand environment officials. Both countries follow a similar approach to dealing with chemical wastes. New Zealand produced a national environmental standard that included a section pertaining to PCDD/F[64] in 2004. The purpose of the environmental standard was to develop mandatory technical requirements for the operation of facilities. The approach to dealing with PCDD/F sources was to ban certain operations:

- Lighting of fires and burning of waste at landfill;
- Burning of tires;
- Burning of bitumen;
- Burning of coated wire;
- Burning of oil;
- Incinerators at schools and healthcare institutions; and,
- High-temperature hazardous waste incinerators.

The regulations are accompanied by clarifications that explain the intent of the bans. For landfills, deliberate burning of waste is prohibited, but landfill gas flares are allowed. Accidental fires are not to be allowed to continue in the landfill. Tires cannot be burned in the open, but can be used

http://www.ephc.gov.au/pdf/EPHC/final_NAP_october_2005_rev.pdf

[64] Government of New Zealand, 2004. Resource Management (National Environmental Standards Relating to Certain Air Pollutants, Dioxins, and Other Toxics) Regulations 2004 SR 2004/309. Available as an Appendix in: http://www.mfe.govt.nz/publications/rma/user-guide-draft-oct05/index.html

in properly permitted industrial facilities. Rehabilitation of roads by burning is banned in all forms and authorities are advised to use less intrusive means of improving road surfaces. The ban on burning coated wire does not apply to licensed facilities. Open burning of oil is also prohibited, but this does not limit the use of oil as a fuel in various processes. While incinerators were allowed in schools and healthcare institutions without permits up to the date of this regulation, as of October 2006 they will require permits. Schools were actively encouraged to cease operating incinerators. The regulation specifically bans using waste as a fuel to heat schools. Furthermore, the user's manual for the regulation suggests that hospitals employ autoclaves for waste disinfection prior to landfill disposal.

The National Dioxin Action Plan[65] states that the applicable limit for incineration sources will be 100 pg TEQ-$WHO_{98\ DFP}$/Nm^3 @ 11% O_2. However, it should be noted that revisions to the standards, which appear to be I-TEQ based[66] would require a formal revision to the Resource Management Act of 1991, and available information cannot confirm that such a measure was taken.

The standard effectively prohibits new hazardous waste incinerators. At the time the user's guide was published 2 of the existing 3 hazardous waste incinerators were either shutdown or being shutdown. The remaining unit can apply to continue to operate after its existing permit expires, although it will need to meet the same target as MSW, school or hospital incinerators.

7.6 European Union

Until 1994 the management of hazardous waste in the European Community was covered either by national policies or under the general rules from waste management issued by the Council of the European Union. In 1990, the Council requested that the Commission develop a position on the incineration of hazardous waste having regard for the fact that as far back as 1975 Member States were required to take the necessary measures to ensure that waste was disposed of without endangering human health and without harming the environment and that a 1984 directive required that no hazardous waste incinerator be operated without a permit. The Commission developed the first EU Directive on Hazardous Waste Incineration which was adopted in 1994[67]. This Directive not only specified air emission limits but also set standards for aqueous releases from APC equipment.

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[65] Government of New Zealand, 2001. An Action Plan for Reducing Discharges of Dioxin to Air. from: http://www.mfe.govt.nz/publications/hazardous/dioxin-action-plan-oct01/html/index.html

[66] Sinclair Knight Merz Limited, 2001. Dioxin Discharges from Waste Incineration Technical Specifications for a National Environmental Standard. New Zealand, August. Available at: http://www.mfe.govt.nz/publications/hazardous/dioxin-waste-incinerators-aug01.pdf

[67] COUNCIL DIRECTIVE 94/67/EC of 16 December 1994 on the incineration of hazardous waste.

The provisions of 94/67/EC came into force at the beginning of 1995 with all nations expected to develop their own internal legislation to enforce these standards and have all facilities meeting the standards by December 2000. As reported by A.J. Chandler & Associates[68] this appears to have been the situation in 2004.

Even with this legislation in place, the European Community[69] recognized in 2000 that new standards for air emissions in other areas required an update of the 1994 Directive. Within the UN- ECE Protocol on persistent organic pollutants the EC adopted targets for PCDD/F emissions for MSW incinerators, biomedical waste incinerators and hazardous waste incinerators and instituted binding limits for metals and particulate emissions. The EU noted that the precautionary principle could still result in further initiatives to lower emissions even though they set what were considered to be minimum requirements for incineration and co-incineration under Directive 2000/76/EC.

The emission limit values for 2000/76/EC for PCDD/F are 100 pg I-TEQ/Nm^3. The emission limit values are regarded as being complied with if none of the average values over the sample period exceeds the 100 pg I-TEQ/m^3 concentration level. The emission value is standardized at the following conditions: temperature 273 K (0 degrees Celsius), pressure 101.3 kPa, 11% oxygen, dry gas, in the exhaust gas of incineration plants but only when the gas stream contains more than 11% O_2. To convert to Canadian units, the EU standards must be multiplied by 0.916 (i.e., 273/298). There were no differences between the 1994 and 2000 standards for PCDD/F.

It is important to note that Directive 2000/76/EC is all encompassing, covering all waste incineration, with the exception of agricultural wastes or biomass. The same emission limitations are applied to MSW incineration and HWI incineration, although the Directive includes provisions for adjusting emission limits for co-incineration facility such as boilers and industrial furnaces where waste is used in conjunction with primary fuels. While Annex II of the 2000/76/EC Directive provides emission limitation values for facilities that co-incinerate waste using a mixing rule, this cannot be applied for PCDD/F emissions and the emission limit for cement kilns and combustion facilities are the same as those for incinerators.

Also included in the 2000/76/EC Directive are statements on Residues and Aqueous discharges. While not limiting the PCDD/F content of bottom ash and slag, the Directive encourages good burn-out which should produce extremely low PCDD/F concentrations. Similarly, Article 9 encourages minimisation of residues, and characterization of these materials for chemical and physical properties. As addressed in the Directive, aqueous wastes are required to meet Emission Limit values at 0.3 ng I-TEQ/L for PCDD/F for aqueous streams from the cleaning of exhaust gases.

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[68] A.J. Chandler & Associates Ltd., 2004. Regulatory Requirements for Hazardous Waste Incinerators. A Report Prepared for Environment Canada Sept 20, 2004

[69] EUROPEAN COUNCIL Directive 2000/76/EC 4 December 2000 on the incineration of waste

The Communication from the Commission on the review of the Community Strategy for waste management assigns prevention of waste the first priority, followed by reuse and recovery and finally by safe disposal of waste; in its Resolution of 24 February 1997 on a Community Strategy for waste management, the Council reiterated its conviction that waste prevention should be the first priority of any rational waste policy in relation to minimising waste production and the hazardous properties of waste.

7.7 United States

The United States Environment Protection Agency defines emission limits for a wide variety of sources under their New Source Performance Standards [NSPS] detailed in 40CFR60[70]. For ease of reference the various NSPS for non-hazardous waste incinerators are listed in Table 7.2.

The U.S. Environmental Protection Agency (U.S. EPA) established emission standards for hazardous waste incinerators and hazardous waste-burning cement kilns, lightweight aggregate kilns on September 30, 1999[71]. This rule is called the Hazardous Waste Combustor Maximum Achievable Control Technology rule (HWC MACT rule) and includes not only the standards themselves, provisions by which the standards are to be implemented. Effectively, these new rules changed the emission standards for hazardous waste incinerators and boilers and industrial furnaces. Subsequent to the 1999 promulgation, the U.S. EPA has issued amendments to this rule that improve the implementation of the emission standards, primarily in the areas of compliance, testing and monitoring[72] for substances including PCDD/F. They also define standards for types hazardous waste incinerators. The rules continued to evolve through various court challenges until the US EPA issued a final rule[73] in October, 2005.

The U.S. EPA has adopted separate legislation for boilers and industrial furnaces burning hazardous wastes. The legislation is found in 40 CFR Part 266, Subpart H. No standards are listed for PCDD/F emissions. The Agency noted in April 2005 to continue to collect data on the operation of these units.

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[70] US EPA, 2006. The 40CFR60 regulations pertaining to incinerators are included in citations available at: http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=d274bb332d27c21ddd7839b5702c498d&tpl=/ecfrbrowse/Title40/40cfr60_main_02.tpl

[71] US EPA, 1999. 40 CFR Part 63,266, and 270, NESHAP: Standards for Hazardous Air Pollutants for Hazardous Waste Combustors. Published September 30,1999, (64 FR 52828).

[72] US EPA, 2002. 6968 Federal Register, Vol. 67, No. 31, Thursday, February 14, 2002. Rules and Regulations.

[73] US EPA, 2005. 40 CFR Parts 9, 63, 260 et al. National Emission Standards for Hazardous Air Pollutants: Final Standards for Hazardous Air Pollutants for Hazardous Waste Combustors (Phase I Final Replacement Standards and Phase II); Final Rule. 70 FR 59402, October 12, 2005.

All US EPA standards were based upon the concept of the Maximum Achievable Control Technology[74] [MACT]. That is, the emission limitations are technology based, reflecting what the best performing facilities are achieving and forcing all facilities to operate at the level of the best.

The procedures used to set the final rule MACT floors involve:

- Arraying, ranking, and evaluating emissions data (as well as feedrate data for chlorine and metals for HAPs (Hazardous Air Pollutants) in hazardous waste) to identify the MACT control used by the average of the 12% of best performing sources.
- Determining an emissions level that the MACT control can routinely achieve in practice based on data from sources employing MACT control.

Thus the standards developed for all incinerators are generally accepted as representing what the technology can achieve.

Having based the emission standards on the MACT approach, there are not only different categories of incinerators but within these incinerators there are different classes of units that have been assigned different emission limits. The categories were developed from review of a broad range of contaminants and thus there are not as many variations in the PCDD/F emission standards for incineration equipment as might be expected. The PCDD/F emission standards for incineration equipment in the United States are summarized in Table 7.3.

It is important to note that US EPA emission standards have changed over the years. While earlier standards were based upon total PCDD/F being emitted from the stack, the latest standards all reference emission concentrations on the basis of I-TEQ values, albeit that all the US standards are referenced at 20^{O}C and 7% oxygen and to correct these to Canadian standard conditions they must be multiplied by 0.7003.

[74] US EPA, 1999. Final Technical Support Document for HWC MACT Standards Volume III: Selection of MACT Standards and Technologies. Prepared by U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington. July.

Table 7.2 US EPA NSPS for Non-Hazardous Waste Incinerator Systems

Subpart	Description	Source and Date
Cb	Emissions Guidelines and Compliance Times for Large Municipal Waste Combustors That are Constructed on or Before September 20, 1994	60 FR 65415, Dec. 19, 1995 as amended at 71 FR 27332, May 10, 2006
Ce	Emission Guidelines and Compliance Times for Hospital/Medical/Infectious Waste Incinerators	62 FR 48379, Sept. 15, 1997
E	Standards of Performance for Incinerators - excluding incinerators covered by Sub-Parts Cb, Eb, AAAA, or BBBB; and, FFF or JJJ of part 62	42 FR 37936, July 25, 1977, as amended at 71 FR 27335, May 10, 2006
Eb	Standards of Performance for Large Municipal Waste Combustors for Which Construction is Commenced After September 20, 1994 or for Which Modification or Reconstruction is Commenced After June 19, 1996	60 FR 65419, Dec. 19, 1995 as amended at 62 FR 45121, 45126, Aug. 25, 1997
Ec	Standards of Performance for Hospital/Medical/Infectious Waste Incinerators for Which Construction is Commenced After June 20, 1996	62 FR 48382, Sept. 15, 1997 as amended at 65 FR 61753, Oct. 17, 2000
AAAA	Standards of Performance for Small Municipal Waste Combustion Units for Which Construction is Commenced After August 30, 1999 or for Which Modification or Reconstruction is Commenced After June 6, 2001	65 FR 76355, Dec. 6, 2000
BBBB	Emission Guidelines and Compliance Times for Small Municipal Waste Combustion Units Constructed on or Before August 30, 1999	65 FR 76384, Dec. 6, 2000
CCCC	Standards of Performance for Commercial and Industrial Solid Waste Incineration Units for Which Construction Is Commenced After November 30, 1999 or for Which Modification or Reconstruction Is Commenced on or After June 1, 2001	65 FR 75350, Dec. 1, 2000
DDDD	Emissions Guidelines and Compliance Times for Commercial and Industrial Solid Waste Incineration Units that Commenced Construction On or Before November 30, 1999	65 FR 75362, Dec. 1, 2000
EEEE	Standards of Performance for Other Solid Waste Incineration Units for Which Construction is Commenced After December 9, 2004, or for Which Modification or Reconstruction is Commenced on or After June 16, 2006	70 FR 74892, Dec. 16, 2005
FFFF	Emission Guidelines and Compliance Times for Other Solid Waste Incineration Units That Commenced Construction On or Before December 9, 2004	70 FR 74907, Dec. 16, 2005

Table 7.3 Summary of PCDD/F Emission Standards for Incinerators in the United States

Type of Incinerator	Category	Emission Limit
Municipal Solid Waste Notes: Small furnaces are <229 Mg/day capacity but >32 Mg/day size Class I facilities >229 Mg/day Class II facilities <229 Mg/day	Small Existing Class I facility	30 ng total /Dsm^3 @ 7% O_2 (no ESP) 60 ng total /Dsm^3 @ 7% O_2 (c/w ESP)
	Small Existing Class II facility	125 ng total /Dsm^3 @ 7% O_2
	Large Existing	30 ng total /Dsm^3 @ 7% O_2 (no ESP) 35 ng total /Dsm^3 @ 7% O_2 (c/w ESP)
	New (any size)	13 ng total /Dsm^3 @ 7% O_2
Commercial and Industrial Waste	Existing or New >32 Mg/day	410 pg I-TEQ/Dsm^3 @ 7% O_2
Other Solid Waste	Existing or New <32 Mg/day MSW or Institutional Solid Waste	33 ng total /Dsm^3 @ 7% O_2
Medical Waste (existing)	Urban setting	125 ng total /Dsm^3 @ 7% O_2 or 2300 pg I-TEQ/Dsm^3 @ 7% O_2
	Rural setting (>50 miles from large population centre and <900 kg/wk charge	800 ng total /Dsm^3 @ 7% O2 or 15000 pg I-TEQ/Dsm^3 @ 7% O_2
Medical Waste (new)	Small (<90 kg/hr continuous or 725 kg/day batch)	125 ng total /Dsm^3 @ 7% O_2 or 2300 pg I-TEQ/Dsm^3 @ 7% O_2
	Medium and Large	25 ng total /Dsm^3 @ 7% O_2 or 260 pg I-TEQ/Dsm^3 @ 7% O_2
Hazardous Waste (Existing/New/Reconstructed) Note: some increase is emissions is allowed if the facility employed rapid quench of exhaust gas	Incinerator (existing or new or reconstructed without dry APCD or waste heat boiler)	200 pg I-TEQ/Dsm^3 @ 7% O_2
	Incinerator (new or reconstructed with dry APCD or waste heat boiler)	110 pg I-TEQ/Dsm^3 @ 7% O_2
	Cement Kiln	200 pg I-TEQ/Dsm^3 @ 7% O_2
	LWAK	200 pg I-TEQ/Dsm^3 @ 7% O_2
	Liquid Fired Boiler (with dry APCD)	400 pg I-TEQ/Dsm^3 @ 7% O_2

7.8 Summary of Emission Standards

The preceding sections have provided a summary of regulatory emission levels for different jurisdictions reported on the basis of the standards for that country. As noted in Chapter 6, standard conditions and diluent corrections in other jurisdictions can be different from those Canadians, but they can be easily converted. At the present time most jurisdictions appear to be applying the I-TEF protocol to provide a single emission number for PCDD/F emissions reported as I-TEQ. While the impact of changing that protocol will be discussed when Canadian data are reviewed, for now the I-TEQ values will be used in the summary table of emissions. Table 7.4 provides the comparison of the regulatory levels in Canadian units.

Most jurisdictions that have set emission limits for PCDD/F require some periodic testing of the emissions to prove that they meet the standards set out in legislation. In the European Union, the Directive requires that incinerator facilities be tested for PCDD/F every 6 months after the first year of operation, and they must be tested every 3 months in the first year. In the United States testing is required on an annual basis, however, for large MWC installations the rules allow facilities with multiple lines and separate APCs and stacks to test just one unit each year provided the emissions from all the units have satisfied a threshold criteria for two years. Should one of the annual tests fail to pass the threshold, the facility must revert to annual testing for each stack until 2 years of satisfactory data are amassed. The testing requirements in the other jurisdictions discussed in Chapter 7 are not as clearly defined. In Canada, Ontario requires annual testing of all incinerators and to date has not allowed the testing frequency to be reduced even if the facility continuously reports levels below the LOQ.

Table 7.4 International Incinerator PCDD/F Emission Regulations
[pg I-TEQ/Rm^3 @ 11% O_2]

COUNTRY	Incinerator Type	Emission Limit	Comments
European Union	All	92	diluent corrections note applied when < 11% O_2
Australian & New Zealand	All	92	
Japan (based upon size and age)	>4 Mg/hr	92	existing facilities have limit of 920
	2 - 4 Mg/hr	920	existing facilities have limit of 4600
	<2 Mg/hr	4600	existing facilities have limit of 9200
United States	MSW		no I-TEQ standards rather use total PCDD/F [ng] existing >225 Mg/d c/w ESP = 25 w/o ESP = 21 new all sizes = 9 ng total/Rm^3 @ 11%O_2 small units <225 Mg/d with Class I total site >225 existing Class I c/w ESP = 50 w/o ESP = 25 existing Class II = 88 ng total/Rm^3 @ 11%O_2
	Medical (existing)	1.61e+08	Existing urban total = 88 ng total/Rm^3 @ 11%O_2 Existing rural total = 560 ng total/Rm^3 @ 11%O_2
	Medical (new)	1821610	<90 kg/hr continuous or <725 kg/day batch (87.5 ng total/Rm^3 @ 11%O_2) >90 kg/hr continuous or >725 kg/day batch (17.5 ng total/Rm^3 @ 11%O_2)
	HazWaste	140 78	without dry APCD system or waste heat boiler with dry APCD or waste heat boiler
	Commercial & Industrial Waste	287	>32 Mg/day capacity
	Other Solid Waste		<32 Mg/day = 23 ng total/Rm^3 @ 11%O_2
Canada (per CWS 2001)	Municipal	80	existing by 2006, all new construction after 2001
	Medical	80	existing by 2006, all new construction after 2001
	Hazardous	80	existing by 2006, all new construction after 2001
	Sewage Sludge	80	all new construction after 2001, existing facilities limited to 100 pg ITEQ/Rm^3 @ 11%O_2

8.0 EMISSION DATA

8.1 Introduction

Operating facilities in the various provinces are required to obtain permits to operate. These permits frequently contain requirements that stack testing be undertaken to establish emission performance. Thus, even before the CWS for PCDD/F was approved in 2001, incinerators were building a database of their emission values which allow site specific emission data to be determined. These are the data that should be used for the annual submissions to NPRI, but since the NPRI numbers are simply given as I-TEQ values that were self-reported, the quality of the data cannot be confirmed. In fact, as noted in the 2003 MSW incinerator report[75] some facilities reverted to using the NPRI default factors which were inappropriate for their case.

This chapter provides a summary of the available data for the different types of incinerators operated in the country. As well as the four main categories:

- large MSW incinerators;
- medical waste incinerators;
- hazardous waste incinerators; and,
- sewage sludge incinerators.

This chapter also includes a data for a group of small batch incinerators that were not included in the 2000 inventory. These units, operated chiefly in remote locations on land leased from the Federal government, burn significantly more waste than the 26 Mg/year cut-off in the CWS PCDD/F standard. Thus, it was considered important that their performance be considered in the Incinerator PCDD/F emission inventory.

Important to the estimation of annual PCDD/F emissions from any of these incinerators are two main factors:

- the amount of waste processed annually at the facility; and,
- the emission factor [ng I-TEQ/Mg of waste disposed] suitable for that facility.

This chapter provides the background information for updating the annual emissions from incinerators in Canada. Since the data availability is not all the same quality, the background of the waste throughput estimates, and the emission factors are addressed in two separate parts of this chapter and the results combined in the estimated emissions.

When discussing emissions from incinerators the usual concern is the amount of contaminants in the stack gases leaving the facility. To date little attention has been focussed on PCDD/F in

[75] Chandler, A.J. & Associates and Compass Environmental, 2003. Municipal Solid Waste Incineration in Canada: An Update on Operations 1999-2001.

residue streams. Air emissions are generally assumed to be the source of the contaminants through which most people become exposed. These are also the emissions that are most frequently measured at facilities. Indeed, few operating facilities have extensive data on PCDD/F concentrations in solid residue streams.

It has generally been accepted that APC residues from incinerators should be handled as hazardous waste due to the quantities of some inorganic species that can leach out of these materials. With this designation, little attention has been paid to quantifying the amount of other contaminants that might be present in these streams. Since bottom ash from MSW incinerators is such a heterogeneous material, it is difficult to gather a representative sample for analysis. Indeed, obtaining a representative sample of the stack gas using the procedures discussed in Chapter 6 is easier than ensuring that samples of bottom ash from the quench tank are representative. On the other hand, sampling the APC residues from ash storage silos, or during transfer of the ash to the silo, is considerably easier. However, fly ash found in other locations including hot gas ducts, or in the hoppers under boilers and economisers is seldom weighed and monitored stream by stream. As noted earlier, it would also be anticipated that depending upon the location of these deposits and their temperature history the level of PCDD/F in the materials could vary.

Liquid streams leaving the systems also have the potential to contain PCDD/F. The effluents from wet scrubbers likely contain some PCDD/F. Since PCDD/F isomers have a very low solubility in water, it is generally recognized that any PCDD/F found in water samples is present as very small suspended particulate matter.

In addressing the issue of PCDD/F emission streams from incinerators, we can take guidance from the UNEP Toolkit[76]. That document suggests that:

> "The PCDD/PCDF emissions to land are negligible and there is no product. Relevant releases to water occur only if wet scrubbers are used for the removal of particulate matter and the water is not recirculated within the process. Releases to water will occur when the effluent is not adequately treated, *e.g.*, to filter out the particles with the PCDD/PCDF adsorbed onto them or water is used to cool down the ashes and the water is not caught. Thus, the most significant release routes are to air and residue. Typically, higher concentrations are found in the fly ash, bottom ash has lower concentrations but the larger volume."

Thus air emissions and solid residues from the grate or bottom ash, fly ash from boilers, and APC residues all contribute to the total burden of PCDD/F arising from incinerators. This chapter reviews literature data to establish default values for residue streams from incinerators because little analytical data on such streams is available, and many incinerators have not even quantified the dry mass of these streams. It also considers literature values and the results of stack sampling

[76] UNEP, 2005. Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases, 2nd edition February 2005 Prepared by UNEP Chemicals Geneva, Switzerland

to define emission factors for releases to the atmosphere.

8.2 Background of Historical Incinerator Installations in Canada

There are four types of incinerators discussed in this report. Most are owned and operated by public bodies or contractors serving governments. As such, large MSW, sewage sludge and medical waste incineration facilities are known to those in the communities where they are located. Hazardous waste incinerators also provide a service to society, for the most part disposing of hazardous organic wastes for industry. Hazardous waste incinerators operated by contractors in the waste disposal business have typically been subject to scrutiny by their local communities. Thus, in most communities at least for some constituents are aware that there are waste incineration facilities in their community. Through those local contacts, other interested parties in the country know of the existence of these facilities. Thus, most commercial facilities are commonly included in incinerator inventories of facilities.

Another group of incinerators are not as well documented. These include:

- captive incinerators processing specific wastes from particular operations such as:
    - the radioactive waste concentration facilities operated at Cameco manufacturing facilities and by Ontario Power Generation;
    - incinerators used for classified document destruction at government facilities;
    - incinerators operated at Canadian Forces Bases; and,
    - federal and provincially operated incinerators that dispose of agricultural wastes to prevent the spread of disease;
- hospital waste incinerators in both urban and remote communities;
- municipal waste incinerators in remote communities;
- general waste incinerators used for mixed waste disposal at mine exploration and development camps or even at remote mine sites.

Much less is known about incinerators in the second group. In many cases they are located on federal lands and, as such, not subject to provincial licensing procedures. Without formal application procedures, size, intended use, and operational procedures are not well documented and providing a list of such facilities requires polling those responsible for their operation. Such a survey was conducted by Environment Canada and required that questionnaire be completed by the operator. Data from that survey forms part of the incinerator inventory in this report. Other data came from the inventory assembled in 2000 for the original CWS efforts.

This section compares earlier inventory data concerning the number and types of incinerators operating in Canada with the data collected during this study.

8.2.1 Canada Wide Standards Basic 2000 Inventory

As part of the original Canada Wide Standards [CWS] PCDD/F committee's work several definitions were developed for the final CWS for PCDD/F. A waste incinerator, as defined for the purposes of the Canada Wide Standards, is:

> "a device, mechanism or structure constructed primarily to thermally treat (e.g., combust or pyrolyze) a waste for the purpose of reducing its volume, destroying a hazardous chemical present in the waste, or destroying pathogens present in the waste. This includes facilities where waste heat is recovered as a byproduct from the exhaust gases from an incinerator, but does not include industrial processes where fuel derived from waste is fired as an energy source as a matter incidental to the manufacture of the primary product. For the purpose of the Dioxins and Furans CWS, conical waste combusters are considered separately from other incineration sectors."

Definitions of waste are also included in the PCDD/F Canada Wide Standard. These serve to limit the systems that are considered in the standard and thus are the subject of this report. These definitions specifically refer to limitations for municipal solid waste and for medical waste:

> *"Municipal solid waste*: any waste which might normally be disposed of in a non-secure landfill site if not incinerated (i.e., including non-hazardous solid wastes regardless of origin), but is not intended to include "clean" wood waste. Clean wood waste means waste from woodworking or forest product operations where the wood waste has not been treated with preservative chemicals (e.g., pentachlorophenol) or decorative coatings."
>
> *"Medical waste*: any waste which includes as a component any Biomedical Waste as defined in the February 1992 CCME Guidelines for the Management of Biomedical Waste in Canada, with the exception that animal wastes derived from animal health care or veterinary research and teaching establishments are excluded."

Furthermore, during the development of PCDD/F CWS there were six different priority sources identified. These included waste incineration as fits the definitions above, and conical municipal waste combustion units operated in Newfoundland. The latter class of equipment was addressed by a specific provincial standard. The province of Newfoundland made the commitment that these units would be phased out of service by 2008.

Incinerators meeting these definitions were identified as part of the Committee's work in 2000, and emission estimates were developed. A summary of the information in that list is provided in Table 8.1. The number of incinerators identified by the committee, by type and province, are listed in Table 8.1 a). The total amount of waste estimated to have been burned in each facility is listed in Table 8.1 b) and the resulting PCDD/F emissions from these facilities are summarized in Table 8.1 c). After the Committee's work was completed, some additional incinerators were identified, including hazardous waste/radionuclide contaminated waste incinerators in Ontario.

Table 8.1a Summary of Operating Incineration Facilities 2000 Inventory

Incinerator Classification	Province													Totals
	AB	BC	MB	NB	NF	NT	NS	NU	ON	PE	QC	SK	YK	
Municipal	1	1			2		1		2	1	3			11
Medical			37	3		6			46	1		7	1	101
Hazardous	1								4		2			7
Sewage Sludge									5		2			7
Federal Agencies	11	7	6	2	6	4	5		16		2	3		62
Remote and Federal Lands														
Totals	13	8	43	5	8	10	6		73	2	9	10	1	188

Table 8.1b Summary of Estimated Quantity of Waste Burned at Incineration Facilities 2000 Inventory [Mg/year]

Incinerator Classification	Province													Totals
	AB	BC	MB	NB	NF	NT	NS	NU	ON	PE	QC	SK	YK	
Municipal	8,512	250,000	-	-	28,000	-	52,500	-	290,000	32,000	289,699	-	-	950,711
Medical	-	-	1,985	1,070	-	321	-	-	1,963	28	-	129	83	5,579
Hazardous	35,000	-	-	-	-	-	-	-	76,328	-	51,880	-	-	163,208
Sewage Sludge	-	-	-	-	-	-	-	-	123,887	-	47,587	-	-	171,474
Federal Agencies	169	112	67	12	140	60	50	-	580	-	27	19	-	1,235
Remote and Federal Lands														
Totals	43,681	250,112	2,051	1,082	28,140	381	52,550	-	492,758	32,028	389,193	148	83	1,292,207

Table 8.1c Summary of Estimated PCDD/F Emissions at Incineration Facilities 2000 Inventory [mg I-TEQ/year]

Incinerator Classification	Province													Totals
	AB	BC	MB	NB	NF	NT	NS	NU	ON	PE	QC	SK	YK	
Municipal	1.4	6.6			116.7		12.8		2034.7	85.3	35.7			2,293
Medical			9268.6	2.3		1500.9			9165.3	132.6		603.0	388.5	21,061
Hazardous	140.9								2.5		35.3			179
Sewage Sludge									81.7		28.9			111
Federal Agencies	791.3	524.2	310.6	53.8	653.4	278.1	235.4		2708.6		123.8	87.2		5,767
Remote and Federal Lands														
Totals	934	531	9579	56	770	1779	248		13993	218	224	690	389	29,410

The 2000 list showed that, based upon the total number of incinerators, 54% were used for medical waste disposal. These incinerators were estimated to account for 72% of the annual PCDD/F emissions at that time.

In terms of the number of incinerators, the other dominant category was the one listing facilities operated on federal lands or by federal entities. Over a third of all the incinerators listed were in this category. Medical waste incinerators operated under federal sponsorship were included with the medical incinerators discussed above. There are 3 such medical incinerators: Norway House, MB; Weeneebayko, ON; and Percy Moore, MB. While large in numbers, the federal incinerators were estimated to account for only 20% of the annual PCDD/F emissions.

Much of the data developed for that inventory was estimated. Only a few of the medical waste incinerators had been tested at the time the inventory was prepared and no data was available on emissions from the federal facilities. Emissions were estimated based upon both the estimated tonnage processed by these incinerators and emission factors from the literature. The emission factor selected for these sources was 4.67 mg I-TEQ/Mg waste burned. The origin of this number is not known. The adequacy of that number will be discussed later in this chapter.

While 11 MSW incinerators were included in the inventory, most of the emissions from this sector were associated with the now closed SWARU facility in Hamilton. At the time the inventory was prepared, with the exception of the conical waste burners in Newfoundland, all MSW incinerators were estimated on the basis of annual throughput and emissions data collected during testing programs. The emissions estimates associated with the Newfoundland facilities are of suspect origin.

Hazardous waste incinerator and sewage sludge incinerator emissions were estimated on the basis of test data and throughput information for the majority of the units.

Total emissions from any facility were estimated by multiplying the annual waste throughput estimate by an emission factor that expressed PCDD/F releases as a function of the waste throughput. As can be appreciated, the use of estimated emission factors, however they are selected, leads to some uncertainty in the emission totals. Equally important is the uncertainty in the estimate of the amount of materials burned in the incinerator. Data reviewed for this study suggests that the waste is seldom weighed before being charged to most small batch incinerators. At best, some of these facilities have the operators' estimates of how much waste was charged. Thus, there is uncertainty in the estimates provided by the 2000 inventory. The amount of uncertainty in these estimates was never determined.

However, the creation of the inventory prompted provincial regulators to start addressing these sources of PCDD/F. In some cases it lead to orders for the cessation of operation of medical waste incinerators even before the CWS standard was ratified. For instance, all medical waste incinerators in hospitals subject to provincial regulation in Ontario were shut down in December 2003. British Columbia had banned such facilities in 1998. Other provinces have ordered the

closing of some facilities as a result of the CWS standard. Thus the nature of the incinerator inventory has changed, and one would expect the PCDD/F to have decreased.

Based upon the 2000 list, and comparisons to the list developed for this study, the facilities that were closed were identified. During the course of this study it became evident that the 2000 identification of incinerators operated by Federal Entities was not specific enough to allow accurate determination of which incinerators were referenced. There were clearly some incinerators in this category that were not included in the 2000 inventory.

8.2.3 CCME 2005 Review

In 2005 CCME commissioned a review of the complete PCDD/F inventory[77] including other sources identified in earlier studies. This review was completed as part of CCME review of the CWS standards. Discussed in the report were emissions from coastal pulp and paper boilers, iron sintering, electric arc furnace steel manufacturing and incineration sources. One objective of the review was to assess the potential for the deployment of new control technologies or production processes in these sectors.

The review states that the National Pollutant Release Inventory should be looked at as the *de facto* inventory of PCDD/F sources in the country. As such the consultant suggests that they chose to summarize emissions on the basis of the NPRI data sorted for NAICS category 5662 Waste Treatment and Disposal, however the presence of sewage sludge incinerators in the summary tables suggests additional searches were undertaken. The data compiled by the consultant is shown in Table 8.2. Unfortunately, the data, which is presumed to have been taken from the NPRI data base has several omissions and mis-classification of incinerators.

Two Quebec incinerators listed under the MSW classification in Table 8.2 should have been classified as sewage sludge incinerators. NPRI ID #5528 Rive Sud in Longueuil and NPRI ID #3571 Ville de Montréal are both listed in the NPRI 2005 reports as Centre d'épuration des eaux usées, waste water treatment facilities. Also not included in the table are the Mercier facility of Clean Harbors and the Bennett facility at St. Ambroise, which likely should be listed under the hazardous waste incinerators in Quebec.

The 2005 review report specifically states that the"conical" waste burners were not included in the scope of the report. However, there are 31 MSW burners listed as operating in the province of Newfoundland. The 2004 NPRI summary for PCDD/F shows 32 filings for Newfoundland

[77] Jacques Whitford, 2005. Dioxins and Furans Canada-Wide Standards – Emission Inventory Update and Review of Technical Pollution Prevention Options. A report to the Canadian Council of Ministers of the Environment.

Table 8.2 Summary of Incinerators listed in NPRI Data (from Jacques Whitford)

Incinerator Classification	Province													Totals
	AB	BC	MB	NB	NF	NT	NS	NU	ON	PE	QC	SK	YK	
Municipal	1	1			31				1	1	5			40
Medical	1		2	2		3			1	2		5	1	17
Hazardous	1								5					6
Sewage Sludge									4					4
Federal Entities	6	1	4		2	4	1	4	3	1	6	1		33
Remote														
TOTALS	9	2	6	2	33	7	1	4	14	4	11	6	1	100

including the Voisey's Bay mine project. The Voisey's Bay facility might be included in the "on Federal Lands" category, but it is not clear. Since the waste burners are not incinerators subject to the CWS PCDD/F standard, their inclusion in the list of incinerators is problematic. Moreover, using the NPRI data, which includes the Newfoundland burners hinders a comparison to those data provided in the 2000 inventory. The 31 "burners" listed in the 2004 NPRI data for Newfoundland are estimated to result in PCDD/F emissions that total 38.2 g I-TEQ/a, or more than 75% of all the 2004 PCDD/F releases from waste management sites listed in the NPRI report. Clearly there is a need to ensure that the incinerator inventory is up to date, and the emission inventory reflects what would be considered typical operating conditions.

Aside from the incinerators that have been closed, there are obvious differences between the incinerator numbers in Table 8.1 and 8.2 that can be explained by sector as follows:

MSW Incinerators – Whereas only 11 units are listed in Table 8.1 there are 40 listed in Table 8.2. Since 2000, the SWARU facility and the two incinerators listed for Newfoundland have been shutdown, or moved to other categories. If Table 8.1 were updated to 2005 it would only contain 8 incinerators. Table 8.2 includes 29 MSW burners in Newfoundland which should not be considered in this report since they are subject to a separate CWS. Table 8.2 also lists two incinerators operating in Quebec as MSW incinerator where, in fact, they are sewage sludge units and should be moved to that category. Table 8.2 is missing the Cape Breton facility which was not closed until 2006.

Sewage Sludge Incinerators – Seven were shown in Table 8.1 and only 4 in Table 8.2. Since 2000, Ashbridges Bay facility in Toronto was closed reducing the number of incinerators in Table 8.1. The two mis-assigned units from the Quebec MSW list would raise the total in Table 8.2 to 6.

Hazardous Waste Incinerators – Six are shown in Table 8.2 and 7 in Table 8.1. The Mercier facility is missing from Table 8.2.

Medical Incinerators – 101 are listed in Table 8.1, and 17 in Table 8.2. The net change in Ontario over the intervening period reflects closure of 45 units. Similarly 1 unit closed in New Brunswick, 3 in the NWT, 2 in Saskatchewan. An extra unit was identified for PEI, and a new system was added in Alberta. The net reduction is 49 units, which would bring to total in table 8.1 to 52 units. The 35 unit discrepancy, according to Table 8.2, is created by the listing of only 2 incinerators as operating in Manitoba. While this would suggest the closure of 35 units, the November 2004 Interjurisdictional report[78] does not indicate that any medical incinerators in Manitoba had ceased operation. The province was actively encouraging the reduction in burning of waste.

Incinerators on Federal land – In Table 8.1 sixty two incinerators are listed, this dropped by nearly 50% as only 33 are shown in Table 8.2. These incinerators have been surveyed by Environment Canada[79,80] to verify their continued operation. More discussion of these units is included later and thus no detailed explanation of the decrease was undertaken. One anomaly noted however was that the 2004 NPRI report for Newfoundland does not list any facilities on federal lands, yet there are 2 shown in Table 8.2. These could be the two Voisey's Bay incinerators.

8.3 Updating the Incinerators Inventory to 2006

To update the PCDD/F emission inventory for incineration facilities in Canada it was first necessary to establish which facilities were operating. Then, if possible, determine how much waste they burn annually, select an appropriate emission factor, and provide an estimate of the total emissions that can be compared to the 2000 numbers. This section discusses the procedures used to confirm the list of operating incinerators, explains how these units are described, and provides a basis for the assumptions used to develop emission estimates for the different types of incinerators.

The starting point for developing a list of operating facilities was the 2000 Inventory list. To

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[78] CCME, 2004. Jurisdictional Interim Progress in Achieving Dioxins and Furans Canada Wide Standards for: Pulp and Paper Boilers Burning Salt Laden Wood, Waste Incineration, Iron Sintering Plants and Steel Manufacturing Electric Arc Furnaces. Available at: http://www.ccme.ca/assets/pdf/df_2004_prgs_rpt_e.pdf

[79] Compass Environmental Inc., 2006. Assessment of Select Federally Owned Waste Incinerators. A report prepared for the Waste Management Division of Environment Canada. Final Report, March.

[80] Compass Environmental Inc., 2005. Assessment of Current Operating Practices for Federally Owned Small Incinerator Units: A Consolidation of Volumes 1,2, and 3. A report prepared for the Waste Management Division of Environment Canada. Final Report, March.

ensure all facilities were properly included in the 2000 listing, provincial regulators were asked to confirm the operational status of the incinerators operating within their jurisdictions and identify any new or closed units. Environment Canada also commissioned a number of studies that provide data on various types of incinerator operated at federal facilities[81]. Utilizing the Compass reviews of incinerators operated by federal entities, or on federal lands, it was possible to refine the federal facilities portion of the 2000 inventory to reflect systems that are operating as of June 2006. Additional information was gleaned from a questionnaire circulated by Environment Canada to companies operating incinerators on federal lands. Large MSW facilities were reviewed in 2003[82] and hazardous waste incinerators were the subject of a report in 2003[83]. During the creation of these reports, contacts had been made with most operators and changes to these facilities were known to the author of this report.

Incinerators that were closed before June 2006 were removed from the list. Any new facilities identified through this process were added to the list. An attempt was then made to provide a description of the various facilities.

The descriptive material for the MSW and Hazardous Waste incinerators was taken from test reports or details available to the author. Where provided, incinerator descriptions from the questionnaires, or incinerator model numbers were used to identify the type of equipment that was installed at a particular location. Data was also received from incinerator manufacturers and provincial regulators.

For ease of presentation, the facilities have been sub-divided into categories as discussed earlier in this report. The data for the individual categories are presented in separate tables.

Information for the installations is described in terms of community and province where they are installed, the classification of the incinerator type, it's manufacturer and design feed rate. Since the presence of heat recovery equipment or air pollution control equipment can influence emissions, where this data was available it was included. Lastly, the annual waste throughput for each of the incinerators is listed in the tables. The annual waste throughput was not derived the same way for each incinerator and the sections that follow discuss how waste throughput values were arrived at for the various facilities.

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[81] Compass Environmental Inc., 2005. Assessment of Current Operating Practices for Federally Owned Small Incinerator Units: A Consolidation of Volumes 1, 2 & 3. A report prepared for National Office of Pollution Prevention, Environment Canada. March.

[82] A.J. Chandler & Associates Ltd, and Compass Environment Inc., 2003. Municipal Solid Waste Incineration in Canada: An Update on Operations 1999-2001.

[83] Chandler, A.J., 2003. Background Study on the Incineration of Hazardous Waste. Final Draft of A Report to ENVIRONMENT CANADA to complete Contract Number K2237-2-0006. Prepared by A.J. Chandler & Associates Ltd. Toronto. March

8.3.1 MSW Incinerators

The number of large commercial incinerators in Canada is small, only seven units are operating in 2006. Data on these units was obtained directly from the operators of two of the systems and is listed as data for 2005. Data for Quebec City and Levis were obtained from both the 2003 EFW update report referenced earlier and more recent studies published by both municipalities on the web sites. The location of these data is referenced on the table. No data was available for the MRC des Iles de la Madeleine in 2003, and none was collected as part of this study. Wainwright was not included in the original study which concentrated on dedicated MSW incinerators, but has been included in this listing. Estimates for the annual throughput of these units were developed.

Large MSW incinerators in Canada can either be owned by municipalities or the private sector. If owned by the municipality, the facility is typically operated by a contractor with knowledge running such facilities. The revenue required to cover costs of the contractor, or the owner, usually comes from tipping fees charged on the basis of the mass passing over the scale at the entry to the facility. Receipts are thus the basis of the quantity of waste incinerated in a year. Assuming that all material received over the scale in a year is burned is a reasonable way to estimate the mass charged to the furnaces in a year. Even if there is waste left on the floor at the end of the year, it is unlikely to be more than needed to charge the furnaces for two or three days, less than 1% of the annual total. Waste rejected as unacceptable is typically weighed as it leaves the facility and can thus be removed from the totals. Since the operator submits the waste receipt records for payment, they can be accepted as a good estimate. Waste throughput data was not available for MRC.

As noted in Table 8.3, which summarizes all the MSW incinerators, Wainwright has a permit that allows for medical waste, municipal solid waste and non-hazardous oil field waste to be disposed in the furnace. In discussions with the facility it was learned that waste feeds are segregated at the facility and only one type of waste is fed at a time. Moreover the rate of feed for the different waste streams varies. For the purposes of the inventory, the MSW burned at Wainwright is listed in Table 8.3 whereas Table 8.4 shows the medical waste burned at the facility.

Incinerators cannot be fed a fixed mass of any type of waste. They should ideally be fed waste at a rate that provides a uniform rate of energy release in the furnace. This means that if the operator is charging wet, low energy waste, for instance a great deal of food waste with high moisture content, the rate for charging this material would be higher than when he was charging predominantly packaging waste. As noted elsewhere in this report, typically MSW is mixed to even out the calorific value of the charge. At Wainwright, the operators segregate the medical waste which is typically twice the calorific value of MSW because it is preferable to handle this

Table 8.3 Summary of Large Scale Municipal Solid Waste Incinerators in Canada

Name	Location	Province	Type	Manufacturer	Heat Recovery	Capacity	APC System	Year of Record	Annual Throughput
						# x [t/day]			[Mg/yr]
Wainwright (MSW feed)	Wainwright	AB	3-Stage Excess	Basic	Yes	1 x 29	WSH/DS/PAC/FF	2005	2,383
GVRD	Burnaby	BC	Mass Burn	Martin	Yes	3 x 240	SNCR/WSH/DS/PAC/FF	2005	275,000
Algonquin Power Energy from Waste	Brampton	ON	2-Stage Starved	Consumat	Yes	5 x 100	WSH/DS/FF/PAC/SCR	2005	140,000
Trigen	Charlottetown	PE	2-Stage Starved	Consumat	Yes	3 x 33	WSH/DS/PAC/FF	2001	32,000
Centre de traiement des residus urbains	Québec City	QC	Mass Burn	Von Roll	Yes	4 x 230	ESP/WSH/DS/PAC/FF	2001	280,000
La Régie Intermunicipale de Gestion Rive-Sud	Levis	QC	Step grate		None	1 x 80	WSH/DS/PAC/FF	2001	24,310
MRC des Iles de la Madeleine	Dune-du-Sud	QC	Step grate		None	1 x 31	WSH/DS/PAC/FF	estimate	9,100
								Total	762,793

Notes:

APC System Key
ESP - electrostatic precipitator for particulate matter removal
WSH - evaporator cooling tower or wet spray humidifier
DS - dry reagent addition or dry scrubber
PAC- powdered activated carbon addition
SNCR - selective non-catalytic reduction for NOx control
SCR - selective catalytic reduction for NOx and PCDD/F control
FF - fabric filter particulate control

Specific Incinerator Comments
Wainwright is licensed to burn MSW, medical & non-hazardous oil feel waste-oil laden materials - limiting input is 12,500 MJ/hr
Levis data from http://www.ville.levis.qc.ca/Fr/Citoyens_Mat_Con.asp represents 2002 operating data and 2001 test data
Iles de la Madeleine emissions assumed to be similar to Levis in absence of data

material without mixing it with other waste and risk the packaging breaking.

Waste records obtained from Alberta Environment show that in 2005 Wainwright burned almost equal quantities of MSW and medical waste: 2288 Mg and 2308 Mg respectively, with 95 Mg of non-hazardous oil field wastes. Operating hours when burning MSW were about half those for medical waste clearly indicating that the higher calorific value medical waste could not be fed at the same rate as MSW. Overall the system operated for an 80% availability in the year.

The estimate for throughput at the MRC facility was based upon the size of the incinerator. The daily feed rate is 31 Mg/d. Systems of this type, particularly in remote areas where waste is limited, do not run continuously but rather operate approximately 80% of the time. This is termed the system availability and is calculated by the number of operating hours divided by the total hours in the year. When available, if can be assumed that the unit is run at its' design feed rate so the annual throughput is 31 Mg/d x 365 days/year x 0.80 or 9,100 Mg/year.

8.3.2 Medical Waste Incinerators

This category of incinerators could be divided into several parts:

- commercial incinerators in Ontario, New Brunswick and Alberta;
- incinerators operated by Federal entities or under agreement with Federal entities; and,
- incinerators operated at specific institutions.

The commercial units are identified in the list with the word (commercial) after the name of the facility. The three medical waste incinerators that are operated under Federal agreements are noted with ** after their name. The balance of the facilities are at hospitals.
During the provincial agency review two additional "medical waste incinerators" were noted, however both these units have been excluded from this study on the basis of the definition of *medical waste* shown in §8.2.1. These facilities are:

- Prairie Diagnostics located on the University of Saskatchewan Saskatoon campus as part of the Western College of Veterinary Medicine, handles animals and wastes from the laboratory of a teaching facility that offers veterinary diagnostic services to farmers in the province. While this unit was used for the disposal of other waste generated on campus up until 2001, this practice ceased at that time.
- An incinerator housed in the Duff Roblin building of the University of Manitoba in Winnipeg. This building[84] houses zoological laboratories and one presumes an incinerator in this building is for animal waste from a research facility located at a teaching institute.

[84] http://umanitoba.ca/maps/

Similar facilities are located at the University of Guelph in Ontario and one presumes in Charlottetown at the Atlantic Veterinary College and in Montreal at the Faculty of Veterinary Medicine. It has also come to the author's attention that a new large animal research centre has been developed in Alberta.

Limited study on emissions from animal waste incinerators suggests that provided that the load is predominantly animal tissue, PCDD/F emissions would be expected to be low[85] and could well satisfy the CWS standard. Data from Environment Canada tests of an EcoWaste CleanAire unit[86] shows concentrations for the 17 congeners to be largely non-detectable.

The 41 locations identified as having incinerator facilities belonging to this category are listed in Table 8.4. One commercial facility is equipped with 2 incinerators, one being used for back-up so the total count for medical incinerators is 42. While listed in the 2000 inventory as having a hospital, information available as part of the latest census data on the provincial government's web site suggests that Reston, Manitoba only has a medical clinic. Reston was removed from the list.

The table shows very little data for many of the hospital incinerators. Estimating annual throughput for these facilities thus requires a number of approaches. Data is most readily available from the commercial facilities in the list. For installations with known installed capacity guidance can be obtained from the US EPA inventory reviews. For hospitals where no data was available it was assumed that the size of the hospital, as defined by the number of beds, could be used as a starting point in estimating waste generation rates. Each of these approaches are discussed in this section.

Commercial incinerators charge tipping fees and thus have records that would allow annual throughput to be determined. If they are restricted to hourly feed rate limits, or daily limits these would be contained in their permits such information can be used as a starting point, but reality with these facilities is that they typically store waste at the facility prior to starting a burn cycle and once running operate around the clock until there is no waste to dispose. At that time they shutdown for maintenance activities. Utilization of these facilities is thus not even at the level of the small MSW facilities discussed in the previous section.

Looking at these facilities, Medical Waste Management in Brampton has a permit that limits daily throughput to 10 Mg, the equipment is operated so as not to exceed this limit and maintain

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[85] Chandler, A.J. & Associates Ltd., 2004. Western College of Veterinary Medicine Waste Management Disposal Procedures. A report prepared for the University of Saskatchewan Saskatoon, Saskatchewan. by A.J. Chandler & Associates Ltd. Toronto, Ontario February 2004

[86] Cianciarelli, Dominic and C. House, 2004. Characterization of Emissions from an Animal Crematorium EcoWaste CleanAire. Report ERMD 2003-03 prepared by the Emissions Research and Measurement Division of the Environmental Technology Advancement Directorate of Environment Canada. Ottawa, March.

Table 8.4 Summary of Medical Waste Incinerators in Canada

Name	Location	Province	Type	Manufacturer	Heat Recovery	Capacity	APC System	Waste	# Beds	Annual Burns	Generation Rate	Feed Limits	Year of Record	Annual Throughput
											(kg/day)			(Mg/yr)
Wainwright (Medical Waste) (commercial)	Wainwright	AB	3-Stage Excess	Basic	Yes	1 x 29	WSH/DS/PAC/FF	medical		continuous			2005	2,308
Medical Waste Management (commercial)	Brampton	ON	2-Stage Starved	Joy Ecolaire MW 2500	None	670 kg/hr	Q/RA/Cond/ACB/HEPA	medical	NA	continuous		<10 Mg/d	2005	2,040
Weeneebayko General Hospital **	Moose Factory	ON	2-Stage Starved	Trecaire 3	None	40 kg/hr	Scrubber	medical	58	4 to 5/week		90 kg/batch		21
Mr. Shredding Waste Management (commercial)	Moncton	NB	2-Stage Starved	Joy JES750	None	195 kg/hr	Q/PTReagent/PAC/VS	medical	NA	continuous		<5 Mg/d	2005	1,000
Mr. Shredding Waste Management (commercial)	Moncton	NB		Vent-o-Matic C180	None	180 kg/hr	WS/Cond/PAC/FF	medical	NA	standby		<5 Mg/d		
Altona Community Memorial Health Centre	Altona	MB							22	160	33			12
Arborg & District Health Centre	Arborg	MB							16	160	24			9
Brandon General Hospital	Brandon	MB							326	160	489			178
Carman Memorial Hospital	Carman	MB							30	160	45			16
Churchill Health Centre	Churchill	MB							31	160	47			17
Dauphin General Hospital	Dauphin	MB							92	160	138			50
Deloraine Memorial Hospital	Deloraine	MB							18	160	27			10
Flin Flon General Hospital	Flin Flon	MB							47	160	71			26
Gillam Hospital	Gillam	MB							10	160	15			5
Grand View District Hospital	Grand View	MB							18	160	27			10
Hamiota District Hospital	Hamiota	MB							22	160	33			12
Percy E. Moore Hospital [hc-sc.gc.ca] **	Hodgson	MB	Multiple Chamber	Plibrico 100P50	None	23 kg/hr	None	Medical	16	7/month avg		13 kg avg		1
Tri-Lake Health Centre	Killarney	MB							26	160	39			14
Minnedosa Hospital	Minnedosa	MB							27	160	41			15
Neepawa District Memorial Hospital	Neepawa	MB							38	160	57			21
Norway House Hospital **	Norway House	MB	Multiple Chamber	Plibrico CAB 50P	None	23 kg/hr	None	Medical	26	5/wk		136 kg		35
Pine Falls Health Centre (Hospital)	Pine Falls	MB							27	160	41			15
Portage General Hospital	Portage	MB							122	160	183			67
Roblin Personal Care Home	Roblin	MB							25	160	38			14
Russell District Hospital	Russell	MB							38	160	57			21
Selkirk General Hospital	Selkirk	MB							75	160	113			41
Souris Health District Hospital	Souris	MB							30	160	45			16
Ste. Rose General Hospital	Ste. Rose	MB							30	160	45			16
Bethesda Health Complex	Steinbach	MB							80	160	120			44
Stonewall District Health Centre	Stonewall	MB							19	160	29			10
Lorne Memorial Hospital	Swan Lake	MB							20	160	30			11
Thompson General Hospital	Thompson	MB							72	160	108			39
Virden District Hospital	Virden	MB							25	160	38			14
Fort Smith Health Centre	Fort Smith	NT	2-Stage AB	Westland CY50CA	None	50 kg/hr	Lime Scrubber	medical	25	1/wk		150 kg/wk		8
Baffin Regional Hospital	Iqaluit	NU						Note 4	26	160	39			14
Kivalliq Health Centre	Rankin Inlet	NU	2-Stage AB	Eco-Waste	None	68 kg/batch	None		Note 4	daily		232 kg/day		60
Kitikmeot Health Centre	Cambridge Bay	NU	2-Stage AB	Eco-Waste	None	58 kg/batch	None		Note 4	daily		136 kg/day		35
Queen Elizabeth Hospital	Charlottetown	PE						Note 3	274	160	411			150
St. Joseph's Hospital	Estevan	SK						Note 2	53	160	80			29
Whitehorse Hospital Corp.	Whitehorse	YK						medical	49	160	74			27
Peace Country Health	Grande Prarie	AB						medical	160	160	240			88
Cristallo Engineering (commercial)	Beiseker	AB				710 kg/hr		medical	NA	continuous		Alberta Env	2002	1,561
													Total	8,082

Notes:

1. In Manitoba census information on web no hospital is listed for Reston so it was removed from the list of incinerators.
2. The facility includes a 53 acute and 38 long term care beds. http://stjosephs.shin.sk.ca/hospital_profile.htm
3. Hospital data from http://www.gov.pe.ca/infopei/onelisting.php3?number=11647
4. In Nunavut there is only one hospital and these two community health centres provide services to local population. Serious cases are sent out. Appears these operate as clinics - clinical waste most likely materials.
http://www.gov.nu.ca/hsssite/nurserecruit.shtml
5. Cristallo, Beiseker facility data from Alberta Environment enforcement order information see text.

optimum performance in the incinerator at all times. Their throughput for 2005 was 2,040 Mg. Mr. Shredding Waste Management in Moncton has two incinerators each approved for 5 Mg/d maximum throughput. Typically, one incinerator is operated while one remains on standby should an equipment malfunction occur on the operating unit. The company operates an incinerator for approximately 5000 hours per year with a total throughput of 1,000 Mg/year.

Cristallo Holdings Inc. is the owner of the Beiseker Waste Treatment plant, a biomedical waste incinerator. A review of information on the internet notes that the facility burns oil field waste as well as medical waste. It has an agreement with a company in Saskatchewan to take their must burn medical waste for destruction. The plant is operated pursuant to an Alberta Environmental approval issued to Cristallo Engineering Technologies Inc. Alberta Environment provided data for 2002 suggesting that the facility processed 1,561 Mg of waste that year.

The Wainwright facility is used for both MSW and medical waste disposal as discussed in the previous section. The amount of medical waste disposed at the facility is listed in the table.

The design capacity of the system installed in the hospital is available for only 6 facilities on the list. The US EPA has used that number for their inventory evaluations in the last 10 years[87]. Based upon the size of the units, and whether they were installed with APC systems or not, the US EPA defined both usage and emissions for medical incinerators. During their evaluations, the US EPA found that there were distinct differences in emissions from units smaller than 91 kg/hr capacity compared to larger furnaces. They suggest that most small units are operated in a batch mode, thereby having more start-up and shut-down time relative to the length of time they operate at ideal conditions. Controlled incinerators were categorised on the basis of the control equipment installed.

Even with these data available, the US EPA still had to address the question of how often are the furnaces operated and for what length of time. To aid with this task the agency suggested that units could be categorized on the basis of use as well as size. Intermittent operations were defined as those where the incinerator is charged on a periodic basis but must be shut down for ash removal. Continuously operated units were assumed to have waste feed and ash removal mechanisms to allow the incinerator to operate around the clock similar to large MSW incinerators. Batch incinerator, load light and burn system, were operated for a fixed period.

An early inventory of medical incinerator emissions[88] suggested that a capacity factor could be

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[87] US EPA, 2005. The Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States: The Year 2000 Update (External Review Draft, March 2005; EPA/600/p-03/002A) Available at http://cfpub.epa.gov/ncea/cfm/"http://www.epa.gov/ncea/pdfs/dioxin/2k-update/"

[88] Randall, D. (1995) Memorandum dated April 8, 1995, from David Randall and Brian Hardee, Midwest Research Institute, Cary, North Carolina, to Richard Copland, Combustion Group, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Subject: Emission factors for medical waste incinerators (MWIs), EPA Contract No. 68-01-0115; EPA Docket Number A-91-61;

related to the design size of the incinerator. Simply put, intermittently operated units of less than 227 kg/hr were assumed to operate about 29% of the available hours in the year, whereas continuously operated units were assumed to operate about 89% of the year. Smaller hospital incinerators are likely to be operated in a batch mode and the US EPA[89] assumed that these units were fed 160 batches per year, or 3 per week. Typically a batch unit will operate for several hours for each cycle. Another conclusion from the EPA study was that most MWI units were only charged at approximately 2/3^{rds} of their design rating. Small batch units currently available on the market have operating cycles on the order of 2.5 to 3 hours, however, as discussed latter large batch systems can run for as long as 10 to 12 hours per cycle. Assuming that the design capacity and cycle time was known, the total throughput would be 160 times that capacity.

Checking this estimate against the reported throughput from Weeneebayko General Hospital shows close agreement. For the other hospitals providing operating data the number of cycles per week is significantly different than presumed and their values were used. The most striking data receiving was from the Kivalliq Health Centre and Kitikmeot Health Centre where it was stated that the units were operated daily at reasonably large feed rates. Since these facilities are not hospitals, but rather clinics, the reported volume of waste suggests that more than medical waste was being incinerated in these units.

Clearly, the US EPA approach seems to reflect the situation that might be found at some facilities and categorisation based upon the design capacity of the furnace would be appropriate. To do this would require that the basic parameters need to be gathered for every medical waste incinerator in the country. Ideally, each of the hospitals should be polled to determine how often the incinerator is operated, and what the operating cycle is, along with verifying the make and model of the installation. Unfortunately, for the most part these data were not forthcoming despite requests to the regulators in most provinces with active medical waste incinerators.

The bulk of the incinerators in the list require a third approach. The only available information on many of the hospitals are the number of beds in the facility. Traditionally this number was used by engineers to specify the capacity of incineration equipment needed for hospitals, but by the early 1990s there were suggestions that this might not be a good measure[90]. Factors suggested to influence the amount of waste include the number of employees, degree of specialisation in the

IV B 042.

[89] US EPA, 1993 Documentation for AP-42 Section 2.6, Medical Waste Incineration. Appendix A Documentation of Emission Estimation Methodologies for Sources of 112(c)(6) Pollutants: Polycyclic Organic Matter (POM), 2,3,7,8-Tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), 2,3,7,8-Tetrachlorodibenzofuran (2,3,7,8-TCDF), and Polychlorinated Biphenyl Compounds (PCBs). Available at: http://pubweb.epa.gov/ttn/atw/112c6/app_a.pdf

[90] Van de Velde, J.M.A., 1982. Aspects of the Disposal of Hospital Waste in the Netherlands. Recycling International. Recovery of Energy and Material from Residues and Waste. K.J. Thome Kozmiersky ed.

facility, work practices including double bagging, and the number of outpatients. Brunner[91] provides an estimate of the total waste stream of 6.8 kg/day/bed. Furthermore, he suggests that nursing homes produce 1.4 kg/bed/day but notes elsewhere that laboratories produce 0.23 kg/patient day suggesting that the number of patient days in a facility might be a better estimate for generation. Ontario data[92] indicated that in the mid-80s after most facilities had started diverting food waste from the incinerators the per bed generation rate was 1.5 kg/day. That number will be used for this study.

Table 8.4 shows 85% of the 8,082 Mg of medical waste incinerated in Canada is disposed at commercial facilities that are, for the most part, equipped with state of the art emission control systems. There are few large hospital incinerators still operating in the country.

8.3.3 Hazardous Waste Incinerators

There are 12 incinerators listed in Table 8.5 that are used for disposal of hazardous wastes in the country. These units are located at 10 different sites across the country, with 2 incinerators located at Swan Hills and 2 on the MRR property in Cornwall. There are only 10 distinct incinerators that can be operated independently. The Belledune facility was subjected to commissioning testing in 2006 but final approval is pending. The car bottom furnace at MRR can only operate when the other unit at that site is operating so it is not considered as a separate unit.

Three of the listed facilities are incinerators used to reduce the volume of waste on sites where radioactive materials are processed, Cameco, Port Hope and Blind River; and, OPG, Tiverton. The Port Hope facility is slated for closure at the end of 2006 and all waste from this facility will be transferred to Blind River where the incinerator is being upgraded. The two Bennett facilities, St. Ambroise and Belledune are rotary kiln soil treatment systems. The remaining sites are commercial operations contracting waste disposal services.

The list of incinerators does not include any other boilers or industrial furnaces that may be used to dispose of production residues generated on the site where such equipment is located.

The range of furnaces include:

- rotary kiln operations in Alberta;
- soil treatment facilities in Quebec and New Brunswick based upon rotary kiln technology;

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[91] Brunner, Calvin R., 1984. Incineration Systems, Selection and Design. Published by Van Nostrand Reinhold Company Limited. ISBN 0-442-21192-9

[92] Chandler, A.J., D.R. Rooney, A.D. Church, and P. DeAngelis, 1987. Hospital Waste Incinerators - A survey of the Ontario Situation. A paper presented at the Thermal Treatment of Municipal, Industrial and Hospital Wastes Specialty Conference. Pittsburgh. APCA SP-62.

Table 8.5 Summary of Hazardous Waste Incinerators in Canada

Name	Location	Province	Type	Manufacturer	Heat Recovery	Capacity	APC System	Annual Throughput
								[Mg/yr]
Swan Hills Treatment Centre	Swan Hills	AB	RK/Afterburner	FBD	None	1676 kg/h halogens	SD/PAC/FF/WS	9,300
Swan Hills Treatment Centre	Swan Hills	AB	RK/Afterburner	CE Raymond	None	365 kg/h halogens	Q/Abs/Scrubber	3,274
Clean Harbors (see note 1)	Corunna	ON	Liquid Injection	unknown	None	245 lpm	SD/PAC/FF	83,818
Material Resouce Recovery Inc. (Metal Reclaim)	Cornwall	ON	2 Chamber	Al-Jon/United	None	12 kg/h PCB	WS+Reheat/PAC/FF in '06	1,183
Material Resouce Recovery Inc. (Car Bottom*)	Cornwall	ON	Fixed Hearth	Al-Jon/United	None	36 kg/h mercaptan		
OPG Bruce Power Development	Tiverton	ON	2 stage starved			2.3 Mg/day	SD/PAC/FF	598
Cameco	Port Hope	ON	2 stage starved	Consumat C-225	None	500 kg/h (trash)	None	416
Cameco	Blind River	ON			None	309 kg/h + ss + liquid	Q/2xPT/reheat/FF/CB/FF	416
Gary Steacy	Grafton	ON	2 Chamber	Al-Jon/United	None	27 lph PCB	None	
Clean Harbors (see note 1)	Mercier	QC	Liquid Injection	unknown	None	135 lpm	SD/PAC/ESP	61,062
RSI Bennett (see note 2)	St-Ambroise	QC	RK/Afterburner	Bennett	None	1 x 300 (soil)	SD/PAC/FF	43,351
Bennett (see note 7)	Belledune	NB	RK/Afterburner	Bennett	None	1 x 300 (soil)	WSH/DS/FF/Q/WS	
							Total	203,418

Note: APC System key

ESP - electrostatic precipitator for particulate matter removal
WSH - evaporator cooling tower or wet spray humidifier
DS - dry reagent addition or dry scrubber
PAC- powdered activated carbon addition
SNCR - selective non-catalytic reduction for NOx control
SCR - selective catalytic reduction for NOx and PCDD/F control
FF - fabric filter particulate control
VS - venturi scrubber
SD - spray dryer for temperature reduction/reagent addition
WS - wet scrubber for acid gas control
Abs - Absorber with reagent addition
Q - rapid quench system
Scrubber - high energy scrubber with mist eliminator
PT - packed tower with reagent addition
CB - carbon bed filter

* Car bottom furnace is simply a fixed hearth mounted on rails so the load can be placed on the hearth outside the furnace and then pushed into the furnace. This unit has 12 burners along the sides of the furnace supplying the heat. Typical use of furnaces is annealing and heat treatment.

1. Annual throughput data for 2005 from operator.
2. RSI/Bennett 2005 annual report for throughput data http://www.bennettenv.com/php/reports/Annual%20report%202005%20-%20BEN-414-05v7_low_res.pdf
3. Bennett MRR facility was upgraded in 2006 with addition of reheat and a fabric filter with PAC addition after the wet scrubber
4. Cameco facility in Port Hope to close in 2006
5. Tiverton throughput value estimated based upon operation five days per week at capacity
6. Cameco throughput values estimated based upon intermittent operation during daytime hours at rated capacity
7. Bennett Belledune not permitted for production operation

- liquid injection furnaces in Ontario and Quebec; and,
- three metal recovery units in Ontario.

The basis by which operations are defined at the various sites varies as can be seen under CAPACITY in the table. This suggests that the annual throughput for each of the units might be expressed on a different basis and this could lead to confusion when trying to assess annual emissions. Clearly, it would be better, given the requirement that these facilities are testing annually, to use annual test data as the basis of emissions. If a site specific emission factor could be developed and applied against the annual throughput emission estimates would be straight forward. If one were lacking either the annual throughput or a consistent expression of input to these furnaces, it would be useful to define a consistent alternative basis for estimating annual emissions. A short digression into hazardous waste incinerator design parameters may help with developing such a definition.

Incinerators are heat release limited devices. Their operation in an effective manner requires that:

- the input to the furnace does not exceed the design limits;
- sufficient air be provided to oxidize the fuel; and,
- in the case of systems with APC equipment that the size and design of those systems be adequate for the output of the furnace.

The design limits of any incinerator are the amount of heat that can be released in the furnace chamber. Too little heat and the material will not burn; too much and the enclosure will be destroyed. The heat of the fuel is generally referred to as the calorific value and defined on the basis of the Higher Heating Value [HHV]. Temperature is controlled either through the air fuel ratio, ie the excess air levels or through heat transfer in the furnace. In the case of liquid injection hazardous waste furnaces, the air fuel ratio is the normal control procedure. To lower the temperature the operator can either increase the air flow to the maximum flow possible, or cut back on the fuel flow rate. Thus, the furnace is designed for a certain fuel feed rate at a certain calorific value of HHV, and the air supply system is sized to provide the appropriate level of excess air to control the temperature to the desired level even if the heat input varies from design. Because the operator cannot allow the temperature to escalate to the point where the furnace will be damaged, the fuel feed rate is typically limited by the amount of air that can be supplied.

The operating temperature is a function of the design of the furnace and the temperature that the designer chose for operation. In a hazardous waste furnace this is combination of the retention time that the designer thinks will be required to destroy the most difficult to treat wastes the furnace will handle and the usual economies of size while maintaining some flexibility for the disposal of wastes that are easier to destroy.

The designer normally starts by defining a target volumetric heat release rate for the furnace and the amount of waste anticipated to need treatment. The volumetric heat release rate is a function of the type of fuel being used in the furnace and its burning characteristics. Harder to burn

materials might require longer residence times in the furnace and the volume would need to be adjusted accordingly. The operating temperature in the furnace is important. Niessen[93] notes that typically the operating temperatures in the system provide a limit for the volumetric heat release rate. He provides typical heat release rate data related to the desired operating temperature:

- 300 - 800^{O}C, requires 125 - 540 MJ/m^3/h;
- 800 - 1100^{O}C requires 550 - 1450 MJ/m^3/h;
- 1100 - 1400^{O}C requires 1450 - 2100 MJ/m^3/h.

Brunner[94] suggests that typical liquid injection burners can have heat release rates in the 750 - 1100 MJ/m^3/h range whereas vortex burners can be 35 times greater. The MOE's 1988 Incinerator Design and Operation Guidance Document specifies a volumetric heat release rate of 1000 - 3000 MJ/m^3/h. North American Mfg. Co.[95] notes that the primary combustion chamber of a hazardous waste kiln system will have a volumetric heat release rate of 260 - 520 MJ/m^3/h with a typical installation operating at 430 MJ/m^3/h. Given the need to destroy solids in the kiln such systems have a lower volumetric heat release rate than liquid injection furnaces.

If the fuel was uniform in heating value that would likely be the end of design considerations, but designers must accommodate fluctuations in the heating value of the waste and even different waste characteristics. They must ensure that the furnace temperatures do not drop due to the injection of aqueous wastes. Typical designs have lean waste being injected into the furnace downstream of the rich fuel combustion zone in such a manner that it surrounds the main flame to limit the cooling effect. Lean waste should not penetrate the flame or it would have too great a cooling effect. Brunner suggests that, if the operator wishes to inject additional waste into the flame, the heating value should be should be in excess of 5000 Btu/lb [11,630 kJ/kg]. Designers need to compensate for differing flow rates too, and typically do this by installing numerous burners to handle different ranges of liquids. It stands to reason that, should the system be able to accommodate multiple injection points, having a number of flame zones each with a smaller more concentrated flame front, it would generally create more turbulence and better mixing, not to mention better flame stability and more even temperature distribution throughout the combustion zone. Good mixing and good combustion are likely to provide more opportunities to limit the effect of upsets that might occur if part of the fuel flow is restricted due to equipment limitations.

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[93] Niessen, Walter R., 1978. Combustion and Incineration Processes. Applications in Environmental Engineering. Marcel Dekker, Inc. Publisher. New York.

[94] Brunner, Calvin R., 1984. Incineration Systems Selection and Design. Van Nostrand Reinhold Company. New York.

[95] Gill, J.H. and J.M. Quiel, 1993. Incineration of Hazardous, Toxic and Mixed Wastes. Published by North American Mfg. Co. ISBN 0960 1596-4-9

The latitude the designer takes in putting the system together establishes a range of operating conditions. For many furnace applications, particularly for solid fuel fired units, the range of operating conditions is frequently referred to as a Stoker Diagram. Such a diagram plots the System Heat Release rate versus the Waste Feed Rate. The constraints on the diagram form an envelope within which the system should be operated and are based upon the desired residence time, system operating temperature, and excess air levels.

Thus, the nature and quantity of to be disposed dictates the size of the incinerator and the amount of combustion air that must be supplied and thus treated in the APC system. An important design limitation related to the ability of the furnace to properly destroy organic materials is ensuring complete combustion. This requires that sufficient air be supplied for the level of energy input. Combustion engineers use a rough rule of thumb that to release 100 Btu requires 1 cubic foot of air (3.725 MJ/m^3 air) at standard conditions (15.6ºC and 1 atmosphere or 101.3 kPa). This approximation is based upon the gross heating value of the fuel or the higher heating value. For a system such as the Clean Harbors liquid injection system in Corunna is designed to handle about 150 GJ/h of heat input the stack gas flow at full input would be expected to be on the order of 88,000 Rm^3/hr @ 11% O_2.

Operating permits written in terms of the allowable heat release rate would thus allow the general stack gas flow rate to be used as the basis for estimating hourly emissions of PCDD/F. This is done simply by multiplying the flow rate by the concentration. Annual operating hours can then by used to provide an upset maximum for emissions from such facilities.

Most of the hazardous waste incinerators included in the inventory are commercial facilities who charge a tipping fee for the waste that passes over their scales. Annual disposal quantities obtained directly from the operators or extracted from the annual reports of the company are included in the table. As noted elsewhere, stack sampling data were used to derive the emission estimates for these facilities.

8.3.4 Sewage Sludge Incinerators

Sewage sludge incinerators are designed on the basis of the anticipated influent flow rate to the treatment facility. The amount of sludge is typically directly proportional to the amount of water treated. When installing equipment to burn the sludge engineers provide extra units to allow for maintenance and breakdowns because sludge storage facilities are limited. This means that in a multi-hearth equipped facility 3 out of 4 of the furnaces are typically operated at any time, bringing the typical utilization to 75% of the design/installed capacity. This would be a reasonable starting point for evaluating emissions from sewage sludge incinerators. Unfortunately, the installed capacity as listed in permits is not a good basis for estimating the amount of sludge disposed at the 6 facilities listed in Table 8.6. Data for the facilities was taken from various references shown on the table. The most comprehensive data was obtained for the Montreal facility. Mass balances for the 2004 operating year were downloaded, reviewed are summarised in the table. The influent flow to the facility is 2.4 x 10^6 m^3/day and the quantity of

dry solids disposed in 2004 was 96,525 Mg. This suggests that sludge production averaged 40,220 Mg/million cubic metres of water entering the plant per day.

Toronto provides data for the Highland Creek facility on their website. This site currently handles all the sludge from Toronto's four wastewater treatment facilities. The 2005 data shows the sludge generation rate to be approximately 62,000 Mg/year.

Comparing the two facilities illustrates how important it is to know the basis of the furnace rating. At the Highland Creek facility the rating is 180 Mg/day of wet sludge whereas the Montreal is listed as having 4 multi-hearth furnaces each with a capacity of 91 Mg/day of dry solids. Given the annual throughput, this suggests an overall utilisation rate is 73% in Montreal. The utilisation for the Highland Creek facility was stated as 32%[96] even though cursory estimates would suggest it is much less.

Clearly, this discrepancy suggests that the furnace rated capacity cannot be used as a good basis for estimating throughput on sewage sludge incinerators. Rather, the throughput should be estimated on the basis of the influent flow to the facility, a number that is available for all waste water treatment facilities, and an assumed average sludge production rate, say 50,000 Mg/10^6 m^3 of flow into the facility. This was the basis for the estimates for the other four incinerators on the list. Listed influent rates are shown on Table 8.6.

The total amount of dry solids disposed in sludge incinerators in Canada annually is estimated to be 172,500 Mg.

[96] Pers. Comm. Anthony Pigaidoulis, City of Toronto to A.J. Chandler, Nov. 29, 2006

Table 8.6 Summary of Sewage Sludge Incinerators in Canada

Name	Location	Province	Type	Manufacturer	Heat Recovery	Capacity	Influent Rate	APC System	Year of Record	Annual Throughput
						# x [Mg/day]	**[cu. metres/day]**			[Mg/yr]
Highland Creek Sewage Treatment Plant	Toronto	ON	Multi-hearth		No	2 x 180 (wet)	168,000	VS	2005	10,500
CUM station d`'épuration des eaux usées	Montreal	QC	Multi-hearth		Yes	4 x 91 (28% solids)	2,400,000	afterburner/VS	2004	96,525
Centre d'épuration de la Rive-Sud	Longueuil	QC	Fluidized Bed		Yes	2 x ??? (35% solids)	300,000	ESP	Estimated	15,000
Duffin Creek W.P.C.P.	Pickering	ON	Fluidized Bed		Yes	2 x 105 (30% solids)	420,000	VS/packed tower	Estimated	21,000
Lakeview Wastewater Facility	Mississauga	ON	Fluidized Bed		Yes	3 x 100 (35% solids)	390,000	VS/packed tower	Estimated	19,500
Greenway	London	ON	Fluidized Bed	Dorr-Oliver		1 x 65 (dry)	200,000	VS/Re-heat	Estimated	10,000
									Total	172,525

Notes:

APC System Key
ESP - electrostatic precipitator for particulate matter removal
WSH - evaporator cooling tower or wet spray humidifier
DS - dry reagent addition or dry scrubber
PAC- powdered activated carbon addition
SNCR - selective non-catalytic reduction for NOx control
SCR - selective catalytic reduction for NOx and PCDD/F control
FF - fabric filter particulate control
VS - venturi scrubber

1. Highland Creek 28.6 dry tonnes/day from http://www.toronto.ca/water/wastewater_treatment/treatment_plants/highland_creek/about.htm
2. Montreal average flow to facility 2.4 million cubic metres per day - sludge disposed in dry tonnes/year from Annual Report 2004 details from http://services.ville.montreal.qc.ca/station/
3. Rive Sud average flow to facility, 0.3 million cubic metres per day data from http://www.longueuil.ca/vw/asp/gabarits/Gabarit.asp?ID_CATEGORIE=924&ID_MESSAGE=6334&CAT_RAC=7
4. Duffin Creek average flow to facility 0.42 million cubic metres per day data from http://www.region.durham.on.ca/departments/works/duffincreek/environmental/draftreport.pdf
5. Lakeview average flow to facility 0.39 million cubic metres per day data from http://www.esemag.com/0904/peel.html
6. Greenway total flow for all facilities served by incinerator 0.2 million cubic metres per day Pers. Comm. T. Van Rossum City of London

8.3.5 Incinerators Operated by Federal Entities or on Federal Lands

Two different tables summarise these incinerator installations. Twenty nine incinerators are listed as being operated by federal entities in Table 8.7. These range from 5 specially designed barrel burners used for oily rag disposal, to MSW incinerators used at remote facilities for disposal of camp wastes and even a conical burner operated at a summer camp run by a DND unit. Also included is an incinerator used to dispose waste oils and solvents with low levels of radioactivity. Six of the incinerators are used at animal research or veterinary facilities but, while they would not be subject to CWS standards given the definitions, they are listed to maintain a record of their existence in this category. The age of the equipment includes a number of multi-chamber incinerators from Plibrico that date back to the 1970s and relatively new EcoWaste systems installed on a First Nations site. For most of these units data on annual throughput is considered to be unreliable. Nine companies operate a total of 22 incinerators at sites that are located on lands leased from the federal government. These are listed in Table 8.8. The list includes one site where no information was obtained on the unit installed; one company where two new incinerators were to be installed in 2006 to replace existing units; and several other sites with multiple units be they regularly used or merely there as back-up.

Generally these incinerators are operated in mining camps and an attempt was made to ascertain the the number of people living in these camps to enable the waste generation rate for the site to be determined. This section discusses issues associated with estimating the quantity of waste these incinerators handle in a year. Much of these data were obtained from questionnaires distributed by Environment Canada.

From the Environment Canada questionnaires it is evident that at the smaller, remote facilities are seldom equipped with weigh scales. Indeed, few operators can offer more than a guess about the amount of waste they incinerate during a given burn cycle. The units are typically batch fed, that is they are loaded with waste and, when the operator judges there is sufficient material to warrant burning it, the door is closed and the burn cycle begins. It is presumed that someone told the operator that the incinerator would handle a certain amount of waste for each burn. One manufacturer provides operating instructions that state[97]:

> "Open the charging door and load incinerator with refuse up to 60% of full capacity. DO NOT OVERLOAD."

Furthermore, given the typical burn and cycle times the manufacturers suggest, some of the questionnaire responses suggest that either the operators are skimping on the burner cycle times, or their loads are very small or very hot in which case they burn quickly. Even if the operation

[97] Westland Environmental Services Inc., unknown date. Cyclonator TMF Forced Air Incinerator Operating Instructions, Incinomite J83-DS-Gas Fired. Supplied by Paramount Resources in response to Environment Canada data request. Response dated August 30, 2006.

Table 8.7 Summary of Canadian Incinerators located at Federal Establishments

Name	Location	Province	Type	Manufacturer	Heat Recovery	Capacity	APC System	Waste	Period	Basis of Estimate	Population	Rate Factor	Generation Rate	Units	Annual Throughput
FEDERAL AGENCIES									[Months]						[Mg/year]
AECL Whiteshell Laboratories	Pinawa	MB	Liquid Injection	Trecan	None	128 L/hr	None	Waste Oil		owner		4 hr/month	115	kg/h	6
CFB Alert	Ellesmere Island	NU	2-Stage Batch	Eco-Waste	None	1.8 Mg/batch	None	MSW Paper	12	population	70-150 avg 70	21 kg/p/wk	1470	kg/wk	76
CFB 4 Wing Fighter Squadron	Cold Lake	AB	Barrel	SmartAsh 100	None	22 kg/hr	None	Oily Rags	12	owner	12 burns/wk	40 kg/burn	480	kg/wk	25
CFB 4 Wing Fighter Squadron	Cold Lake	AB	Barrel	SmartAsh 100	None	22 kg/hr	None	Oily Rags	12	owner	12 burns/wk	40 kg/burn	480	kg/wk	25
CFB Eureka	Nanset Sound	NU	2-Stage AB	Eco-Waste	None	91 kg/batch	None	MSW	3	population	60 max	30 kg/p/wk	1800	kg/wk	23
CFB 8 Wing Transport	Trenton	ON	2-Stage Batch	Midland Ross Mk VI-H	None	200 kg/batch	None	Int'l MSW	12	owner	3 burns/week	200 kg/batch	600	kg/wk	31
CFB 17 Wing Training	Winnipeg	MB	Multiple Chamber	Plibrico CAB 20-S	None	70 kg/hr	None	Documents	12	owner	1 burn/month	280 kg/batch	280	kg/m	3
CFB 17 Wing Training	Winnipeg	MB	Barrel	SmartAsh 100	None	22 kg/hr	None	Oily Rags	12	owner	2 burns/week	40 kg/burn	80	kg/wk	4
CFB 17 Wing Training	Winnipeg	MB	Barrel	SmartAsh 100	None	22 kg/hr	None	Oily Rags	12	owner	2 burns/week	40 kg/burn	80	kg/wk	4
DFO Experimental Lakes Research Stn	Kenora	ON	Multiple Chamber	Plibrico RB50	None	23 kg/hr	None	Putresibles	12	population	50 max	14 kg/p/wk	700	kg/wk	36
Cree Nation of Wemindji	Wemindji	QC	2-Stage AB	Eco-Waste	None	3 Mg/batch	None	MSW	12	size	1200	6.5 kg/p/wk	7800	kg/wk	406
Hesquiaht Nation	Hot Springs Cove	BC	2-Stage AB	Therm-Tec G12-1	None	550 kg/day	None	MSW	12	size	500	6.5 kg/p/wk	3250	kg/wk	169
DND Family Wilderness Camp 5 Wing Training	Goose Bay	NF	Conical Burner		None	80 kg/batch	None	MSW	13 wks	population	75/wk	6 kg/p/wk	450	kg/wk	6
DND North Warning System BAF-3	Brevoort Island	NU	2-Stage Starved	Consumat C-32P	None	100 kg/batch	None	MSW	10 wks	population	4-7each	20 kg/p/wk	140	kg/wk	1
DND North Warning System LAB-2	Saglek	NF	2-Stage Starved	Consumat C-32P	None	100 kg/batch	None	MSW	10 wks	population	4-7each	20 kg/p/wk	140	kg/wk	1
DND North Warning System LAB-6	Cartwright	NF	2-Stage Starved	Consumat C-32P	None	100 kg/batch	None	MSW	10 wks	population	4-7each	20 kg/p/wk	140	kg/wk	1
EnvCan Eureka	Nanset Sound	NU	2-Stage AB	Eco-Waste	None	60 kg/batch	None	MSW	12	population	8-12W/20S	20 kg/p/wk	320	kg/wk	17
EnvCan Sable Island	Sable Island	NS	2-Stage Batch	Consumat C-32P	None	37 kg/hr	None	MSW	12	population	8 average	10 kg/p/wk	80	kg/wk	4
RCMP G Division Headquarters	Yellowknife	NWT	Multiple Chamber	CJS Comb.Prod. CJS-205	None		None	Documents	12	from records	5 burns/yr	32 kg/batch	32	kg/burn	0
RCMP/PWC	Winnipeg	MB	Multiple Chamber	Plibrico CAB 20-S	None	70 kg/hr	None	Documents	12	owner	2 burns/week	280 kg/batch	560	kg/wk	29
AAFC Brandon	Brandon	MB	Multiple Chamber	Plibrico	None	23 kg/hr	None	Lab wastes	12	owner	as required	150 kg/wk	150	kg/wk	8
AAFC Lethbridge Research Centre **	Lethbridge	AB	2-Stage AB	Howell Refractories	None		None	pathological	12	owner	as required	80 kg/wk	80	kg/wk	4
AAFC Ottawa **	Ottawa	ON	Multiple Chamber	Plibrico	None	23 kg/hr	None	pathological	12	owner	as required	1 kg/wk	1	kg/wk	0
CFIA Plant and Animal Lab	Charlottetown	PE	Multiple Chamber	Pyrox B-100-M	None	72 kg/load	None	vegetable	12 wks	owner	6 burns/week	72 kg/batch	432	kg/wk	5
CFIA Animal Diseases Research **	Lethbridge	AB	2-Stage Batch	Vertec 1000 TLM	None	400 kg/hr Type 4	None	pathological	12	size	3 burns/week	300 kg/batch	900	kg/wk	47
CFIA Animal Diseases Research	Lethbridge	AB	2-Stage Batch	Vertec 150 E-HE	None	68 kg/hr all types	None	Lab wastes	12	size	3 burns/week	150 kg/batch	450	kg/wk	23
CFIA Animal Diseases Research **	Nepean	ON	2-Stage Batch	Bigelow-Liptak	None	545 kg/hr	None	pathological	12	owner	2005 data	1000 kg/wk	1000	kg/wk	52
CFIA Health of Animals Research **	Saskatoon	SK	Multiple Chamber	Plibrico 200-P	None	45 kg/hr	None	pathological	12	owner		125 kg/wk	125	kg/wk	7
DRDC Suffield **	Medicine Hat	AB	2-Stage AB	Westland CY-200-CAPL	None	91 kg/hr	None	pathological	12	size	3 burns/week	270 kg/burn	810	kg/wk	42
DRDC Suffield	Medicine Hat	AB	2-Stage AB	Westland CY-50-CA	None	64 kg/hr	Lime spray	hazardous	12	size	3 burns/week	190 kg/burn	570	kg/wk	30
														Total	1087

Notes: 1. Alert - assuming 66% of food waste is diverted to sewage lagoon, remote generation of 30 kg/wk is reduced to 21 kg/wk.

2. DFO Environmental Lake sends most of waste except food and soiled paper off site for recycling or disposal, 30 kg/p/wk estimate reduced to reflect food waste only.

3. DND Early Warning and Eureka assumed to have less food waste due to smaller populations

4. Sable Island backhauls much of non-burnable and recyclable wastes contribution only food and non-recyclable 50% normal rate but with small population less food waste

5. Charlottetown facility is mainly plant materials after inspections during harvesting period so used was restricted and from reported data 6 cycles per week were typical

6. CFIA Lethbridge the larger unit is an animal incinerator and would be exempt from the CWS standard by definition - conservative estimate for weekly loads provided since no data supplied.

7. Nepean and Lethbridge are animal related materials and the quantities are from federal survey data

8. Suffield's two incinerators have similar function to those in Lethbridge, one for animal carcasses and the other for chemical and lab wastes assume 3 burns/wk 3 hours per at capacity.

** These incinerators, operating at animal research and veterinary facilities, are listed at the request of EnvCanada even though the waste does not meet the CWS definition for inclusion.

Table 8.8 Summary of Canadian Incinerators located in Remote Areas or on Federal Lands

Name	Location	Province	Type	Manufacturer	Heat Recovery	Capacity	APC System	Waste	Use	Period	Basis of Estimate	Population	Rate Factor	Generation Rate	Units	Annual Throughput
										[Months]						[Mg/year]
CARA Operations Limited (Airport Services)	Winnipeg	MB	Multiple Chamber	PyroThermtec HU-150	None	70 kg/hr	None	Int'l MSW	periodic	5	owner Dec-Apr	4-5/wk	210 kg/batch	1050	kg/wk	23
Voisey's Bay	Voisey's Bay	NF	2-Stage AB	Eco-Waste	None	500 kg/day	None	MSW	routine	12	size		500 kg/day	500	kg/wk	26
Voisey's Bay	Voisey's Bay	NF	2-Stage AB	Eco-Waste	None	750 kg/day	None	MSW	routine	12	size		750 kg/day	750	kg/wk	39
BHPB Billiton Diamonds Inc.	EKATI Misery	NWT	2-Stage AB	Westland CV-350	None		None	MSW	routine	12	owner	20-30 burns/wk	45 kg/batch	1350	kg/wk	70
BHPB Billiton Diamonds Inc.	EKATI Misery	NWT	2-Stage AB	Westland CV-350	None		None	MSW	routine	12	owner	20-30 burns/wk	45 kg/batch	1350	kg/wk	70
BHPB Billiton Diamonds Inc.	EKATI Main Res.	NWT	2-Stage AB	Westland CV-350	None		None	MSW	routine	12	owner	20-30 burns/wk	45 kg/batch	1350	kg/wk	70
BHPB Billiton Diamonds Inc.	EKATI Waste Management	NWT	2-Stage AB	Westland CV-350	None		None	Process waste	routine	12	owner	20-30 burns/wk	45 kg/batch	1350	kg/wk	70
BHPB Billiton Diamonds Inc.	EKATI Process	NWT	2-Stage AB	Westland CV-350	None		None	MSW	routine	12	owner	20-30 burns/wk	100 kg/batch	3000	kg/wk	156
BHPB Billiton Diamonds Inc. (new unit ordered)	EKATI Main Bldg.	NWT	2-Stage AB	Westland CY-130-CAO	None	64 kg/hr	Water Scrubber	MSW	routine	12						
BHPB Billiton Diamonds Inc. (new unit ordered)	EKATI Main Bldg.	NWT	2-Stage AB	Westland CY-130-CAO	None	64 kg/hr	Water Scrubber	MSW	routine	12						
Paramount Resources	Laird West 1	NWT	2-Stage AB	Westland CY-1020-FAD	None	45 kg/hr	None	MSW	routine	12	size	3 burns/day	135 kg/burn	2835	kg/wk	147
Paramount Resources	Laird West 2	NWT	2-Stage AB	Westland CY-1020-FAD	None	45 kg/hr	None	MSW	routine	12	size	3 burns/day	135 kg/burn	2835	kg/wk	147
Paramount Resources	Cameron Hills	NWT	2-Stage AB	Westland THF-1020-D	None	64 kg/hr	None	MSW	routine	12	size	3 burns/day	192 kg/burn	4032	kg/wk	210
Diavik Diamond Mine Inc.	Lac de Gras	NWT	2-Stage AB	Westland CY-2050-FAD	None	90 kg/hr	None	MSW	routine	12	population	363	30 kg/p/wk	10890	kg/wk	566
Diavik Diamond Mine Inc.	Lac de Gras	NWT	2-Stage AB	Westland CY-75-CAD	None	64 kg/hr	None	MSW	routine	12	population	273	30 kg/p/wk	8190	kg/wk	426
De Beers Canada Inc.	Snap Lake	NWT	2-Stage AB	Eco-Waste	None	720 kg/day	None	MSW/SS	routine	12	size		720 kg/day	5040	kg/wk	262
De Beers Canada Inc.	Snap Lake	NWT	2-Stage AB	Eco-Waste	None	720 kg/day	None	MSW	routine	12	size		720 kg/day	5040	kg/wk	262
De Beers Canada Inc.	Attawapiskat	ON	2-Stage AB	Westland CY-200-CA ?	None	200 kg/hr	VS	MSW	routine	12	size	2 burns/day	1200 kg/day	8400	kg/wk	437
Shell Canada	Camp Farewell	NWT						MSW	routine	12					kg/wk	NA
North American Tungsten Corp.	Watson Lake	YK	2-Stage AB	Yellowhead Manu.	None	na	None	MSW	routine	12	owner		500 kg/day	3500	kg/wk	182
Tahera Corporation	Jericho Diamond	NU	2-Stage AB	Westland CY-2050-FA	None	90 kg/hr	None	MSW	routine	12	population	100	30 kg/p/wk	3000	kg/wk	156
Tahera Corporation	Jericho Diamond	NU	2-Stage AB	Westland CY-1020-FA	None	64 kg/hr	None	MSW	backup unit						kg/wk	
															Total	3320

Notes:

1. Ekati incinerators are operated on different waste streams.

Misery 1	waste includes MSW and spill pads hydrocarbon contaminated materials note information states, 20 - 30 burns/week at 100 lbs/burn each 3 - 5 hrs. Totals 60 Mg/yr.
Misery 2	waste includes spill pads and hydrocarbon contaminated materials note information states, 20 - 30 burns/week at 100 lbs/burn each 3 to 5 hrs. Totals 59 Mg/yr.
Main Residence	waste is accomodation waste note information states, 3 burns/day at 100 lbs/burn each 3 to 5 hrs in one place 20 - 30 per week in another Totals 50 - 60 Mg/yr.
Waste Management	waste includes spill pads and hydrocarbon contaminated materials note information states, 20 - 30 burns/week at 100 lbs/burn each 3 to 5 hrs. Totals 59 Mg/yr.
Process	waste includes MSW and spill pads hydrocarbon contaminated materials note information states, 20 - 30 burns/week at 220 lbs/burn each 3.5 hrs. Totals 130 Mg/yr.
2 new units	not operational at July 2006 supposed to replace older units

could be optimized, it appears that the units are frequently operated on a time schedule rather than on the basis of when the unit is full.

When ask to define quantity the operator says: "the incinerator is charged and cycled 3 times per day". If one knows the capacity of the incinerator in kg/hr from the model number and typical run times, the number of cycles per day may provide a reasonable annual throughput. However, in other cases such data is lacking so an alternate approach must be used to complete the inventory.

Waste audit data, and anecdotal observations, can be used to provide a basis for estimating the mass of waste charged to the furnaces. Whenever such approaches are used, the basic assumptions must be tempered with judgement, because any estimate can be misleading if one does not account for the differences likely to be manifest by procedures for handling wastes at different remote, small sites. Moreover, one cannot compare data from these locations to typical urban single family residential waste audit data. Take for instance the following example from the Compass report.

The Environment Canada Eureka Weather Station is typical of small remote facilities. Staffed by 8 - 12 people year round, the station gets about 80 visitors, researchers and other transient residents, during the year. At some times the population can reach 30 people. On average though it might be appropriate to suggest there could be a maximum of 20 people on site. All food is flown in on regular supply flights every 3 weeks. If more people are anticipated to be on site, more food is provided. Of course, food shipments can result in large quantities of packaging materials being discarded as the food is loaded into storage lockers, and any waste audit results must account for this variability.

A waste audit at the Station[98] in 2003 provided a snapshot of the amount and nature of waste generated. During periods when no visitors were on site, the audit documented the waste generation rate at approximately 8 kg/person/wk with the composition being putresibles [56%], paper [19%], plastics [4%], wood [12%] and the rest being non-combustibles. During periods of high transient population, the waste quantities were higher - up to 21 kg/person - with 70% putresibles, 10% paper, 10% plastics etc., and 10% non-combustibles such as glass, metal etc.

At first glance the normal generation rate would appear to be similar to the national average. Stats Canada's survey of waste management[99] quotes a per capita residential waste generation

[98] Compass Environmental Inc., 2005. Assessment of Current Operating Practices for Federally Owned Small Incinerator Units: A Consolidation of Volumes 1, 2 & 3. A report prepared for National Office of Pollution Prevention, Environment Canada. March.

[99] Statistics Canada, 2004. Waste Management Industry Survey: Business and Government Sectors 2002. Stats Canada Report Catalogue no. 16F0023XIE. September. Available at: http://www.statcan.ca/english/freepub/16F0023XIE/16F0023XIE2002001.pdf

rate of 383 kg/year, or 7.4 kg/person/wk. However, it must be noted that typical waste collection in urban areas includes a contribution from yard waste and other components not expected to be found in waste incinerated at a remote facility.

The typical residential municipal waste stream composition is shown in Table 8.9. The data represent the average composition determined during audits in three communities of different size across Canada. The major difference in the individual numbers was significantly more yard waste in the large urban centre.

Table 8.9 Typical Residential Waste Composition[100]

Waste Component as defined for the Study including constituents	Percent of Total	Removed at Remote Sites	Revised Remote %
Paper	29	15	25.0
Plastic	8	2	10.7
Metal	4		7.1
Glass	5		8.9
HHW	1		1.8
Compostables (food[26.5%], yard[11.5%], sanitary including diapers[6%])	43.5	17.5	46.4
Other (textiles, C&D, White and Oversize or Bulky Goods, & Electronics)	9.5	9.5	0
Total	100	44	100

One would not expect to see diapers, yard waste or even the "Other" components in the waste stream of a research camp, or a mining camp. Similarly, it is unlikely that the 11% average newsprint found in the waste streams would be found in remote locations, nor would you expect to see books, telephone directories or junk mail or garden hoses and other plastic items which account for 2% of the plastic stream. Allowing for the removal of these non-typical components, the remote site composition might be expected to look more like the numbers in the last column of the table. While the metal, glass and plastic component percentages shown in the table are high compared to the Eureka audit, they are not that far out of line.

Higher generation rates, and higher putresible loads found at Eureka during the high occupancy

[100] Totten Sims Hubicki, 2006. Municipal Solid Waste [MSW] Options: Integrating Organics Management and Residual Treatment/Disposal. A report prepared for the Municipal Waste Integration Network, and Recycling Council of Alberta with funding support from Environment Canada and Natural Resources Canada. March.

audit are typical of food preparation practices in mining camps etc. Anecdotal data[101] suggests that in facilities where a large number of people are being fed the standard procedure is to serve meals buffet style. The quantities of food prepared allows most people to have a choice of different food thus there are higher percentages of waste food than one would expect from normal operations.

Some remote facilities segregate wastes and ship materials out for disposal. North Warning sites, the Sable Island weather station, the experimental lakes camp and seasonal facilities such as the Goose Bay family camp reduce the amount of waste incinerated in this way. The CFB facility at Alert grinds all putresible materials and directs them to the sewage lagoon, thereby changing the nature of the waste charged to the furnace to predominantly paper.

Brunner[102] recognized the need to characterise waste streams, if only to properly size incineration systems for different applications, and provides guidance on both the quantity of waste expected to be generated from different applications and the anticipated operating time for incinerators in those applications. He suggests that in high class hotels the waste per sleeping room would average about 9.5 kg/week and kitchen wastes would average 2.7 kg/person per day or 28.5 kg/week. Medium class hotels produce about half this quantity of waste per resident each week. For trailer camps Brunner suggests that the waste stream would be on the order of 2.3 - 4.5 kg/trailer per day but presumably this would be related to more than one person being resident in the trailer. He suggests that incinerators on industrial sites should be sized to allow all the waste to be burned within a 7 hour shift whereas for hotels, institutions and commercial buildings the rule of thumb was 6 hours of operation per day.

To test how realistic these estimates might be, consider one of the mining camps in question. The camp has approximately 100 people in camp, and it reports that the 90 kg/hr batch incinerator is loaded and run for 3 hours 3 times each day. Allowing that the active burn may only be 2 hours, the incinerator should dispose of 2.5 Mg of waste per week. The total would go to 3.7 Mg if it truly operated for 3 hours on every burn. That would imply that the average per person generation rate is between 25 and 37 kg/wk.

For the purposes of estimating the charge to incinerators handling mainly MSW at remote sites, it has been assumed that the weekly waste generation rate would be on the order of 30 kg/person. Thus, if the camp population is known, an annual throughput can be calculated. If diversion activities such as: shipping out materials, or diverting putresibles to sewage lagoons are noted, the generation rate can be adjusted assuming approximately 60% of the 30 kg generation rate is food waste, and plastic, paper, and wood each account for 10% of the waste with non-combustibles making up the rest of the waste stream.

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[101] Personal Communication, Jean Lucas, EcoWaste to John Chandler, July 31, 2006.

[102] Brunner, Calvin R., 1984. Incineration Systems, Selection and Design. Published by Van Nostrand Reinhold Company Limited. ISBN 0-442-21192-9

In some case all that is known about a particular installation is the size of the incinerator. In this case the annual throughput should be based upon the design rated capacity of the specific incinerator. Since it is possible that these units can be run for more than one cycle in a day, it is also recommended that the number of batches assumed to be charged to the unit be based upon 24 divided by twice the manufacturer's cycle time for the unit in hours.

Typically small batch units are designed to burn a batch in 2 -3 hours and require maybe 1 hour to cool sufficiently to allow ash removal. Larger batch units can have a burn time of 8 - 12 hours and can require 5 - 8 hours before they have cooled down sufficiently to allow ash to be removed and a new charge loaded. Under the recommendations above, a unit rated at 70 kg/batch operating on a 4 hours cycle, could be run up 3 times per day and would be estimated to dispose of 767 Mg/year. A large unit, burning say 1 Mg on a 14 hour cycle, could process only 365 Mg/year.

The incinerators operated by federal entities include units in various government laboratories and facilities supporting remote settlements such as weather stations and the north warning system. The estimated total amount of waste incinerated is 918 Mg/year. The laboratories are generally related for food and agriculture and are destroying materials containing pathogens etc. Those used for animal carcasses destroy an estimated 154 Mg of material annually but they would not be included in the CWS list of subject facilities were they located elsewhere. The one First Nations settlement on the list has 1200 people. For this unit the waste disposal rate was based upon typical per capita rates for family homes and this one unit accounts for 44% of the total estimated disposal capacity.

The incinerators operated on federal lands, or in remote areas by commercial enterprises, were largely unrecognized in the 2000 survey. They are used to meet the needs of mining and exploration camps to dispose of food and sleeping quarter wastes from large dormitory facilities. It is estimated that approximately 3300 Mg of waste are burned in these units in a year. The estimates are based upon owner provided data, either on burn rates, or in some cases the population in the camps which were assumed to generate waste at a rate of 30 kg/p/wk. Where throughput per day was provided the units were assumed to run every day of the year. The majority of the estimates were based upon the installed capacity of the units, assuming 3 burns per day at that capacity every day of the year. As note, the majority of these units were not included in the 2000 inventory and thus they represent new capacity added to the inventory.

8.3.6 Other Incinerators in Remote Locations

Another previously unlisted group of incinerators are those licenced by various companies or individuals for specific purposes. During the course of this study discussions with the two major suppliers in Canada revealed that they had sold more incinerators for use in the country than had been identified by provincial regulators or Environment Canada. Many of the units are used in similar fashion to those being operated on Federal lands as discussed in the previous section, but no listing of these units could be obtained. A limited list of units was obtained from Alberta Environment and are shown in Table 8.10. Various other systems were added to the list as they

were identified but no data could be obtained for these units. Some of these units were identified from manufacturer's reference lists on the internet.

The units listed include pet crematoria which could be excluded from consideration under the CWS standard. Should these types of units be considered appropriate to include in the inventory, sources have suggested that there will be numerous installations found in most provinces.

This list raises a question about how smaller units can be identified and their throughput estimated, or indeed, if these units are small, whether the issue of emissions from them is significant. At this time, not throughput estimates are possible and is no further discussion of these units in this report.

Table 8.10 Summary of Miscellaneous Small Incinerators Operating in Canada

Name	Location	Province	Type
1083296 Alberta Ltd.	Red Deer County	AB	
Alberta Research Council Inc.	Edmonton	AB	
AltaGas Ltd.	Calgary	AB	
Brian Johnston	Calgary	AB	
Carstairs Veterinary Services Inc.	Carstairs	AB	
CE3 Technologies	Edmonton	AB	
Country Club Pet Resort Inc.	Calgary	AB	proposed
Darcy Kroetsch	Lougheed	AB	
Devon Canada Corporation	Calgary	AB	
Devon Canada Corporation	Calgary	AB	
Devon Canada Corporation	Calgary	AB	
Devon Canada Corporation	Calgary	AB	
Devon Canada Corporation	Calgary	AB	
Friesen Logging Ltd.	La Crete	AB	
Friesen Logging Ltd.	La Crete	AB	
Innisfail District Co-operative Association Limited	Innisfail	AB	
Invertek Inc.	Calgary	AB	
Mackenzie Pork Producers Inc.	La Crete	AB	
Material Processing Canada Inc.	Edmonton	AB	proposed
Nelson Environmental Remediation Ltd.	Calgary	AB	
Nelson Environmental Remediation Ltd.	Calgary	AB	
Nelson Environmental Remediation Ltd.	Calgary	AB	proposed
Paradise Moving Services Inc.	Calgary	AB	
Paramount Resources Ltd.	Calgary	AB	
Pet Heaven Crematorium and Funeral Chapel Ltd.	Calgary	AB	
Rainbow Pipe Line Company, Ltd.	Slave Lake	AB	
Rainbow Pipe Line Company, Ltd.	Slave Lake	AB	
Ray Pelletier	Nisku	AB	
Remedx Remediation Services Inc.	Calgary	AB	
Research and Scientific Support Division	Vegreville	AB	
Ryan & Brenda Cumberland	Fairview	AB	proposed
Smithbrook Waste Management Systems Inc.	Brooks	AB	
University of Calgary	Calgary	AB	
Vermilion Veterinary Clinic (1977) Ltd.	Vermilion	AB	proposed
Yvo Schmucki	Red Deer	AB	
Millar Western Industries Ltd.	Edmonton	AB	
University of Manitoba - Chown Building	Winnipeg	MB	
Manitoba Hydro - Brandon GS	Brandon	MB	Barrel
Manitoba Hydro - Grand Rapids GS	Grand Rapids	MB	Barrel
Manitoba Hydro - Henday Converter Station	Gillam	MB	Barrel
Manitoba Hydro - Jenpeg GS	Cross Lake	MB	Barrel
Manitoba Hydro - Kelsey GS	Thompson	MB	Barrel
Manitoba Hydro - Kettle GS	Gillam	MB	Barrel

8.4 PCDD/F Emissions in Exhaust Gas Stream

Chapter 5 reviews stack sampling techniques available to characterise emissions from incinerators. Typically, stack sampling provides a concentration for PCDD/F in the gases leaving the stack. The concentration [pg ITEQ/Rm^3 @ 11% O_2] is important because it can be used to judge the acceptability of the facility with respect to emission standards. However, the PCDD/F inventory for Canada, and the numbers reported to NPRI are provided in terms of mass of PCDD/F released per year. To easiest way to use the concentration data to define the annual emission rate is to convert the concentration to a mass per tonne of waste burned, assuming that under all conditions the emissions will be in the same range that they were in during testing. Since the stack gas flow rate is related to the amount of material being burned at any given time, multiplying the stack concentration by the flow rate provides an emission rate [pg ITEQ/hour] and dividing this by the rate of waste charged to the furnace [Mg/hour] produces an emission factor [pg ITEQ/Mg waste].

Determining the appropriate emission factor for a given installation requires a description of the facility such as provided in the inventory tables. In some cases facilities installed many years ago will likely have a multiple chamber incinerator rather than the more efficient two stage combustion systems. A different emission factor would be appropriate to distinguish between these two types of facilities. Clearly, if the facility is equipped with reasonably good controlled combustion furnaces and emission control equipment capable of reducing PCDD/F emissions it would be inappropriate to characterise emissions as coming from an uncontrolled, poorly operating facility. Ideally, rather than basing potential emissions on emission factors, it would be preferable to use actual emission data from the individual facilities to estimate their emissions. Where these data are not available, there is some guidance on emission factors available in the literature.

It was not until 2001 that the first version of the UNEP Toolkit[103] was released. Designed to assist countries in developing PCDD/F emission inventories. Unfortunately that information was not available at the time of the initial inventory, however data in the 1999 PCDD/F inventory suggests that typical emission concentrations for small MSW incinerators were on the order of 35 ng I-TEQ/m^3. With specific volumetric flow rates on the order of 10,000 m^3/Mg, the emissions would be approximately 350 mg/Mg.

For some of the large incinerators in the country emission test data was made available for inclusion in this report. Not all the test data is from 2005. The hazardous waste incinerator data was included in the 2003 hazardous waste report prepared for Environment Canada referenced elsewhere in this report unless noted. For some MSW incinerators, the data was taken from the

[103] UNEP Chemicals, 2001. Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases DRAFT. Prepared by UNEP Chemicals Geneva, Switzerland under contract with Hans-Ulrich Hartenstein, E&EC - energy and environmental consultants GmbH, Waldbröl, Germany, Patrick H. Dyke, PD Consulting, Lechlade, United Kingdom and Dr. Heidelore Fiedler of UNEP Chemicals. January.

2003 MSW incinerator update. For facilities where copies of test reports were not available, alternative emission factors, derived from similar systems or defaults from the UNEP Toolkit have been applied. The results are presented in a series of tables that a facility specific. Discussion of the various incinerator groups and the results follows.

8.4.1 MSW Incinerators

Test data dated 2005 was available for 3 of the MSW incinerators. That data is summarized in Table 8.11. The Quebec City data was based upon the 1993 test data[104] which agrees well with data from both the Algonquin Power and GVRD. Wainwright testing was completed for both MSW charging and medical waste charging, which as was noted in the previous section is segregated in the operation. Emission concentrations from the one MW test and the two MSW tests were used to establish the numbers for that facility.

GVRD, Algonquin Power, and the Quebec City data are all recorded with the below detection limit values included at the detection limit according to the CWS protocol. All three facilities show values below the EnvCan LOQ of 32 pg ITEQ/Rm^3 @ 11% O_2 thus they would not have been required to list PCDD/F emissions in their NPRI filings. In May 2006 emission testing from the PEI facility showed the concentrations to also be below the EnvCan LOQ.

The balance of the facilities have not reported recent test data. Levis's most recent data, 2001, was used for the emissions. Given that the APC system at Levis is similar to that in Iles de la Madeleine the Levis emission value was used for Iles de la Madelaine.

The total PCDD/F air emissions from MSW incinerators is estimated at 60 mg ITEQ/year.

[104] A.J. Chandler & Associates Ltd, and Compass Environment Inc., 2003. Municipal Solid Waste Incineration in Canada: An Update on Operations 1999-2001.

Table 8.11 Summary of Air Emissions from Large Scale Municipal Solid Waste Incinerators in Canada

Name	Annual Throughput	Basis	Test Date	Stack Flow	Waste Feed	Specific Flow	Emission Concentration	Emission Factor	Annual Emissions to Air
	[Mg/yr]			**[Rm^3/s]**	**[Mg/hr]**	**[Rm^3/Mg]**	**[pg ITEQ/Rm^3]**	**[pg ITEQ/Mg]**	**[mg ITEQ/year]**
Wainwright (MSW)	2,383	test data	2005	2.3	1.13	7,327	213	1,560,743	3.72
GVRD	275,000	test data	2005	17.7	10.00	6,366	5.07	32,276	8.88
Algonquin Power Energy from Waste	140,000	test data	2005	35.2	19.89	6,371	4.19	26,695	3.74
Trigen	32,000	test data	2006	7.3	4.00	6,590	20	131,804	4.22
Centre de traiement des residus urbains	280,000	reported	1993			6,500	5.70	37,050	10.37
La Régie Intermunicipale de Gestion Rive-Sud	25,132	test data	2002			6,500	130	845,000	21.24
MRC des Iles de la Madeleine	9,100	estimated				6,500	130	845,000	7.69
								Total	60

Notes:

Levis data from http://www.ville.levis.qc.ca/Fr/Citoyens_Mat_Con.asp represents 2002 operating data and 2001 test data

Iles de la Madeleine emissions assumed to be similar to Levis in absence of site data and similar APC equipment

8.4.2 Medical Waste Incinerators

Two of the commercial medical waste incinerators have been tested in the last year. Their emissions data, from the test reports are shown in Table 8.12. Both tests show results well below the LOQ.

A third incinerator has 2006 test data, that being the 50 kg/hr unit operated in Fort Smith. This unit is relatively new and has a simple scrubber on the back end to control emissions. Unfortunately, during the testing it was being operated in a "Continuous-Intermittent" feed mode. According to the test report:

> "Prior to waste introduction, the secondary chamber was pre-heated to approximately 1100°C, and the primary chamber was pre-heated to 800°C. Once the primary and secondary chambers reached the setpoint operating temperatures, waste was manually introduced to the primary chamber via the main charge door. Approximately 4 kg of waste including red bag waste and sharps containers were loaded at various intervals. Incineration of the charges proceeded until the oxygen probe indicated combustion was complete, and another charge was introduced to the "hot" primary."

The test report indicates that the furnace was charged with between 37 and 46 kg of waste during the period of the various tests, with average feed rates of 9 - 13 kg/hr. This severely under loads the primary chamber and opening the door periodically changes the temperature regime and air flow rates throughout the furnace leading to the performance listed in the table. Note the discrepancy between the specific flow for the two commercial facilities, and even Wainwright when operating on medical waste and this data suggesting very high specific flows. This could lead to poor performance. While the average emission concentration was 126 pg I-TEQ/Rm^3 @ 11% O_2, the tests were 40, 80 and 256 pg I-TEQ/Rm^3 @ 11% O_2 with the latter test being the middle of the three. Additional review of these test data was not conducted.

Two relatively new incinerators are installed at two clinics in Nunavut. These units are similar in nature to an MSW incinerator from the same manufacturer that was tested by Environment Canada in 2002[105] and a CleanAire animal unit tested in 2003 by the same team. Both these tests showed the units to have very low PDCC/F emission concentrations, and low specific flows.

The Toolkit document suggests that uncontrolled batch combustion can release as much as 40 mg I-TEQ/Mg waste burned, corresponding to a stack concentration of 2,000 ng I-TEQ/Nm^3. For controlled batch combustion of medical waste in a system without APC equipment, an emission factor of 3 mg I-TEQ/Mg waste burned is recommended, based upon emission concentrations of

[105] Cianciarelli, D. and C. House, 2003. Characterization of Emissions from the EcoWaste Solutions Thermal Waste Oxidizer, Burlington, Ontario. Report ERMD 2002-03. Environment Canada ETC.

Table 8.12 Summary of Air Emissions from Medical Waste Incinerators in Canada

Name	**Annual Throughput**	Basis	Test Date	Stack Flow	Waste Feed	Specific Flow	Emission Concentration	Emission Factor	Annual Emissions to Air
	(Mg/yr)			**[Rm^3/s]**	**[Mg/hr]**	**[Rm^3/Mg]**	**[pg ITEQ/Rm^3]**	**[pg ITEQ/Mg]**	**[mg ITEQ/year]**
Wainwright (Medical Waste)	2,308	test data	2005	2.6	0.69	13,670	173	2,364,835	5.46
Medical Waste Management	2,040	test data	2006	1.08	0.44	8,836	1.59	14,050	0.03
Weeneebayko General Hospital	21	estimate	class 2					3.E+09	63.18
Mr. Shredding Waste Management	1,000	test data	2005	0.68	0.19	12,884	3.75	48,316	0.05
Mr. Shredding Waste Management	NA								
Altona Community Memorial Health Centre	12	estimate	class 2					3.E+09	36.14
Arborg & District Health Centre	9	estimate	class 2					3.E+09	26.28
Brandon General Hospital	178	estimate	class 2					3.E+09	535.46
Carman Memorial Hospital	16	estimate	class 2					3.E+09	49.28
Churchill Health Centre	17	estimate	class 2					3.E+09	50.92
Dauphin General Hospital	50	estimate	class 2					3.E+09	151.11
Deloraine Memorial Hospital	10	estimate	class 2					3.E+09	29.57
Flin Flon General Hospital	26	estimate	class 2					3.E+09	77.20
Gillam Hospital	5	estimate	class 2					3.E+09	16.43
Grand View District Hospital	10	estimate	class 2					3.E+09	29.57
Hamiota District Hospital	12	estimate	class 2					3.E+09	36.14
Percy E. Moore Hospital [hc-sc.gc.ca]	1	estimate	class 2					3.E+09	3.28
Tri-Lake Health Centre	14	estimate	class 2					3.E+09	42.71
Minnedosa Hospital	15	estimate	class 2					3.E+09	44.35
Neepawa District Memorial Hospital	21	estimate	class 2					3.E+09	62.42
Norway House Hospital	35	estimate	class 2					3.E+09	106.08
Pine Falls Health Centre (Hospital)	15	estimate	class 2					3.E+09	44.35
Portage General Hospital	67	estimate	class 2					3.E+09	200.39
Roblin Personal Care Home	14	estimate	class 2					3.E+09	41.06
Russell District Hospital	21	estimate	class 2					3.E+09	62.42
Selkirk General Hospital	41	estimate	class 2					3.E+09	123.19
Souris Health District Hospital	16	estimate	class 2					3.E+09	49.28
Ste. Rose General Hospital	16	estimate	class 2					3.E+09	49.28
Bethesda Health Complex	44	estimate	class 2					3.E+09	131.40
Stonewall District Health Centre	10	estimate	class 2					3.E+09	31.21
Lorne Memorial Hospital	11	estimate	class 2					3.E+09	32.85
Thompson General Hospital	39	estimate	class 2					3.E+09	118.26
Virden District Hospital	14	estimate	class 2					3.E+09	41.06
Fort Smith Health Centre	8	test data	2006	0.144	0.014	37,029	126	4,665,600	0.04
Baffin Regional Hospital	14	estimate						3.E+09	42.71
Kivalliq Health Centre	60	tool kit	class 3	see note 1		8,000	256	2,048,000	0.12
Kitikmeot Health Centre	35	tool kit	class 3	see note 1		8,000	256	2,048,000	0.07
Queen Elizabeth Hospital	150	estimate	class 2					3.E+09	450.05
St. Joseph's Hospital	5	estimate	class 2					3.E+09	14.78
Whitehorse Hospital Corp.	27	estimate	class 2					3.E+09	80.48
Peace Country Health	88	estimate	class 2					3.E+09	262.80
Cristallo Engineering Technologies, Inc.	1,561	test data	Alberta Env	1.34			9.8		0.15
								Total	3,141.52

Notes:

1. Unit by same manufacturer tested by EnvCan when burning MSW had emission concentration 40 pg/Rm^3 and low specific flow - 3039 Rm^3/Mg

200 ng I-TEQ/Nm^3. Data published by Environment Canada[106] in 1999 noted that a medical waste incinerator in Ontario had average emissions of 25 ng I-TEQ/m^3 which was in the range of European data (average 35 ng I-TEQ/m^3) for a well operated controlled combustion furnace system equipped with an APC system. At this emission concentration the emission factor would be 0.375 mg I-TEQ/Mg. The original inventory used a value fo 4.67 mg I-TEQ/Mg.

The Environment Canada tests justify using a smaller emission factor than the Class 2 values from the UNEP Toolkit for the newer batch incinerators. A specific flow of 8,000 was selected based upon the measured specific flow for MSW and the fact that medical waste is generally considered to have a calorific value approximately twice that of MSW. The emission concentration selected was the top value found in the other newer incinerator tests, even though this was at least 6 times the average measured during the MSW tests.

The balance of the incinerators in the table are units that were included in the original inventory list. The emission factor chosen for these units is that of Class 2 as defined in the Toolkit. This value, 3 mg I-TEQ/Mg is 2/3rds of the value used in the 2000 inventory that reflects a broader evaluation of operating data on older incinerators.

The total emissions from medical waste incinerators is 3.1 g/year, most being contributed by installations at large hospitals.

8.4.3 Hazardous Waste Incinerators

Hazardous waste incinerators in Canada have emission concentration data available from stack testing. Based upon the test data available, as listed in Table 8.13, if one makes an assumption on annual hours of operation it is possible to project the annual emissions, even though waste charging rates are not available for all units.

Alberta Environment provided the hours of operation for both of the furnaces at the Swan Hills facility. One operated for 3,595 hours, the other for 1,303 hours in 2005. Taking the product of the stack flow rate, the operating hours and the emission concentration provides an annual emission estimate.

Experience suggests that the availability of the Clean Harbors liquid injection furnaces at Corunna and Mercier is significantly higher than that listed for the Swan Hills facility. Operating hours for both these facilities were assumed to be on the order 7,000 hours, or 80% availability.

[106] Environment Canada, 1999. Dioxins and Furans and Hexachlorobenzene Inventory of Releases. A report prepared by Environment Canada and the Federal/Provincial Task Force on Dioxins and Furans for the Federal-Provincial Advisory Committee for the Canadian Environmental Protection Act (CEPA-FPAC). January

Table 8.13 Summary of Air Emissions from Hazardous Waste Incinerators in Canada

Name	Annual Throughput	Basis	Test Date	Stack Flow	Waste Feed	Specific Flow	Emission Concentration	Emission Factor	Annual Emissions to Air
	[Mg/yr]			**[Rm^3/s]**	**[Mg/hr]**	**[Rm^3/Mg]**	**[pg ITEQ/Rm^3]**	**[pg ITEQ/Mg]**	**[mg ITEQ/year]**
Swan Hills Treatment Centre	9,300	Alberta Env	2005	11.30	2.60	Note 1	126		18.43
Swan Hills Treatment Centre	3,274	Alberta Env	2005	2.36	2.60	Note 1	160		1.77
Clean Harbors Corunna	83,818	test data	2003	16.50	80 GJ/hr		44.00		18.30
Material Resouce Recovery Inc. (Metal Reclaim)	1,183	test data	2005	0.46			8.20		0.05
Material Resouce Recovery Inc. (Car Bottom*)		Note 2							
OPG Bruce Power Development	598	test data	2006	0.57	0.08	25,650	28.90		0.15
Cameco Port Hope	416	test data	2004	0.73	0.13	19,972	2,564		17.58
Cameco Blind River	416	test data	2003	0.74			108		0.75
Gary Steacy		test data	2006	0.49			542		3.35
Clean Harbors Mercier	61,062	test data	2003	9.77	77 GJ/hr		800		196.96
RSI Bennett	43,351	test data	2002	5.00			7		0.44
Bennett Belledune	NA 2005	Note 3							
								Total	257.77

Notes:

1. Alberta Environment provided operating hours for year and assumed stack concentration was the same for the period. 3595 hr for FBD and 1303 hr for CER
2. Permit requires both units to be run together so the emission factor is combined.
3. Belledune facility not operating at the present time.

Both the Steacy and MRR facilities operate on a batch basis where the furnaces are filled and the operated until the materials of concern are destroyed and the residual are emptied after the charge cools. The MRR furnace is typically loaded at a rate of approximately 700 kg/batch, and each processing run requires approximately 2.5 hours. Based upon the total annual throughput, 1,690 batches were processed in 2005 for a total of 4,225 hours of operation. Assuming the operation is similar at Gary Steacy, the same value was used for this site.

The three furnaces that dispose of radionuclide contaminated wastes, Cameco and OPG installations, are operated on an as needed basis. These operations serve to reduce the volume of radioactively contaminated materials that need to be handled for disposal by concentrating the radionuclides in the ash and residue streams. Data in the test reports suggests that these units may operate a few days per week. Assuming the availability of these units is 10 hours per day, 5 days per week, the operating hours would be 2,600 hours per year.

The last operating unit on the list is the RSI soil destruction facility. PCDD/F emissions are consistently very low for this facility which uses a rotary kiln to volatilize hydrocarbons from soils being treated and an afterburner to destroy the fumes. The average stack gas flow rate is 5 Rm^3/s and the average feed rate to the furnace is 12.5 Mg/h. The 2005 throughput divided by the average feed rate suggests the unit operated for about 3,500 hours in 2005.

The total emissions from hazardous waste incinerators are dominated by the Mercier facility. Eighty percent of the releases in this category arise from this facility. The ESP used for particulate control at the facility likely does not provide the level of control for fine particulate matter than can be achieved at the Corunna facility.

8.4.4 Sewage Sludge Incinerators

Emissions of PCDD/F to the air from sewage sludge incinerators are summarized in Table 8.14. Test data is available for the Ontario facilities and the results of these tests were used to project the typical emission factor that should be used for the two Quebec facilities in the absence of specific test data.

The test data available for the Highland Creek facility was an extract of the test report and did not contain any feed rate data. The feed rate was estimated by taking the 2005 daily feed rate and assuming that a similar amount was being fed to the incinerator during the testing. Flow and emission concentration data were available to be converted to the appropriate basis for inclusion in the table. The calculated emission factor is close to 400,000 pg I-TEQ/Mg that is recommended for Class 3 facilities in the Toolkit.

Since CUM is a multi-hearth installation, the Class 3 default was used for this installation.

Table 8.14 Summary of PCDD/F Emissions from Sewage Sludge Incinerators in Canada

Name	Annual Throughput	Basis	Test Date	Stack Flow	Waste Feed	Specific Flow	Emission Concentration	Emission Factor	Annual Emissions to Air
	Dry Mg				**Dry Mg**				
	[Mg/yr]			**[Rm^3/s]**	**[Mg/hr]**	**[Rm^3/Mg]**	**[pg ITEQ/Rm^3]**	**[pg ITEQ/Mg]**	**[mg ITEQ/year]**
Highland Creek Sewage Treatment Plant	10,500	test data	2005	6.86	1.19	20,743	18	373,374	3.92
CUM station d`'épuration des eaux usées	96,525	estimated						400,000	38.61
Centre d'épuration de la Rive-Sud	15,000	estimated						100,000	1.50
Duffin Creek W.P.C.P.	21,000	test data	2005	10.61	2.40	15,908	2.87	45,590	0.96
Lakeview Wastewater Facility	19,500	test data	2004	8.70	8.93	3,509	9.2	32,281	0.63
Greenway	10,000	test data	2006	7.92	3.02	9,454	2.46	23,256	0.23
								Total	45.85

No feed rate data was available in the test report for the Duffin Creek facility. It was assumed that the annual throughput represented the average feed rate for the year for this facility, and the feed rate was estimated at that rate. Stack flow and emission concentration were available and the calculated emission factor is an order of magnitude lower than the Toolkit Class 3 guideline.

All the data for Lakeview was extracted from the test report.

Greenway test data included sludge feed rate, however this was not on the basis of dry solids. All the emission factor and throughput data for sewage sludge incinerators in this report is presented on this basis and a conversion was necessary. The solids content in the sludge was estimated to be 26% similar to the supplied Lakeview data.

The total PCDD/F emissions estimated to occur from sewage sludge incinerators is less than 50 mg/year. The majority of this arises from the multi-hearth facility in Montreal which is estimated to dispose of more than half of all the sewage sludge burned in the country, but accounts for 80% of the estimated emissions from this category.

8.4.5 Incinerators Operated by Federal Entities

There is no specific emission test data for this category of incinerators, however, the Environment Canada test data, referred to earlier, can be used to approximate the performance of the incinerators manufactured by the company. These units are among some of the newer incinerators installed in these facilities. The balance of the incinerators, for the most part, are older units installed at least 15 years ago. They include multi-chamber units that have been shown to have poorer combustion control than newer incinerators. All units are assumed to be operated on a batch basis; loaded as waste is produced and fired when sufficient waste has be placed in the combustion chamber.

The incinerators' use can be divided into two categories: MSW disposal covering camp waste, oily rags and even some of the laboratory wastes disposed in incinerators; and, pathological waste covering the vegetable and animal materials disposed in incinerators at research facilities. None of these incinerators have emission control equipment, nor are they equipped with heat recovery systems. The temperature of the exhaust gases would thus be expected to be above the *de novo* temperature window during operation which should result in low concentrations of PCDD/F in the stack gases if the units are run at the design heat input levels. Although emission concentrations would be expected to be low, the fact that they are operated in a batch mode could result in the ash left in the systems contributing to *de novo* creation of PCDD/F. Such material would be expected to be released the next time the system was operated, unless all the ash was removed from the system. Multi-chamber incinerators,such as Plibrico units, do not lend themselves to routine cleaning and would be expected to produce the highest emissions concentrations. Newer two chamber units with afterburners are unlikely to have much ash remaining in the secondary chamber after operation.

In the absence of emission factors for these units, the class 2 factors from the Toolkit have been used. The class 2 factor was taken from the MSW category for MSW incinerators and from the pathological waste category for the laboratory pathological waste incinerators. The data are provided in Table 8.15.

Reviewing Table 8.15, a total of 100 mg I-TEQ PCDD/F are estimated to be released from this category of incinerators. The majority of this is emitted from 8 units, each of which is estimated to provide about 10% of the total emissions. There is some question whether the emission factor applied to SmartAsh barrel systems is appropriate given that these units employ a high intensity afterburner arrangement to minimize smoke emissions. These units do not have a secondary chamber to collect flyash and as such may perform better than estimated. Given the stated use of these units, and the fact that other entities are starting to use the same units, it would be appropriate to have them tested to determine potential emissions. Unfortunately, to test one of these units it would need to be modified to contain the exhaust gases so they could be tested. This could upset the operation of the afterburner.

Clearly some of the units with a larger throughput should be tested to establish site specific emission factors.

8.4.6 Incinerators Operated in Remote Locations on Federal Lands or elsewhere

This group of incinerators are generally newer than those in the previous category. Like the previous units, they are not equipped with heat recovery steam generators or air pollution control systems. The stack emissions are expected to be a temperatures well above the *de novo* synthesis range and thus, provided combustion conditions are maintained and little residual is left in the incinerator after each burn, emissions would be expected to be low. They were manufactured by two different Canadian companies and test data from a unit manufactured by each company are available and have been discussed earlier in this report. Rather than use the average from these test reports, the maximum concentration obtained during testing was incorporated into Table 8.16.

It should be noted that while the test data is listed in the table, ie. the flow and waste feed rates would not reflect those expected to be measured at the various sites, the emission factor derived from these data is the number used to derive annual emissions. Since this value would be consistent with the test data it can be applied to any similar incinerator. The emission factor is used to calculate the Annual Emissions by multiplying the annual throughput [Mg] by the emission factor [pg I-TEQ/Mg].

A total of 34 mg I-TEQ PCDD/F are estimated to be emitted from this category of incinerators.

Table 8.15 Estimate of PCDD/F Emissions from Canadian Incinerators located at Federal Establishments

Name	**Annual Throughput**	Basis	Test Date	Stack Flow	Waste Feed	Specific Flow	Emission Concentration	Emission Factor	Annual Emissions to Air
FEDERAL AGENCIES	**[Mg/year]**			**[Rm^3/s]**	**[Mg/hr]**	**[Rm^3/Mg]**	**[pg ITEQ/Rm^3]**	**[pg ITEQ/Mg]**	**[mg ITEQ/year]**
AECL Whiteshell Laboratories	6	estimate	class 2 MSW					3.50E+08	1.93
CFB Alert	76	test data	EC 2002	0.77	0.914	3,039	70.98	2.16E+05	0.02
CFB 4 Wing Fighter Squadron	25	estimate	class 2 MSW					3.50E+08	8.74
CFB 4 Wing Fighter Squadron	25	estimate	class 2 MSW					3.50E+08	8.74
CFB Eureka	23	estimate	class 2 MSW					3.50E+08	8.18
CFB 8 Wing Transport	31	estimate	class 2 MSW					3.50E+08	10.92
CFB 17 Wing Training	3	estimate	class 2 MSW					3.50E+08	1.18
CFB 17 Wing Training	4	estimate	class 2 MSW					3.50E+08	1.46
CFB 17 Wing Training	4	estimate	class 2 MSW					3.50E+08	1.46
DFO Experimental Lakes Research Stn	36	estimate	class 2 MSW					3.50E+08	12.74
Cree Nation of Wemindji	406	test data	EC 2002	0.77	0.914	3,039	70.98	2.16E+05	0.09
Hesquiaht Nation	169	estimate	class 2 MSW					3.50E+08	59.15
DND Family Wilderness Camp 5 Wing Training	6	estimate	class 2 MSW					3.50E+08	2.05
DND North Warning System BAF-3	1	estimate	class 2 MSW					3.50E+08	0.49
DND North Warning System LAB-2	1	estimate	class 2 MSW					3.50E+08	0.49
DND North Warning System LAB-6	1	estimate	class 2 MSW					3.50E+08	0.49
EnvCan Eureka	17	test data	EC 2002	0.77	0.914	3,039	70.98	2.16E+05	0.004
EnvCan Sable Island	4	estimate	class 2 MSW					3.50E+08	1.46
RCMP G Division Headquarters	0	estimate	class 2 MSW					3.50E+08	0.05
RCMP/PWC	29	estimate	class 2 MSW					3.50E+08	10.19
AAFC Brandon	8	estimate	class 2 MSW					3.50E+08	2.73
AAFC Lethbridge Research Centre	4	estimate	class 2 path					5.00E+07	0.21
AAFC Ottawa	0	estimate	class 2 path					5.00E+07	0.00
CFIA Plant and Animal Lab	5	estimate	class 2 path					5.00E+07	0.26
CFIA Animal Diseases Research	47	estimate	class 2 path					5.00E+07	2.34
CFIA Animal Diseases Research	23	estimate	class 2 MSW					3.50E+08	8.19
CFIA Animal Diseases Research	52	estimate	class 2 path					5.00E+07	2.60
CFIA Health of Animals Research	7	estimate	class 2 path					5.00E+07	0.33
DRDC Suffield	42	estimate	class 2 path					5.00E+07	2.11
DRDC Suffield	30	estimate	class 2 MSW					3.50E+08	10.37
								Total	158.95

Table 8.16 PCDD/F Emissions from Incinerators located in Remote Areas or on Federal Lands

Name	Annual Throughput	Basis	Test Date	Stack Flow	Waste Feed	Specific Flow	Emission Concentration	Emission Factor	Annual Emissions to Air
	[Mg/year]			**[Rm^3/s]**	**[Mg/hr]**	**[Rm^3/Mg]**	**[pg ITEQ/Rm^3]**	**[pg ITEQ/Mg]**	**[mg ITEQ/year]**
CARA Operations Limited (Airport Services)	23	estimate	class 2 MSW					3.5E+08	7.96
Voisey's Bay	26	test data	EC 2002	0.77	0.914	3,039	70.98	2.2E+05	0.006
Voisey's Bay	39	test data	EC 2002	0.77	0.914	3,039	70.98	2.2E+05	0.008
BHPB Billiton Diamonds Inc.	70	test data	Fort Smith	0.144	0.014	37,029	255.90	9.5E+06	0.67
BHPB Billiton Diamonds Inc.	70	test data	Fort Smith	0.144	0.014	37,029	255.90	9.5E+06	0.67
BHPB Billiton Diamonds Inc.	70	test data	Fort Smith	0.144	0.014	37,029	255.90	9.5E+06	0.67
BHPB Billiton Diamonds Inc.	70	test data	Fort Smith	0.144	0.014	37,029	255.90	9.5E+06	0.67
BHPB Billiton Diamonds Inc.	156	test data	Fort Smith	0.144	0.014	37,029	255.90	9.5E+06	1.48
BHPB Billiton Diamonds Inc. (new unit ordered)		NA	class 2 MSW					3.5E+08	0.00
BHPB Billiton Diamonds Inc. (new unit ordered)		NA	class 2 MSW					3.5E+08	0.00
Paramount Resources	147	test data	Fort Smith	0.144	0.014	37,029	255.90	9.5E+06	1.40
Paramount Resources	147	test data	Fort Smith	0.144	0.014	37,029	255.90	9.5E+06	1.40
Paramount Resources	210	test data	Fort Smith	0.144	0.014	37,029	255.90	9.5E+06	1.99
Diavik Diamond Mine Inc.	566	test data	Fort Smith	0.144	0.014	37,029	255.90	9.5E+06	5.37
Diavik Diamond Mine Inc.	426	test data	Fort Smith	0.144	0.014	37,029	255.90	9.5E+06	4.04
De Beers Canada Inc.	262	test data	EC 2002	0.77	0.914	3,039	70.98	2.2E+05	0.06
De Beers Canada Inc.	262	test data	EC 2002	0.77	0.914	3,039	70.98	2.2E+05	0.06
De Beers Canada Inc.	437	test data	Fort Smith	0.144	0.014	37,029	255.90	9.5E+06	4.14
Shell Canada	NA								
North American Tungsten Corp.	182	test data	Fort Smith	0.144	0.014	37,029	255.90	9.5E+06	1.72
Tahera Corporation	156	test data	Fort Smith	0.144	0.014	37,029	255.90	9.5E+06	1.48
Tahera Corporation		test data	Fort Smith	0.144	0.014	37,029	255.90	9.5E+06	0.00
								Total	33.75

8.5 PCDD/F Emissions in Solid and Liquid Streams

To predict emissions related to solid waste streams from a facility it is necessary to determine how much solid waste is generated in various parts of the system, and then apply available concentration data for the various types of streams. Data from Toolkit will be used to establish the factors that should be used to calculate PCDD/F in residues because there is very little PCDD/F concentration data available for Canadian incinerators.

8.5.1 MSW Incinerators

The IAWG[107] reports that for every Mg of waste burned, the ash generated in a typical MSW incinerator is proportioned as follows:

- 300 kg/Mg bottom ash;
- 5 kg/Mg grate siftings;
- 5 kg/Mg boiler ash;
- 42 kg/Mg filter and APC residues; and,
- 0.05 kg/Mg in the stack gases.

In the 2003 report prepared for Environment Canada the bottom ash generation rate, even including the moisture present in the ash after passing through the quench tank, averaged 25% of the total amount of waste processed at the MSW incinerators included in the study. GVRD data from 1988 to 2005 shows bottom ash to account for between 15 and 18% of the waste fed to the furnace. Typically, bottom ash is weighed as it leaves the incinerator facility and no attempt is made to determine the average moisture content of this material. Moisture content recorded at one site have ranged between 22 - 37%, a variation that has been determined to relate largely to the amount of fine carbon left in the ash. This fine material is very hygroscopic. In the Environment Canada report, the amount of fly ash and APC residue generated consistently represented about 11% of the amount of bottom ash produced. Overall the solid residues accounted for 28% of the mass fed to the furnaces. The long term data from GVRD suggests that annual fly ash shipments are on the order of 2.7 - 4.1% of the annual waste processed. This is higher than the averages seen in the Environment Canada report.

The differences relate to the nature of the furnace, with European grate systems producing very high levels of burnout. Higher carbon levels in the ash from the two stage combustion process, can be expected to retain more moisture and thus weigh more than the European type grate. European grate systems might be expected to have higher boiler ash and APC residue quantities due to more ash leaving the bed due to higher air velocities in the burning zone than found in a starved air furnace.

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[107] International Ash Working Group, 1997. Municipal Solid Waste Incinerator Residues. Published by Elsevier, ISBN 0-444-82563-0.

The UNEP Toolkit suggests that bottom ash from MSW incinerators could be as low as 10 - 20% of the charge, and fly ash in the range of 1 - 2% of the charge. These data agree reasonably well with the Canadian data.

For this study it will be assumed that bottom ash will be 20% of the mass charged to the furnace. Flyash will be assumed to be 2% of the mass charged to the furnace.

With the lack of any specific data on PCDD/F concentrations, again necessary to refer to literature data.

The IAWG suggest that newer, well operating incinerators will produce bottom ash with a concentration of 0.020 ng TE/g and flyash could be as high as 0.300 ng TE/g based a conversion that looked at the ratio of PCDD/PCDF in the sample and multiplied the sum of the PCDD by between one quarter or one half the factor used for the PCDF total. The same reference suggests that older systems can produce flyash with concentrations between 50 and 100 times higher.

The Toolkit suggests that concentrations for bottom ash from newer facilities could be 0.005 ng I-TEQ/g and flyash could be as high as 1 ng I-TEQ/g. The Toolkit suggests that Type 3 incinerators could be characterised with 0.05 ng I-TEQ/g of bottom ash and 15 ng I-TEQ/kg fly ash.

Data in the US EPA inventory document shows data that generally fits within the range of the data shown above.

For this assessment, the Toolkit class 3 data, 7 ng I-TEQ/kg in bottom ash and 200 ng I-TEQ/kg fly ash will be used to calculate the PCDD/F in residues. The PCDD/F estimated to be released in residues from MSW incinerators is listed in Table 8.17.

8.5.2 Medical Waste Incinerators

Commercial medical waste incinerators are handling a mix of waste very similar to MSW, in furnaces that are similar to the two stage systems used for MSW. These units are also equipped with APC systems, but do not have HRSGs. The commercial units all have a form of quench or wet scrubber prior to the balance of the APC train, and generate water that is sent to sewer.

As noted above, the PCDD/F in the effluent from a wet scrubber will likely be in the form of fine particulate matter, not dissolved in the water. The particulate matter is generated mainly through the liberation of fly ash from the furnace bed and most two stage systems typically have low particulate loads due to low velocities as discussed in Chapter 3. Furthermore, since the gases leave the furnace at high temperature and are immediately quenched to temperatures below the *de novo* synthesis window, the possibility of PCDD/F formation is limited to poor combustion in the secondary chamber. These measures would suggest that the PCDD/F

Table 8.17 PCDD/F in Residues from Large Scale Municipal Solid Waste Incinerators

Name	Annual Throughput	Basis	Ash Percentage		PCDD/F Concentration [pg ITEQ/g]		Emission Rate [ug ITEQ/year]		Annual Emissions in Residues
	[Mg/yr]		**Bottom**	**Fly**	**Bottom**	**Fly**	**Bottom**	**Fly**	**[mg ITEQ/year]**
Wainwright (MSW)	2,383	estimated	20	2	7	200	3,336	9,532	13
GVRD	275,000	estimated	20	2	7	200	385,000	1,100,000	1,485
Algonquin Power Energy from Waste	140,000	estimated	20	2	7	200	196,000	560,000	756
Trigen	32,000	estimated	20	2	7	200	44,800	128,000	173
Centre de traiement des residus urbains	280,000	estimated	20	2	7	200	392,000	1,120,000	1,512
La Régie Intermunicipale de Gestion Rive-Sud	24,310	estimated	20	2.4	7	200	34,034	116,688	151
MRC des Iles de la Madeleine	9,100	estimated	20	2	7	200	12,740	36,400	49
								Total	4,139

Note: Levis fly ash data from 2002 ops report

available to be transferred to the water would be low. The Toolkit suggests that where concentrations have been measured in MSW incinerators the PCDD/F concentration has been found to be between a few pg I-TEQ/L to 200 pg I-TEQ/L.

Without being able to further quantify these sources, the use of wet scrubber/quench towers should be noted and testing recommended to fill this hole in the inventory.

These systems generate little or no fly ash from the wet scrubbers, except in cases where activated carbon is introduced into the gas stream to remove residual PCDD/F. As with the wet scrubber effluent, this potential source should be noted and testing should be conducted to complete the inventory.

Bottom or grate ash from these incinerators can be assumed to be similar in quantity to that found in MSW incinerators, 200 kg/Mg. The Toolkit suggests that the concentration of PCDD/F will be between 10 - 100 ng I-TEQ/kg of ash. Given the nature of two stage incinerator ash a value of 50 ng I-TEQ/kg will be selected for this report.

Little detail is available for many of the rest of the medical waste incinerators in the country. There is no information on most of the installations, although it is known that there are some newer batch fed, two stage afterburner systems of the type discussed in Chapter 3 in operation in some locations. These units, for the most part, have no APC system so no fly ash is created, and only grate ash needs to be included in the inventory. For all these systems the 200 kg/Mg generation rate will suffice. The concentration of PCDD/F in the grate ash for all but the newer batch fed units should default to the Category 2 value in the Toolkit, 100 ng I-TEQ/kg, whereas the newer systems should use the 50 ng I-TEQ/kg value selected above.

The PCDD/F estimated to be released in residues from medical waste incinerators is listed in Table 8.18.

8.5.3 Hazardous Waste Incinerators

The incinerators classified as hazardous waste units perform a myriad of functions from:

- liquid injection furnaces with only limited grate ash and APC residues (2);
- soil treatment facilities with no grate ash but APC residues (2);
- metal recovery furnaces with no grate ash and limited APC residues (3);
- radioactive waste destruction facilities that handle contaminated materials similar to MSW and produce grate and APC residues (3); and,
- conventional hazardous waste rotary kiln incinerators that produce grate ash and APC residues (2).

Quantifying the potential PCDD/F releases from these facilities requires consideration of the

Table 8.18 PCDD/F in Residues from Medical Waste Incinerators in Canada

Name	Annual Throughput	Basis	Ash Percentage		PCDD/F Concentration [pg ITEQ/g]		Emission Rate [ug ITEQ/year]		Annual Emissions in Residues
	(Mg/yr)		Bottom	Fly	Bottom	Fly	Bottom	Fly	[mg ITEQ/year]
Wainwright (Medical Waste)	2,308	estimated	20	2	7	200	3,231	9,232	12
Medical Waste Management	2,040	estimated	20		50		20,400	0	20.400
Weeneebayko General Hospital	21	estimated	20		100		421	0	0.421
Mr. Shredding Waste Management	1,000	estimated	20		50		10,000	0	10.000
Mr. Shredding Waste Management	0	estimated							
Altona Community Memorial Health Centre	12	estimated	20		100		241	0	0.241
Arborg & District Health Centre	9	estimated	20		100		175	0	0.175
Brandon General Hospital	178	estimated	20		100		3,570	0	3.570
Carman Memorial Hospital	16	estimated	20		100		329	0	0.329
Churchill Health Centre	17	estimated	20		100		339	0	0.339
Dauphin General Hospital	50	estimated	20		100		1,007	0	1.007
Deloraine Memorial Hospital	10	estimated	20		100		197	0	0.197
Flin Flon General Hospital	26	estimated	20		100		515	0	0.515
Gillam Hospital	5	estimated	20		100		110	0	0.110
Grand View District Hospital	10	estimated	20		100		197	0	0.197
Hamiota District Hospital	12	estimated	20		100		241	0	0.241
Percy E. Moore Hospital [hc-sc.gc.ca]	1	estimated	20		100		22	0	0.022
Tri-Lake Health Centre	14	estimated	20		100		285	0	0.285
Minnedosa Hospital	15	estimated	20		100		296	0	0.296
Neepawa District Memorial Hospital	21	estimated	20		100		416	0	0.416
Norway House Hospital	35	estimated	20		100		707	0	0.707
Pine Falls Health Centre (Hospital)	15	estimated	20		100		296	0	0.296
Portage General Hospital	67	estimated	20		100		1,336	0	1.336
Roblin Personal Care Home	14	estimated	20		100		274	0	0.274
Russell District Hospital	21	estimated	20		100		416	0	0.416
Selkirk General Hospital	41	estimated	20		100		821	0	0.821
Souris Health District Hospital	16	estimated	20		100		329	0	0.329
Ste. Rose General Hospital	16	estimated	20		100		329	0	0.329
Bethesda Health Complex	44	estimated	20		100		876	0	0.876
Stonewall District Health Centre	10	estimated	20		100		208	0	0.208
Lorne Memorial Hospital	11	estimated	20		100		219	0	0.219
Thompson General Hospital	39	estimated	20		100		788	0	0.788
Virden District Hospital	14	estimated	20		100		274	0	0.274
Fort Smith Health Centre	8	estimated	20		50		78	0	0.078
Baffin Regional Hospital	14	estimated	20		100		285	0	0.285
Kivalliq Health Centre	60	estimated	20		50		603	0	0.603
Kitikmeot Health Centre	35	estimated	20		50		354	0	0.354
Queen Elizabeth Hospital	150	estimated	20		100		3,000	0	3.000
St. Joseph's Hospital	29	estimated	20		100		580	0	0.580
Whitehorse Hospital Corp.	27	estimated	20		100		537	0	0.537
Peace Country Health	88	estimated	20		100		1,752	0	1.752
Cristallo Engineering Technologies, Inc.	1,561	estimated	20		50		15,610	0	15.610
								Total	80.894

nature of the operation. The Toolkit assumes that hazardous waste incinerator grate ash has a negligible PCDD/F content due to the high temperatures and typical excess air present in the primary combustion zone.

Soil treatment and metal recovery furnaces essentially heat the materials to be treated to volatilise the organic constituents present in the contaminated materials and then burn the volatile gases to destroy these organics. As such they have little carry over of fly ash and likely produce fly ash quantities that are far below the 3 kg/Mg waste charged suggested by the Toolkit. In the case of soil treatment facilities, where reagents are added to the APC system, the fly ash quantities might be higher than metal recovery furnaces, but the concentration would be expected to be diluted too. Concentrations of PCDD/F in these units, all of which would meet the Toolkit's definition of high technology combustion can be assumed to be 30 ng I-TEQ/kg of fly ash.

The radioactive waste incinerators can be assumed to be similar in nature to the MSW 2-stage combustion starved air furnaces they are derived from. Given that the performance of two of these units could only be considered to meet the Category 2 definition of the Toolkit, it will be assumed that the grate ash at 200 kg/Mg waste charged will have a concentration of 15 ng I-TEQ/kg. Fly ash generated in these units, likely 3 kg/Mg of waste charged, should be assumed to have a concentration of PCDD/F of 500 ng I-TEQ/kg.

The two liquid injection furnaces generate little grate ash, which as noted earlier, can be assumed to have negligible PCDD/F. The fly ash for Corunna, 3 kg/Mg of waste charged would be classified by the Toolkit to be a Category 4 system with a concentration of 30 ng I-TEQ/kg of fly ash. The presence of an ESP on the Mercier facility could be expected to result in higher concentrations of PCDD/F in the APC residues. A value of 250 ng I-TEQ/kg is suggested.

The two rotary kiln incinerators in Alberta can be considered to be Category 4 facilities under the Toolkit definition. No PCDD/F would be found in the bottom ash and the fly ash concentration of PCDD/F will be assumed to be 30 ng I-TEQ/kg.

The PCDD/F estimated to be released in residues from hazardous waste incinerators is listed in Table 8.19.

8.5.4 Sewage Sludge Incinerators

The Toolkit provides some guidance on the expected quantity and quality of residues from sewage sludge incinerators. Incineration of sewage sludge[108] (dewatered to approximately 20

[108] US DOT Turner-Fairbank Highway Research Center, 1994. Sewage Sludge Incineration: Meeting Air Emissions in the Nineties and Beyond," Proceedings of the National Waste Processing Conference, ASME, 1994. Available at: http://www.tfhrc.gov/hnr20/recycle/waste/ss1.htm

Table 8.19 PCDD/F in Residues from Hazardous Waste Incinerators in Canada

Name	Annual Throughput	Basis	Ash Percentage		PCDD/F Concentration [pg ITEQ/g]		Emission Rate [ug ITEQ/year]		Annual Emissions in Residues
	[Mg/yr]		**Bottom**	**Fly**	**Bottom**	**Fly**	**Bottom**	**Fly**	**[mg ITEQ/year]**
Swan Hills Treatment Centre	9,300	estimated		3.00		30	0	8,370	8.370
Swan Hills Treatment Centre	3,274	estimated		3.00		30	0	2,947	2.947
Clean Harbors Corunna	83,818	estimated		3.00		30	0	75,436	75.436
Material Resouce Recovery Inc. (Metal Reclaim)	1,183	estimated		1.00		30	0	355	0.355
Material Resouce Recovery Inc. (Car Bottom*)		estimated							
OPG Bruce Power Development	598	estimated	20	3.00	15	500	1,794	8,970	10.764
Cameco Port Hope	416	estimated	20	3.00	15	500	1,248	6,240	7.488
Cameco Blind River	416	estimated	20	3.00	15	500	1,248	6,240	7.488
Gary Steacy	1000	estimated		1.00		30		300	0.300
Clean Harbors Mercier	61,062	estimated		3.00		250	0	457,965	457.965
RSI Bennett	43,351	estimated		3.00		30	0	39,016	39.016
Bennett Belledune		estimated		3.00			0	0	0.000
								Total	610.13

percent solids) reduces the weight of feed sludge requiring disposal by approximately 85 percent implying that for every tonne of sludge fed to the incinerator, 150 kg of grate ash is created. This number is less than reported in the Toolkit, where it is suggested that about 43% of the feed remains after incineration in a multi-hearth furnace. This could be a function of the definition of the input to the incinerator in that a higher solids fraction in the sludge could change the input level. Without any data, it is assumed that 200 kg grate ash will be created for every dry tonne of sludge fed to a multi-hearth incinerator. Fluidised bed incinerators create no grate ash.

The Toolkit quotes data suggesting that the quantity of fly ash from a multi-hearth system is on the order of 13 kg/Mg of sludge. This rises to 373 kg/Mg of sludge with fluidised bed furnaces.

The PCDD/F in the grate ash quoted by the Toolkit for multi-hearth furnaces was 39 ng I- TEQ/kg and 470 ng I-TEQ/kg was found in the fly ash from the ESP. PCDD/F levels in fly ash from fluidised bed combustion, again from an ESP, were much lower <1 ng I-TEQ/kg. The Toolkit recommends that the combined residues from multi hearth furnaces be assessed at an emission factor of 23 ng I-TEQ/Mg of sludge. Fluidised bed systems are assessed at 0.5 ng I- TEQ/Mg of waste.

The Toolkit notes that where facilities use wet scrubbers or simple water quench to cool the off-gases or to quench grate ash, that between 1.2 and 6.5 pg I-TEQ/L of PCDD/F can be found in scrubber effluents. Typically these effluents are fed back to the waste water treatment system in the facility.

The PCDD/F estimated to be released in residues from sewage sludge incinerators is listed in Table 8.20.

8.5.5 Incinerators Operated by Federal Entities or on Federal Lands

There is a mix of incinerator equipment in this category, but most burn materials similar to MSW. Older units, Pilbrico multi-chamber incinerators typically have not performed well and should likely be categorized as Category 1 or maybe 2 according to the Toolkit guidance. The units operated by companies leasing Federal lands are newer units designed to provide good combustion control. Without HRSG on any of these units they are anticipated to have no flyash component to their residue streams.

Grate ash generation levels can be assumed to be 200 kg/Mg of waste charged.

Concentration of PCDD/F in these systems will be assumed to be 100 ng I-TEQ/kg for the multi-chamber systems, and 20 ng I-TEQ/kg for the newer systems. The PCDD/F estimated to be released in residues from incinerators operated by federal entities is listed in Table 8.21 and from those on federal lands or in remote locations in Table 8.22.

Table 8.20 PCDD/F in Residues from Sewage Sludge Incinerators in Canada

Name	Annual Throughput	Basis	Ash Percentage		PCDD/F Concentration [pg ITEQ/g]		Emission Rate [ug ITEQ/year]		Annual Emissions in Residues
	Dry Mg		**Bottom**	**Fly**	**Bottom**	**Fly**	**Bottom**	**Fly**	**[mg ITEQ/year]**
	[Mg/yr]								
Highland Creek Sewage Treatment Plant	10,500	estimated	20	1.30	39	470	81,900	64,155	146
CUM station d`'épuration des eaux usées	96,525	estimated	20	1.30	39	470	752,895	589,768	1,343
Centre d'épuration de la Rive-Sud	15,000	estimated		37.30		0.5		2,798	2.8
Duffin Creek W.P.C.P.	21,000	estimated		37.30		0.5		3,917	3.9
Lakeview Wastewater Facility	19,500	estimated		37.30		0.5		3,637	3.6
Greenway	10,000	estimated		37.30		0.5		1,865	1.9
								Total	1,501

Table 8.21 PCDD/F in Residues Emissions from Incinerators located at Federal Establishments

Name	**Annual Throughput**	Basis	Ash Percentage		PCDD/F Concentration [pg ITEQ/g]		Emission Rate [ug ITEQ/year]		Annual Emissions in Residues
FEDERAL AGENCIES	**[Mg/year]**		**Bottom**	**Fly**	**Bottom**	**Fly**	**Bottom**	**Fly**	**[mg ITEQ/year]**
AECL Whiteshell Laboratories	6	estimated	20		100		111	0	0.111
CFB Alert	76	estimated	20		100		1,529	0	1.529
CFB 4 Wing Fighter Squadron	25	estimated	20		20		100	0	0.100
CFB 4 Wing Fighter Squadron	25	estimated			20				
CFB Eureka	23	estimated	20		20		94	0	0.094
CFB 8 Wing Transport	31	estimated	20		20		125	0	0.125
CFB 17 Wing Training	3	estimated	20		100		67	0	0.067
CFB 17 Wing Training	4	estimated	20		100		83	0	0.083
CFB 17 Wing Training	4	estimated	20		100		83	0	0.083
DFO Experimental Lakes Research Stn	36	estimated	20		100		728	0	0.728
Cree Nation of Wemindji	406	estimated	20		20		1,622	0	1.622
Hesquiaht Nation	169	estimated	20		20		676	0	0.676
DND Family Wilderness Camp 5 Wing Training	6	estimated	20		100		117	0	0.117
DND North Warning System BAF-3	1	estimated	20		100		28	0	0.028
DND North Warning System LAB-2	1	estimated	20		100		28	0	0.028
DND North Warning System LAB-6	1	estimated	20		100		28	0	0.028
EnvCan Eureka	17	estimated	20		20		67	0	0.067
EnvCan Sable Island	4	estimated	20		100		83	0	0.083
RCMP G Division Headquarters	0	estimated	20		100		3	0	0.003
RCMP/PWC	29	estimated	20		100		582	0	0.582
AAFC Brandon	8	estimated	20		100		156	0	0.156
AAFC Lethbridge Research Centre	4	estimated	20		100		83	0	0.083
AAFC Ottawa	0	estimated	20		100		1	0	0.001
CFIA Plant and Animal Lab	5	estimated	20		100		104	0	0.104
CFIA Animal Diseases Research	47	estimated	20		100		936	0	0.936
CFIA Animal Diseases Research	23	estimated	20		100		468	0	0.468
CFIA Animal Diseases Research	52	estimated	20		100		1,040	0	1.040
CFIA Health of Animals Research	7	estimated	20		100		130	0	0.130
DRDC Suffield	42	estimated	20		20		168	0	0.168
DRDC Suffield	30	estimated	20		20		119	0	0.119
								Total	9.36

Table 8.22 PCDD/F in Residues from Incinerators located in Remote Areas or on Federal Lands

Name	Annual Throughput	Basis	Ash Percentage		PCDD/F Concentration [pg ITEQ/g]		Emission Rate [ug ITEQ/year]		Annual Emissions in Residues
	[Mg/year]		**Bottom**	**Fly**	**Bottom**	**Fly**	**Bottom**	**Fly**	**[mg ITEQ/year]**
CARA Operations Limited (Airport Services)	23	estimated	20		100		455	0	0.455
Voisey's Bay	26	estimated	20		20		104	0	0.104
Voisey's Bay	39	estimated	20		20		156	0	0.156
BHPB Billiton Diamonds Inc.	70	estimated	20		20		281	0	0.281
BHPB Billiton Diamonds Inc.	70	estimated	20		20		281	0	0.281
BHPB Billiton Diamonds Inc.	70	estimated	20		20		281	0	0.281
BHPB Billiton Diamonds Inc.	70	estimated	20		20		281	0	0.281
BHPB Billiton Diamonds Inc.	156	estimated	20		20		624	0	0.624
BHPB Billiton Diamonds Inc. (new unit ordered)		estimated	20		20		0	0	0.000
BHPB Billiton Diamonds Inc. (new unit ordered)		estimated	20		20		0	0	0.000
Paramount Resources	147	estimated	20		20		590	0	0.590
Paramount Resources	147	estimated	20		20		590	0	0.590
Paramount Resources	210	estimated	20		20		839	0	0.839
Diavik Diamond Mine Inc.	566	estimated	20		20		2,265	0	2.265
Diavik Diamond Mine Inc.	426	estimated	20		20		1,704	0	1.704
De Beers Canada Inc.	262	estimated	20		20		1,048	0	1.048
De Beers Canada Inc.	262	estimated	20		20		1,048	0	1.048
De Beers Canada Inc.	437	estimated	20		20		1,747	0	1.747
Shell Canada		estimated	20		20				0.000
North American Tungsten Corp.	182	estimated	20		20		728	0	0.728
Tahera Corporation	156	estimated	20		20		624	0	0.624
Tahera Corporation		estimated	20		20		0	0	0.000
								Total	13.64

8.6 Summary of Estimated PCDD/F Emissions from Incinerators

Four tables summarise the incinerators currently installed in Canada and the estimated emissions attributed to them. The emission data is based upon 2005 operating data where that is available. Table 8.23 lists all the incinerators installed by province and type. The emissions are estimated for incinerators that were operating in 2005. The total installed number in Table 8.23 does not agree with the total in Table 8.26 because some of the installed units were not operating or had no data upon which to base estimates. The seven incinerators for which emissions data were not determined include:

- the backup medical waste incinerator in New Brunswick(1) and the backup unit operated by Tahera in Nunavut (all waste was assumed to be processed in one unit);
- incinerators that were installed in late 2005 or 2006, but not operated: Ekati(2); Bennett, Belledune(1);
- the second furnace at MRR that cannot be operate unless the first unit is operating and all the waste was assumed to go through the first unit; and,
- in the absence of any data on the Shell Camp Farewell unit, no estimates were provided.

For the operating incinerators annual emissions to air and in residues are summarized Tables 8.24 and 8.25. The annual PCDD/F emissions associated with both the stack releases and the amount of PCDD/F shipped off site in residues streams are estimates and the reader is cautioned that there is uncertainty inherent in these numbers. The details of the calculations presented earlier in this chapter should be reviewed.

In the case of the large MSW incinerators, the air emissions assigned for the Trigen facility need to be verified. The latest NPRI report for this facility shows these numbers to be lower but there is no basis for using a lower number at this time since the 2004 data was even higher than the value used for this study. PCDD/F in residues from large MSW incinerators account for two thirds of the PCCD/F in residues estimated for this study. These estimates are based upon default values and could be refined if residue volumes could be confirmed, and analytical data for these materials could be collected.

For medical waste incinerators, the Cristallo facility emissions are based upon default factors as no test data was made available. The emissions from this facility could be up to 3 orders of magnitude higher than are being estimated depending upon the amount of waste being disposed. The mass of medical waste being disposed at most of the facilities in this category is only an estimate since little data was available, and without test data from the larger individual hospitals, the emission values are based upon default values. The estimates could be refined by obtaining better information on waste volumes disposed and a limited amount of site specific monitoring data, especially from the larger facilities.

Hazardous waste incinerator estimates are based upon test data and an interpretation of operating hours based upon waste feed totals for most facilities. The air emissions from Mercier are close to the NPRI value reported for 2005. The estimates for PCDD/F in residues could be refined both with respect to the quantity and quality of the residues.

Residue related emissions from multi-hearth furnaces dominate the sewage sludge incinerator total emissions value. Montreal, which processes a large quantity of sludge, and uses older technology has the highest emissions. The use of an estimated number for the air emissions, as well as the default values for residues exacerbates this situation. There is some indication that Montreal may be moving towards other methods of sludge disposal and these might result in a decrease of the emissions. More information on emissions from multi-hearth incinerators, both to the atmosphere and in the residues, should be obtained.

The incinerators operated by federal entities dispose of an estimated 1,000 Mg of waste per year. While there are several situations where this is the only viable alternative for disposal of the materials, the lack of site specific data on waste generation rates, or emissions lend uncertainty to the estimates. Better waste generation data is needed for most sites, and site specific emission data should be generated for the larger facilities. The quantity and quality of residues should be defined for these sources.

Over 3,000 Mg of waste may be disposed in incinerators located at isolated resource development facilities. While air emissions and residue related PCDD/F levels have been estimated for these sources, as with the other categories waste generation rates and the quantity of PCDD/F in air and residue streams should be confirmed if only on a limited number of sites.

Table 8.23 Summary of Installed Incinerators by Province 2005/2006

Incinerator Classification	Province													Totals
	AB	BC	MB	NB	NF	NT	NS	NU	ON	PE	QC	SK	YK	
Municipal	1	1							1	1	3			7
Medical	3		28	2		1		3	2	1		1	1	42
Hazardous	2			1					7		2			12
Sewage Sludge									4		2			6
Federal Agencies	7	1	6		3	1	1	4	4	1	1	1		30
Remote and Federal Lands			1		2	15		2	1				1	22
Totals	13	2	35	3	5	17	1	9	19	3	8	2	2	119

Table 8.24 Summary of PCDD/F Air Emissions [mg I-TEQ/yr] from Operating Incinerators by Province

Incinerator Classification	Province													Totals
	AB	BC	MB	NB	NF	NT	NS	NU	ON	PE	QC	SK	YK	
Municipal	3.7	8.9							3.7	4.2	39.3			59.9
Medical	268.4		2222	0.05		0.04		42.9	63.2	450.0		14.8	80.5	3141.5
Hazardous	20.2								40.2		197.4			257.8
Sewage Sludge									5.7		40.1			45.8
Federal Agencies	40.7	59.2	18.9		3.0	0.1	1.5	8.7	26.3	0.3	0.1	0.3		158.9
Remote and Federal Lands			8.0		0.01	18.4		1.5	4.1				1.7	33.7
Totals	333.0	68.0	2249	0.05	3.0	18.5	1.5	53.1	143.3	454.5	276.9	15.1	82.2	3697.7

Table 8.25 Summary of PCDD/F in Residues [mg I-TEQ/yr] from Operating Incinerators by Province

Incinerator Classification	Province													Totals
	AB	BC	MB	NB	NF	NT	NS	NU	ON	PE	QC	SK	YK	
Municipal	12.9	1485							756.0	172.8	1712			4138.5
Medical	29.8		14.8	10.0		0.1		1.2	20.8	3.0		0.6	0.5	80.9
Hazardous	11.3								101.8		497.0			610.1
Sewage Sludge									155.5		1345			1500.9
Federal Agencies	1.9	0.7	1.1		0.2	0.0	0.1	1.7	1.9	0.1	1.6	0.1		9.4
Remote and Federal Lands			0.5		0.3	9.8		0.6	1.7				0.7	13.6
Totals	55.9	1486	16.3	10.0	0.4	9.9	0.1	3.6	1038	175.9	3556	0.7	1.3	6353.5

Table 8.26 Summary of 2005 PCDD/F Emissions from Operating Canadian Incinerators

Incinerator Classification	Number Identified	Waste Quantity [Mg/year]	Releases of PCDD/F [mg I-TEQ/year]		
			Air	Residues	Total
Large Municipal	7	762,793	60	4,139	4,198
Medical	41	8,082	3,142	81	3,222
Hazardous	10	204,418	258	610	868
Sewage Sludge	6	172,525	46	1,501	1,547
Federal Agencies	30	1,087	159	9	168
Remote and Federal Lands	18	3,320	34	14	47
Totals	112	1,152,225	3,698	6,353	10,051

9.0 ALTERNATIVE EQUIVALENCY FACTORS

9.1 Introduction

As discussed earlier in this report, there are alternatives to the I-TEQ equivalency factor. While the general consensus presented there suggests that utilising the WHO_{98} protocol will raise the effective emissions by less than 15%, this conclusion should be tested for various incinerator types and the use of different treatments of laboratory results that are at or below the quantification limit. While the ideal situation would be to perform this evaluation on all the existing data from different types of incinerators operated in Canada, the effort to accomplish this was considered beyond the scope of this report. For starters, the individual stack testing reports would need to be quality checked before the analysis was performed. This checking requires the researcher to go back to the raw laboratory data and the stack sampling team's data sheets to redo all the calculations in the test reports. Rather than doing this, data that the author has already quality controlled will be used to provide an indication of how this change would effect reported emission levels.

In the course of examining test reports to obtain the data used in the previous section several different treatments of BDL data were identified. Some reports provided I-TEQ estimates based upon including unquantifiable concentrations as zero contributors, others took ½ DL values, and still other follow the CWS guidance:

> "Jurisdictions must report measurements that are below the detection limit in a consistent manner . These measurements should be reported as the limit of detection."

Undefined in definition is how the laboratories chose to define their specific quanitification limit. In many cases it can be observed that this level changes in a specific laboratory either day by day, or at least test series by test series. There is a need for a standard definition of when the data should be considered below the level of quantification. The approach outline in EN1948 and discussed in Chapter 5 should, in the opinion of the author, be used as a consistent basis for defining the limit. Remember, the formulation is $LOQ_i = 0.5\ [pg/m^3]/I\text{-}TEF_i$. Using this approach, facilities who do not require the testers to conduct testing of a reasonable length will end up substituting higher detection limit values in their determination of the TEQ values than will facilities who opt to pay the testers for more sampling time.

This chapter thus presents data:

- as typically calculated with the I-TEQ factors;
- using the same basic values by applying the WHO_{98} factors;
- using the laboratory data and the sample volumes to determine individual LOQ values and applying the I-TEQ factors, with and without incorporating the values that are below the LOQ; and,
- doing step 3 with the WHO_{98} factors.

9.1 Data for Analysis

Table 9.1 lists PCDD/F analytical results for 13 triplicate tests conducted at 5 different facilities. All tests were conducted on Canadian incinerators:

- Facility 1 - an MSW incinerator with a capacity in excess of 500 Mg/day;
- Facility 2 - a medical waste incinerator burning 10 Mg/day;
- Facility 3 - an MSW incinerator with a capacity in excess of 700 Mg/day;
- Facility 4 - a medical waste incinerator burning about 15 kg/hr;
- Facility 5 - an MSW incinerator burning 1 Mg/day.

The table lists the values by facility and the date of the test. For each test the blank train data is entered as the first data for the test series and the balance of the test data includes the volume of the sample collected and the oxygen concentration for that test run. PCDD/F data in the table were entered as the mass of the congener measured [pg] directly from the laboratory analyses. Values reported by the laboratory to be less than the detection limit defined by the laboratory were entered as a negative value at the detection limit.

The sample volume and the oxygen concentration were used to convert the individual congener mass values to a concentration at standard conditions including the diluent concentration value. The concentration data is provided in Table 9.2.

The EN1948 LOQ values discussed above are a function of the volume of the sample that is collected. Two tables, Table 9.3 and 9.4 show the LOQ values in concentration for each of the tests. There are two tables because both the I-TEF and the WHO_{98} TEF approach must be used to determine the LOQ values for the individual congeners from each sample.

The data presentation requirements in EN1948 suggest that the measured concentration for each congener must be compared to the LOQ determined on the basis of the sample volume and the individual congener TEF. If the concentration is less than the LOQ, the TEQ for the sample is calculate both with and without the values below the LOQ included in the summation. These calculations were completed and the results are summarized in Table 9.5. Again the table reflects calculations with the TEQ factors for both the I-TEF and WHO_{98}-TEF schemes. The header designates the manner in which the value was determined. In the Alternative Calculation Regimes section of the table, the first two columns show the value determined assuming that values below the LOQ are excluded from the sum. The 3rd and 4th columns of data present the results when the LOQ is substituted for the values that are below the LOQ. The last two columns provide the data as it is currently required to be calculated by the CWS PCDD/F standard.

Table 9.6 shows the increase in the TEQ produced by using the WHO_{98}-TEF for each approach.

Table 9.1 Raw Analytical Data [pg] from Stack Testing Programs Various Facilities

Facility			Sample Specifics		TCDF2378	TCDD2378	PCDF1	PCDF4	PCDD1	HXCDF14	HXCDF16	HXCDF46	HXCDF19	HXCDD14	HXCDD16	HXCDD19	HPCDF146	HPCDF149	HPCDD146	OCDF	OCDD	TCDF	PCDF	HXCDF	HPCDF	TCDD	PCDD	HXCDD	HPCDD
	ITEQ				0.1	1	0.05	0.5	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	0.01	0.01	0.001	0.001								
	WHO98				0.1	1	0.05	0.5	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	0.01	0.01	0.0001	0.0001								
	Date	Sample	Volume	Oxygen																									
			[Rm^3]	[%]																									
1	10232000	Blank			-9.5	-8.2	-8.1	9.8	-5.3	-14	-5.5	15	-6.6	-5.7	-4.3	-5.5	32	-12	31	-21	65	-9.5	37	14	41	-8.2	-13	76	31
1	10232000	T1OC	5.061	10.6	3200	300	1500	1600	550	3000	1500	1400	86	330	420	670	3100	350	2400	870	4800	25000	25000	15000	5600	5500	6500	7200	5000
1	10242000	T2OC	5.085	10.7	2200	220	1200	1200	420	2300	1100	1100	64	330	400	620	2900	330	2200	990	4800	20000	19000	11000	5200	4100	5000	6700	4600
1	10252000	T3OC	5.093	10.7	1500	120	640	820	260	1300	680	740	39	220	260	-370	1900	-220	1700	-670	3700	11000	11000	6700	3200	2600	3500	4900	3500
1	11192001	blankOC			-2	-2	-1.9	2.6	-1.9	-1.8	-1.4	-1.9	-2	-1.9	-1.6	-1.9	-1.6	-1.7	-2	6.3	4.7	-2	2.6	-1.7	-1.6	-2	-1.9	-1.8	-2
1	11192001	T1OC	5.047	11.07	82	-6.4	43	61	19	93	49	51	-5.4	20	26	52	210	32	190	660	430	600	570	390	310	74	120	390	350
1	11202001	T2OC	5.388	11.17	50	-3.1	19	34	7	61	25	34	-3.2	5.6	11	20	95	16	70	50	150	270	290	230	150	49	41	180	140
1	11212001	T3OC	5.445	10.76	28	-2	8.9	20	5.2	30	13	23	-2.2	8.8	12	26	65	15	110	42	200	150	160	120	120	40	55	220	220
1	9232002	blankOC			-5.5	-8.9	-4.3	-4.3	-4.1	-3	-2.6	-3.2	-3.4	-6.4	-5.4	-5.7	-4.4	-4.2	-5.4	23	18	-5.5	-4.3	4	-4.4	-8.9	11	-5.8	-5.4
1	9232002	T1OC	5.792	11.4	-31	-7.2	-3	16	-5.1	15	8.1	-11	-3.9	-5.3	11	15	-30	4.8	83	33	150	170	65	70	13	280	140	250	160
1	9242002	T2OC	5.82	11.6	-21	-7.4	-2.8	9.9	5.1	8.2	-3.5	7	-3.1	-4	8.1	6.9	-13	-3.5	45	25	76	80	58	26	7.4	200	95	170	85
1	9252002	T3OC	5.792	11.7	-23	-11	-3.2	15	6.7	19	8.8	12	-2.8	-7.8	11	13	-36	6.8	97	40	170	110	110	89	26	290	150	240	180
1	9232003	blankOC			3.8	2.7	-2.1	-2.9	-2	2.4	-1.7	-2.2	-2.5	2.6	-2	3.2	-2.3	-2.9	-3.7	18	59	3.8	-2.9	2.4	-2.6	2.7	-2	5.8	-3.7
1	9232003	T1OC	5.154	10.9	-26	-3.5	-10	14	-5.7	20	16	23	-4.5	-5.6	15	17	-44	15	110	88	560	120	100	97	35	160	170	220	220
1	9242003	T2OC	5.145	11.3	-29	-3.6	-7.8	13	6	20	11	14	-3.4	7.5	15	15	-32	6.1	86	26	160	180	79	81	6.1	170	110	270	170
1	9252003	T3OC	5.175	10.9	-26	-4.2	-7.1	13	-5.2	17	9.5	-11	-3.4	5.9	13	15	-21	-6	78	-36	260	150	54	52	9.1	190	190	310	160
1	9202004	blankOC			-7.7	-11	-14	-13	-11	-4	-4	-4.4	-5	-6.5	-6.5	-6.4	-8.5	-11	-3.7	16	29	-7.7	-13	-4.3	-9.7	-11	-11	-6.5	-3.7
1	9202004	T1OC	4.825	10.9	36	-10	12	-16	-13	-21	-11	-12	-14	-12	19	16	-24	-11	84	-23	110	310	100	31	-24	470	210	500	160
1	9212004	T2OC	4.866	10.9	-23	-10	-12	-11	-10	18	-8.3	-5.3	-6	-8	19	19	-25	-15	92	-23	110	72	21	52	-25	490	230	560	170
1	9222004	T3OC	4.794	10.6	-22	-14	-33	-30	-11	15	-11	-12	-13	-14	21	21	-23	-21	92	38	140	63	-31	33	-23	450	150	480	180
1	10112005	blankOC			-2.8	-2.8	-2.9	5	-2.7	-2.6	-2.4	-2.9	-3.2	-2.9	-2.6	-2.7	-2.3	-3.2	3.1	6.4	10.8	6.6	5	-2.8	-2.7	-68	-18	-9.2	3.1
1	10112005	T1OC	5.461	12.1	-13	-2.9	-5.5	10.8	4.4	10.7	6.6	4.5	-3	3.9	8.9	9.1	-13	-3.1	44	14.3	59	79.7	58.3	39.9	3.1	263	112	256	79.7
1	10122005	T2OC	5.458	11.7	-24	-3	10.2	15.5	5.5	19.4	11.6	7.5	-3.1	6.3	11.3	13.3	-24	4.2	66.3	18.8	89.1	162	103	78.4	13.9	221	128	407	126
1	10132005	T3OC	5.453	11.9	-15	-2.8	-6.8	12.6	-4.5	14.6	8.9	6.2	-3.2	5.2	11.7	11.8	-19	-3.4	70.6	19.2	127	91.4	71.6	52.3	4.6	288	169	729	139
2	20021219	blankOC			-10	-6.3	-6.7	-7.4	-4.2	4.5	-5.2	7.4	-5.2	-6.7	-5.1	-6.2	-4.7	-6.7	-7	-17	57	-10	-7.7	11	-5.7	-6.3	-4.2	-5.9	-7
2	20021217	T1OC	3.75	8.05	-11	-8.9	-7.2	6.1	-4	-6.7	-5.5	-7.8	-8.7	-7.9	-6	-7.3	-6.1	-8.4	-11	-12	-11	-11	6.3	-7	-7.1	-8.9	-4	-7	-11
2	20021218	T2OC	4.23	7.8	-14	-16	-6.8	-8.2	-6.6	-6.2	-5.2	-9.2	-8	-12	-9.2	-11	-5.3	-7.2	-11	-15	-13	-14	-8.5	-8.3	-6.1	-16	-6.6	-11	-11
2	20021219	T3OC	3.89	7.98	17	-13	-7.5	14	-8.5	8.6	-7.1	12	-7.6	-9.5	-7.1	9.5	-16	-11	-16	-18	-24	17	14	19	-18	-13	-8.5	9.1	-17
2	20040622	blankOC			-5	-5.5	-4.6	-3.9	-6.8	-2.7	-2.7	-3.1	-2.9	-5.2	-5.1	-5	-2.8	-3.3	-4.1	5	8.9	-5	-4.2	-2.8	-3.1	-5.5	-6.8	-5.1	-4.1
2	20040622	T1OC	3.538	13.54	17	-5.5	-4.9	6.3	-6.6	7.4	3.9	4.4	-2.8	-3.6	-3.6	-3.5	-10	-5.6	13	7.5	20	37	25	21	-10	-5.5	-6.6	13	22
2	20040623	T2OC	3.445	11.37	8.5	-4.6	-5.2	-4.4	-6.8	-3.5	-3.5	-3.9	-3.7	-3.8	-3.8	-3.7	-4.9	-4.4	9.1	5.8	-14	8.5	-4.8	-3.6	-4.9	-4.6	-6.8	5.1	17
2	20040624	T3OC	3.663	11.49	8.9	-4.5	-5.1	7.1	-4	12	7.3	6.9	-4.6	-3.2	-3.2	4.7	-21	-4.9	18	8.7	23	8.9	14	40	-21	-4.5	-4	21	31
2	20050906	blankOC			-0.5	-0.8	-1.3	-1	-0.8	-0.4	-0.8	-1.9	-1	-1	-1.7	-1.2	-2.8	-0.9	-2.2	-1.2	-3.4	-0.5	-1	-1.9	-2.8	-0.8	-0.8	-1.7	-2.2
2	20050906	T1OC	3.667	10.48	13.1	-2.2	3.1	2.6	-0.5	-3.2	2.9	3.1	-2	-1.6	-3.1	-2.1	-4	1.2	3.6	-2.2	8.8	76.7	19.2	6	1.2	5.6	-0.5	-3.1	3.6
2	20050907	T2OC	4.438	10.59	9.5	-2.3	3.2	-10.6	-0.5	4.5	2.5	-3.3	-0.4	-1.6	2.4	-2.4	4.2	-1.5	4.3	2.9	10.4	83.7	13.3	11.1	4.2	2.9	3.9	-0.5	10.3
2	20050908	T3OC	4.243	10.85	-3.7	-0.8	2.5	-8.5	-0.5	4.2	4.1	3.4	2	-0.9	-4.5	-1.5	7	2	4.6	-4.2	8.5	40	7.1	21	13.3	-0.8	-0.5	-4.5	9.4
3	20031031	blank			-2	-2	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-20	-20	-2	-4	-4	-4	-2	-4	-4	-4
3	20031031	Run1	4.484	10.8	45	-5	16	30	22	50	31	14	26	-15	100	34	110	-30	710	65	980	400	460	420	110	260	740	1800	1700
3	20031103	Run2	4.458	10.6	44	-2	16	26	19	21	24	8.4	2.8	22	81	38	110	11	960	47	1200	520	430	250	194	280	720	1900	1800
3	20031104	Run3	4.476	9.9	22	-2	20	28	12	64	27	-4	26	17	71	36	110	-8	840	31	1100	550	430	278	140	310	870	1900	1600
3	20050802	blank			-2	-2	-4	6.5	9	-4	-4	-4	5.9	-4	6.6	5.9	7.3	-4	30	-15	23	53	25	26	15	250	160	180	57
3	20050802	Run1	5.893	12.4	2.6	2.4	6.3	11	12	13	9.2	4	15	12	26	20	44	-4	140	-15	210	82	81	130	56	310	290	510	270
3	20050803	Run2	5.51	10.9	4.4	-2	5	11	9.6	9.3	7.4	-4	12	7.4	20	15	32	-4	130	16	200	160	53	88	47	240	240	390	290
3	20050804	Run3	5.917	12.6	2.7	2.3	5.3	18	20	11	11	-4	16	15	27	22	31	-4	150	-15	190	110	110	120	44	380	330	480	300
4	20060502	blank			-2	-2	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-15	-15	-2	10	-4	-4	23	-4	44	22
4	20060502	Run1	3.2492	14	27	37	45	54	22	30	28	1.9	25	6.2	9.7	6.8	29	4.2	37	-15	45	1500	810	300	48	3200	830	260	71
4	20060503	Run2	3.1964	14.3	220	190	210	270	230	170	130	8	110	61	130	110	150	19	320	21	130	810	3800	1400	210	14000	5200	2200	700
4	20060504	Run3	3.116	14.1	77	43	68	160	39	62	45	-4	42	7.6	16	11	32	5.7	29	-15	24	2000	1200	480	46	3700	1200	610	63
5	20021023	blank			0.8	-0.4	-0.2	-0.4	2	0.9	-0.2	0.5	-0.3	0.6	0.5	-0.4	-1.1	-1.6	4.1	2.7	11.1	1.2	-0.3	2.7	-1.4	4.4	3.1	5.5	5.6
5	20021023	Run1	4.075	13.9	30.4	1.2	8.8	16.2	4.1	41.9	18.8	51.4	3.8	2.1	3.8	4.1	127.5	65.1	38.2	377.9	96.9	136.2	149.3	223.6	340.1	80.8	36	51.6	64.6
5	20021024	Run2	3.894	13.9	106.6	2.5	30.6	59.6	7.1	148.6	76.5	142.3	19.2	8.5	16.8	15.5	358.1	189.2	199.2	1013.6	502.8	520.9	513	709.9	913.4	74.9	70.1	201.2	327
5	20021025	Run3	4.043	14.8	168.4	9.2	42.3	92.8	19.4	301.3	110.8	257.4	15.6	24.5	31.5	70.1	638.3	219.6	294.6	827.2	481.8	927	942.2	1334.5	1305.9	215.6	184.1	425.9	494.3

Table 9.2 Stack Testing Data Congener Concentrations [pg/Rm^3 @ 11% Oxygen]

Facility			Sample Specifics		TCDF2378	TCDD2378	PCDF1	PCDF4	PCDD1	HXCDF14	HXCDF16	HXCDF46	HXCDF19	HXCDD14	HXCDD16	HXCDD19	HPCDF146	HPCDF149	HPCDD146	OCDF	OCDD	TCDF	PCDF	HXCDF	HPCDF	TCDD	PCDD	HXCDD	HPCDD
	ITEQ				0.1	1	0.05	0.5	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	0.01	0.01	0.001	0.001								
	WHO98				0.1	1	0.05	0.5	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	0.01	0.01	0.0001	0.0001								
	Date	Sample	Volume	Oxygen																									
			[Rm^3]	[%]																									
1	10232000	Blank			-1.8	-1.6	-1.5	1.9	-1.0	-2.7	-1.0	2.9	-1.3	-1.1	-0.8	-1.0	6.1	-2.3	5.9	-4.0	12.4	-1.8	7.0	2.7	7.8	-1.6	-2.5	14.5	5.9
1	10232000	T1OC	5.061	10.6	607.7	57.0	284.9	303.9	104.5	569.7	284.9	265.9	16.3	62.7	79.8	127.2	588.7	66.5	455.8	165.2	911.6	4747.9	4747.9	2848.7	1063.5	1044.5	1234.5	1367.4	949.6
1	10242000	T2OC	5.085	10.7	419.9	42.0	229.0	229.0	80.2	439.0	210.0	210.0	12.2	63.0	76.3	118.3	553.5	63.0	419.9	189.0	916.2	3817.5	3626.6	2099.6	992.5	782.6	954.4	1278.8	878.0
1	10252000	T3OC	5.093	10.7	285.9	22.9	122.0	156.3	49.5	247.7	129.6	141.0	7.4	41.9	49.5	-70.5	362.1	-41.9	324.0	-127.7	705.1	2096.3	2096.3	1276.8	609.8	495.5	667.0	933.8	667.0
1	11192001	blankOC			-0.4	-0.4	-0.4	0.5	-0.4	-0.3	-0.3	-0.4	-0.4	-0.4	-0.3	-0.4	-0.3	-0.3	-0.4	1.2	0.9	-0.4	0.5	-0.3	-0.3	-0.4	-0.4	-0.3	-0.4
1	11192001	T1OC	5.047	11.07	16.4	-1.3	8.6	12.2	3.8	18.6	9.8	10.2	-1.1	4.0	5.2	10.4	41.9	6.4	37.9	131.7	85.8	119.7	113.7	77.8	61.9	14.8	23.9	77.8	69.8
1	11202001	T2OC	5.388	11.17	9.4	-0.6	3.6	6.4	1.3	11.5	4.7	6.4	-0.6	1.1	2.1	3.8	17.9	3.0	13.2	9.4	28.3	51.0	54.8	43.4	28.3	9.3	7.7	34.0	26.4
1	11212001	T3OC	5.445	10.76	5.0	-0.4	1.6	3.6	0.9	5.4	2.3	4.1	-0.4	1.6	2.2	4.7	11.7	2.7	19.7	7.5	35.9	26.9	28.7	21.5	21.5	7.2	9.9	39.4	39.4
1	9232002	blankOC			-1.0	-1.6	-0.8	-0.8	-0.7	-0.5	-0.5	-0.6	-0.6	-1.2	-1.0	-1.0	-0.8	-0.8	-1.0	4.2	3.3	-1.0	-0.8	0.7	-0.8	-1.6	2.0	-1.1	-1.0
1	9232002	T1OC	5.792	11.4	-5.6	-1.3	-0.5	2.9	-0.9	2.7	1.5	-2.0	-0.7	-1.0	2.0	2.7	-5.4	0.9	14.9	5.9	27.0	30.6	11.7	12.6	2.3	50.4	25.2	45.0	28.8
1	9242002	T2OC	5.82	11.6	-3.8	-1.4	-0.5	1.8	0.9	1.5	-0.6	1.3	-0.6	-0.7	1.5	1.3	-2.4	-0.6	8.2	4.6	13.9	14.6	10.6	4.8	1.4	36.6	17.4	31.1	15.5
1	9252002	T3OC	5.792	11.7	-4.3	-2.0	-0.6	2.8	1.2	3.5	1.6	2.2	-0.5	-1.4	2.0	2.4	-6.7	1.3	18.0	7.4	31.6	20.4	20.4	16.5	4.8	53.9	27.9	44.6	33.4
1	9232003	blankOC			0.7	0.5	-0.4	-0.6	-0.4	0.5	-0.3	-0.4	-0.5	0.5	-0.4	0.6	-0.4	-0.6	-0.7	3.5	11.5	0.7	-0.6	0.5	-0.5	0.5	-0.4	1.1	-0.7
1	9232003	T1OC	5.154	10.9	-5.0	-0.7	-1.9	2.7	-1.1	3.8	3.1	4.4	-0.9	-1.1	2.9	3.3	-8.5	2.9	21.1	16.9	107.6	23.1	19.2	18.6	6.7	30.7	32.7	42.3	42.3
1	9242003	T2OC	5.145	11.3	-5.8	-0.7	-1.6	2.6	1.2	4.0	2.2	2.8	-0.7	1.5	3.0	3.0	-6.4	1.2	17.2	5.2	32.1	36.1	15.8	16.2	1.2	34.1	22.0	54.1	34.1
1	9252003	T3OC	5.175	10.9	-5.0	-0.8	-1.4	2.5	-1.0	3.3	1.8	-2.1	-0.7	1.1	2.5	2.9	-4.0	-1.1	14.9	-6.9	49.7	28.7	10.3	9.9	1.7	36.3	36.3	59.3	30.6
1	9202004	blankOC			-1.6	-2.2	-2.8	-2.6	-2.2	-0.8	-0.8	-0.9	-1.0	-1.3	-1.3	-1.3	-1.7	-2.2	-0.8	3.2	5.9	-1.6	-2.6	-0.9	-2.0	-2.2	-2.2	-1.3	-0.8
1	9202004	T1OC	4.825	10.9	7.4	-2.1	2.5	-3.3	-2.7	-4.3	-2.3	-2.5	-2.9	-2.5	3.9	3.3	-4.9	-2.3	17.2	-4.7	22.6	63.6	20.5	6.4	-4.9	96.4	43.1	102.6	32.8
1	9212004	T2OC	4.866	10.9	-4.7	-2.0	-2.4	-2.2	-2.0	3.7	-1.7	-1.1	-1.2	-1.6	3.9	3.9	-5.1	-3.1	18.7	-4.7	22.4	14.6	4.3	10.6	-5.1	99.7	46.8	113.9	34.6
1	9222004	T3OC	4.794	10.6	-4.4	-2.8	-6.6	-6.0	-2.2	3.0	-2.2	-2.4	-2.6	-2.8	4.2	4.2	-4.6	-4.2	18.4	7.6	28.1	12.6	-6.2	6.6	-4.6	90.2	30.1	96.2	36.1
1	10112005	blankOC			-0.6	-0.6	-0.6	1.0	-0.5	-0.5	-0.5	-0.6	-0.6	-0.6	-0.5	-0.5	-0.5	-0.6	0.6	1.3	2.2	1.3	1.0	-0.6	-0.5	-13.7	-3.6	-1.9	0.6
1	10112005	T1OC	5.461	12.1	-2.7	-0.6	-1.1	2.2	0.9	2.2	1.4	0.9	-0.6	0.8	1.8	1.9	-2.7	-0.6	9.1	2.9	12.2	16.4	12.0	8.2	0.6	54.2	23.1	52.7	16.4
1	10122005	T2OC	5.458	11.7	-4.7	-0.6	2.0	3.1	1.1	3.8	2.3	1.5	-0.6	1.2	2.2	2.6	-4.7	0.8	13.1	3.7	17.6	31.9	20.3	15.5	2.7	43.6	25.2	80.2	24.8
1	10132005	T3OC	5.453	11.9	-3.0	-0.6	-1.4	2.5	-0.9	2.9	1.8	1.3	-0.6	1.0	2.4	2.4	-3.8	-0.7	14.2	3.9	25.6	18.4	14.4	10.6	0.9	58.1	34.1	147.1	28.0
2	20021219	blankOC			-1.9	-1.2	-1.3	-1.4	-0.8	0.9	-1.0	1.4	-1.0	-1.3	-1.0	-1.2	-0.9	-1.3	-1.4	-3.3	11.0	-1.9	-1.5	2.1	-1.1	-1.2	-0.8	-1.1	-1.4
2	20021217	T1OC	3.75	8.05	-2.3	-1.8	-1.5	1.3	-0.8	-1.4	-1.1	-1.6	-1.8	-1.6	-1.2	-1.5	-1.3	-1.7	-2.3	-2.5	-2.3	-2.3	1.3	-1.4	-1.5	-1.8	-0.8	-1.4	-2.3
2	20021218	T2OC	4.23	7.8	-2.5	-2.9	-1.2	-1.5	-1.2	-1.1	-0.9	-1.6	-1.4	-2.1	-1.6	-2.0	-0.9	-1.3	-2.0	-2.7	-2.3	-2.5	-1.5	-1.5	-1.1	-2.9	-1.2	-2.0	-2.0
2	20021219	T3OC	3.89	7.98	3.3	-2.6	-1.5	2.8	-1.7	1.7	-1.4	2.4	-1.5	-1.9	-1.4	1.9	-3.2	-2.2	-3.2	-3.5	-4.7	3.3	2.8	3.7	-3.5	-2.6	-1.7	1.8	-3.3
2	20040622	blankOC			-1.6	-1.8	-1.5	-1.2	-2.2	-0.9	-0.9	-1.0	-0.9	-1.7	-1.6	-1.6	-0.9	-1.1	-1.3	1.6	2.8	-1.6	-1.3	-0.9	-1.0	-1.8	-2.2	-1.6	-1.3
2	20040622	T1OC	3.538	13.54	6.5	-2.1	-1.9	2.4	-2.5	2.8	1.5	1.7	-1.1	-1.4	-1.4	-1.3	-3.8	-2.1	4.9	2.9	7.6	14.1	9.5	8.0	-3.8	-2.1	-2.5	4.9	8.4
2	20040623	T2OC	3.445	11.37	2.6	-1.4	-1.6	-1.3	-2.1	-1.1	-1.1	-1.2	-1.1	-1.1	-1.1	-1.1	-1.5	-1.3	2.7	1.7	-4.2	2.6	-1.4	-1.1	-1.5	-1.4	-2.1	1.5	5.1
2	20040624	T3OC	3.663	11.49	2.6	-1.3	-1.5	2.0	-1.1	3.4	2.1	2.0	-1.3	-0.9	-0.9	1.3	-6.0	-1.4	5.2	2.5	6.6	2.6	4.0	11.5	-6.0	-1.3	-1.1	6.0	8.9
2	20050906	blankOC			-0.1	-0.2	-0.3	-0.2	-0.2	-0.1	-0.2	-0.4	-0.2	-0.2	-0.4	-0.3	-0.7	-0.2	-0.5	-0.3	-0.8	-0.1	-0.2	-0.4	-0.7	-0.2	-0.2	-0.4	-0.5
2	20050906	T1OC	3.667	10.48	3.4	-0.6	0.8	0.7	-0.1	-0.8	0.8	0.8	-0.5	-0.4	-0.8	-0.5	-1.0	0.3	0.9	-0.6	2.3	19.9	5.0	1.6	0.3	1.5	-0.1	-0.8	0.9
2	20050907	T2OC	4.438	10.59	2.1	-0.5	0.7	-2.3	-0.1	1.0	0.5	-0.7	-0.1	-0.3	0.5	-0.5	0.9	-0.3	0.9	0.6	2.3	18.1	2.9	2.4	0.9	0.6	0.8	-0.1	2.2
2	20050908	T3OC	4.243	10.85	-0.9	-0.2	0.6	-2.0	-0.1	1.0	1.0	0.8	0.5	-0.2	-1.0	-0.3	1.6	0.5	1.1	-1.0	2.0	9.3	1.6	4.9	3.1	-0.2	-0.1	-1.0	2.2
3	20031031	blank			-0.4	-0.4	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-4.2	-4.2	-0.4	-0.8	-0.8	-0.8	-0.4	-0.8	-0.8	-0.8
3	20031031	Run1	4.484	10.8	9.8	-1.1	3.5	6.6	4.8	10.9	6.8	3.1	5.7	-3.3	21.9	7.4	24.0	-6.6	155.2	14.2	214.2	87.4	100.6	91.8	24.0	56.8	161.8	393.5	371.6
3	20031103	Run2	4.458	10.6	9.5	-0.4	3.4	5.6	4.1	4.5	5.2	1.8	0.6	4.7	17.5	8.2	23.7	2.4	207.0	10.1	258.7	112.1	92.7	53.9	41.8	60.4	155.2	409.6	388.1
3	20031104	Run3	4.476	9.9	4.4	-0.4	4.0	5.6	2.4	12.9	5.4	-0.8	5.2	3.4	14.3	7.2	22.1	-1.6	168.9	6.2	221.2	110.6	86.5	55.9	28.2	62.3	174.9	382.0	321.7
3	20050802	blank			-0.4	-0.4	-0.8	1.2	1.7	-0.8	-0.8	-0.8	1.1	-0.8	1.3	1.1	1.4	-0.8	5.8	-2.9	4.4	10.2	4.8	5.0	2.9	48.0	30.7	34.6	10.9
3	20050802	Run1	5.893	12.4	0.5	0.5	1.2	2.2	2.4	2.6	1.8	0.8	3.0	2.4	5.1	4.0	8.7	-0.8	27.7	-3.0	41.5	16.2	16.0	25.7	11.1	61.3	57.3	100.8	53.4
3	20050803	Run2	5.51	10.9	0.8	-0.4	0.9	2.0	1.7	1.7	1.3	-0.7	2.2	1.3	3.6	2.7	5.7	-0.7	23.4	2.9	35.9	28.7	9.5	15.8	8.4	43.1	43.1	70.1	52.1
3	20050804	Run3	5.917	12.6	0.5	0.5	1.1	3.6	4.0	2.2	2.2	-0.8	3.2	3.0	5.4	4.4	6.2	-0.8	30.2	-3.0	38.3	22.2	22.2	24.2	8.9	76.6	66.5	96.8	60.5
4	20060502	blank			-0.9	-0.9	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-6.9	-6.9	-0.9	4.6	-1.8	-1.8	10.6	-1.8	20.2	10.1
4	20060502	Run1	3.2492	14	11.9	16.3	19.9	23.8	9.7	13.2	12.4	0.8	11.0	2.7	4.3	3.0	12.8	1.9	16.3	-6.6	19.9	662.4	357.7	132.5	21.2	1413.1	366.5	114.8	31.4
4	20060503	Run2	3.1964	14.3	103.2	89.2	98.5	126.7	107.9	79.8	61.0	3.8	51.6	28.6	61.0	51.6	70.4	8.9	150.2	9.9	61.0	380.1	1783.3	657.0	98.5	6569.9	2440.2	1032.4	328.5
4	20060504	Run3	3.116	14.1	36.0	20.1	31.8	74.8	18.2	29.0	21.0	-1.9	19.6	3.6	7.5	5.1	15.0	2.7	13.5	-7.0	11.2	934.5	560.7	224.3	21.5	1728.7	560.7	285.0	29.4
5	20021023	blank			0.3	-0.1	-0.1	-0.1	0.7	0.3	-0.1	0.2	-0.1	0.2	0.2	-0.1	-0.4	-0.6	1.5	1.0	4.1	0.4	-0.1	1.0	-0.5	1.6	1.1	2.0	2.1
5	20021023	Run1	4.075	13.9	10.6	0.4	3.1	5.6	1.4	14.5	6.5	17.8	1.3	0.7	1.3	1.4	44.3	22.6	13.3	131.2	33.6	47.3	51.8	77.6	118.0	28.0	12.5	17.9	22.4
5	20021024	Run2	3.894	13.9	38.7	0.9	11.1	21.6	2.6	54.0	27.8	51.7	7.0	3.1	6.1	5.6	130.1	68.7	72.3	368.1	182.6	189.2	186.3	257.8	331.7	27.2	25.5	73.1	118.8
5	20021025	Run3	4.043	14.8	67.6	3.7	17.0	37.3	7.8	120.9	44.5	103.3	6.3	9.8	12.6	28.1	256.2	88.2	118.3	332.1	193.4	372.1	378.2	535.7	524.2	86.5	73.9	171.0	198.4

Table 9.3 LOQ Values Derived from Test Data and I-TEF [pg/Rm^3 @ 11% Oxygen Basis]

Facility			Sample Specifics		TCDF2378	TCDD2378	PCDF1	PCDF4	PCDD1	HXCDF14	HXCDF16	HXCDF46	HXCDF19	HXCDD14	HXCDD16	HXCDD19	HPCDF146	HPCDF149	HPCDD146	OCDF	OCDD
	ITEQ				0.1	1	0.05	0.5	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	0.01	0.01	0.001	0.001
	WHO98				0.1	1	0.05	0.5	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	0.01	0.01	0.0001	0.0001
	Date	Sample	Volume	Oxygen																	
			[Rm^3]	[%]																	
1	10232000	Blank			24.57	2.46	49.14	4.91	4.91	24.57	24.57	24.57	24.57	24.57	24.57	24.57	245.71	245.71	245.71	2457.10	2457.10
1	10232000	T1OC	5.061	10.6	25.31	2.53	50.61	5.06	5.06	25.31	25.31	25.31	25.31	25.31	25.31	25.31	253.05	253.05	253.05	2530.50	2530.50
1	10242000	T2OC	5.085	10.7	25.43	2.54	50.85	5.09	5.09	25.43	25.43	25.43	25.43	25.43	25.43	25.43	254.25	254.25	254.25	2542.50	2542.50
1	10252000	T3OC	5.093	10.7	25.47	2.55	50.93	5.09	5.09	25.47	25.47	25.47	25.47	25.47	25.47	25.47	254.65	254.65	254.65	2546.50	2546.50
1	11192001	blankOC			26.47	2.65	52.93	5.29	5.29	26.47	26.47	26.47	26.47	26.47	26.47	26.47	264.67	264.67	264.67	2646.67	2646.67
1	11192001	T1OC	5.047	11.07	25.24	2.52	50.47	5.05	5.05	25.24	25.24	25.24	25.24	25.24	25.24	25.24	252.35	252.35	252.35	2523.50	2523.50
1	11202001	T2OC	5.388	11.17	26.94	2.69	53.88	5.39	5.39	26.94	26.94	26.94	26.94	26.94	26.94	26.94	269.40	269.40	269.40	2694.00	2694.00
1	11212001	T3OC	5.445	10.76	27.23	2.72	54.45	5.45	5.45	27.23	27.23	27.23	27.23	27.23	27.23	27.23	272.25	272.25	272.25	2722.50	2722.50
1	9232002	blankOC			30.77	3.08	61.54	6.15	6.15	30.77	30.77	30.77	30.77	30.77	30.77	30.77	307.68	307.68	307.68	3076.78	3076.78
1	9232002	T1OC	5.792	11.4	28.96	2.90	57.92	5.79	5.79	28.96	28.96	28.96	28.96	28.96	28.96	28.96	289.60	289.60	289.60	2896.00	2896.00
1	9242002	T2OC	5.82	11.6	29.10	2.91	58.20	5.82	5.82	29.10	29.10	29.10	29.10	29.10	29.10	29.10	291.00	291.00	291.00	2910.00	2910.00
1	9252002	T3OC	5.792	11.7	28.96	2.90	57.92	5.79	5.79	28.96	28.96	28.96	28.96	28.96	28.96	28.96	289.60	289.60	289.60	2896.00	2896.00
1	9232003	blankOC			25.88	2.59	51.75	5.18	5.18	25.88	25.88	25.88	25.88	25.88	25.88	25.88	258.77	258.77	258.77	2587.71	2587.71
1	9232003	T1OC	5.154	10.9	25.77	2.58	51.54	5.15	5.15	25.77	25.77	25.77	25.77	25.77	25.77	25.77	257.70	257.70	257.70	2577.00	2577.00
1	9242003	T2OC	5.145	11.3	25.73	2.57	51.45	5.15	5.15	25.73	25.73	25.73	25.73	25.73	25.73	25.73	257.25	257.25	257.25	2572.50	2572.50
1	9252003	T3OC	5.175	10.9	25.88	2.59	51.75	5.18	5.18	25.88	25.88	25.88	25.88	25.88	25.88	25.88	258.75	258.75	258.75	2587.50	2587.50
1	9202004	blankOC			23.66	2.37	47.33	4.73	4.73	23.66	23.66	23.66	23.66	23.66	23.66	23.66	236.64	236.64	236.64	2366.36	2366.36
1	9202004	T1OC	4.825	10.9	24.13	2.41	48.25	4.83	4.83	24.13	24.13	24.13	24.13	24.13	24.13	24.13	241.25	241.25	241.25	2412.50	2412.50
1	9212004	T2OC	4.866	10.9	24.33	2.43	48.66	4.87	4.87	24.33	24.33	24.33	24.33	24.33	24.33	24.33	243.30	243.30	243.30	2433.00	2433.00
1	9222004	T3OC	4.794	10.6	23.97	2.40	47.94	4.79	4.79	23.97	23.97	23.97	23.97	23.97	23.97	23.97	239.70	239.70	239.70	2397.00	2397.00
1	10112005	blankOC			30.02	3.00	60.03	6.00	6.00	30.02	30.02	30.02	30.02	30.02	30.02	30.02	300.15	300.15	300.15	3001.53	3001.53
1	10112005	T1OC	5.461	12.1	27.31	2.73	54.61	5.46	5.46	27.31	27.31	27.31	27.31	27.31	27.31	27.31	273.05	273.05	273.05	2730.50	2730.50
1	10122005	T2OC	5.458	11.7	27.29	2.73	54.58	5.46	5.46	27.29	27.29	27.29	27.29	27.29	27.29	27.29	272.90	272.90	272.90	2729.00	2729.00
1	10132005	T3OC	5.453	11.9	27.27	2.73	54.53	5.45	5.45	27.27	27.27	27.27	27.27	27.27	27.27	27.27	272.65	272.65	272.65	2726.50	2726.50
2	20021219	blankOC			15.12	1.51	30.23	3.02	3.02	15.12	15.12	15.12	15.12	15.12	15.12	15.12	151.16	151.16	151.16	1511.62	1511.62
2	20021217	T1OC	3.75	8.05	18.75	1.88	37.50	3.75	3.75	18.75	18.75	18.75	18.75	18.75	18.75	18.75	187.50	187.50	187.50	1875.00	1875.00
2	20021218	T2OC	4.23	7.8	21.15	2.12	42.30	4.23	4.23	21.15	21.15	21.15	21.15	21.15	21.15	21.15	211.50	211.50	211.50	2115.00	2115.00
2	20021219	T3OC	3.89	7.98	19.45	1.95	38.90	3.89	3.89	19.45	19.45	19.45	19.45	19.45	19.45	19.45	194.50	194.50	194.50	1945.00	1945.00
2	20040622	blankOC			20.04	2.00	40.07	4.01	4.01	20.04	20.04	20.04	20.04	20.04	20.04	20.04	200.37	200.37	200.37	2003.71	2003.71
2	20040622	T1OC	3.538	13.54	17.69	1.77	35.38	3.54	3.54	17.69	17.69	17.69	17.69	17.69	17.69	17.69	176.90	176.90	176.90	1769.00	1769.00
2	20040623	T2OC	3.445	11.37	17.23	1.72	34.45	3.45	3.45	17.23	17.23	17.23	17.23	17.23	17.23	17.23	172.25	172.25	172.25	1722.50	1722.50
2	20040624	T3OC	3.663	11.49	18.32	1.83	36.63	3.66	3.66	18.32	18.32	18.32	18.32	18.32	18.32	18.32	183.15	183.15	183.15	1831.50	1831.50
2	20050906	blankOC			19.86	1.99	39.72	3.97	3.97	19.86	19.86	19.86	19.86	19.86	19.86	19.86	198.58	198.58	198.58	1985.79	1985.79
2	20050906	T1OC	3.667	10.48	18.34	1.83	36.67	3.67	3.67	18.34	18.34	18.34	18.34	18.34	18.34	18.34	183.35	183.35	183.35	1833.50	1833.50
2	20050907	T2OC	4.438	10.59	22.19	2.22	44.38	4.44	4.44	22.19	22.19	22.19	22.19	22.19	22.19	22.19	221.90	221.90	221.90	2219.00	2219.00
2	20050908	T3OC	4.243	10.85	21.22	2.12	42.43	4.24	4.24	21.22	21.22	21.22	21.22	21.22	21.22	21.22	212.15	212.15	212.15	2121.50	2121.50
3	20031031	blank			21.15	2.12	42.31	4.23	4.23	21.15	21.15	21.15	21.15	21.15	21.15	21.15	211.53	211.53	211.53	2115.26	2115.26
3	20031031	Run1	4.484	10.8	22.42	2.24	44.84	4.48	4.48	22.42	22.42	22.42	22.42	22.42	22.42	22.42	224.20	224.20	224.20	2242.00	2242.00
3	20031103	Run2	4.458	10.6	22.29	2.23	44.58	4.46	4.46	22.29	22.29	22.29	22.29	22.29	22.29	22.29	222.90	222.90	222.90	2229.00	2229.00
3	20031104	Run3	4.476	9.9	22.38	2.24	44.76	4.48	4.48	22.38	22.38	22.38	22.38	22.38	22.38	22.38	223.80	223.80	223.80	2238.00	2238.00
3	20050802	blank			31.99	3.20	63.98	6.40	6.40	31.99	31.99	31.99	31.99	31.99	31.99	31.99	319.90	319.90	319.90	3199.03	3199.03
3	20050802	Run1	5.893	12.4	29.47	2.95	58.93	5.89	5.89	29.47	29.47	29.47	29.47	29.47	29.47	29.47	294.65	294.65	294.65	2946.50	2946.50
3	20050803	Run2	5.51	10.9	27.55	2.76	55.10	5.51	5.51	27.55	27.55	27.55	27.55	27.55	27.55	27.55	275.50	275.50	275.50	2755.00	2755.00
3	20050804	Run3	5.917	12.6	29.59	2.96	59.17	5.92	5.92	29.59	29.59	29.59	29.59	29.59	29.59	29.59	295.85	295.85	295.85	2958.50	2958.50
4	20060502	blank			23.32	2.33	46.63	4.66	4.66	23.32	23.32	23.32	23.32	23.32	23.32	23.32	233.15	233.15	233.15	2331.52	2331.52
4	20060502	Run1	3.2492	14	16.25	1.62	32.49	3.25	3.25	16.25	16.25	16.25	16.25	16.25	16.25	16.25	162.46	162.46	162.46	1624.60	1624.60
4	20060503	Run2	3.1964	14.3	15.98	1.60	31.96	3.20	3.20	15.98	15.98	15.98	15.98	15.98	15.98	15.98	159.82	159.82	159.82	1598.20	1598.20
4	20060504	Run3	3.116	14.1	15.58	1.56	31.16	3.12	3.12	15.58	15.58	15.58	15.58	15.58	15.58	15.58	155.80	155.80	155.80	1558.00	1558.00
5	20021023	blank			29.58	2.96	59.16	5.92	5.92	29.58	29.58	29.58	29.58	29.58	29.58	29.58	295.82	295.82	295.82	2958.18	2958.18
5	20021023	Run1	4.075	13.9	20.38	2.04	40.75	4.08	4.08	20.38	20.38	20.38	20.38	20.38	20.38	20.38	203.75	203.75	203.75	2037.50	2037.50
5	20021024	Run2	3.894	13.9	19.47	1.95	38.94	3.89	3.89	19.47	19.47	19.47	19.47	19.47	19.47	19.47	194.70	194.70	194.70	1947.00	1947.00
5	20021025	Run3	4.043	14.8	20.22	2.02	40.43	4.04	4.04	20.22	20.22	20.22	20.22	20.22	20.22	20.22	202.15	202.15	202.15	2021.50	2021.50

Table 9.4 LOQ Values Derived from Test Data and WHO98-TEF [pg/Rm^3 @ 11% Oxygen Basis]

Facility			Sample Specifics		TCDF2378	TCDD2378	PCDF1	PCDF4	PCDD1	HXCDF14	HXCDF16	HXCDF46	HXCDF19	HXCDD14	HXCDD16	HXCDD19	HPCDF146	HPCDF149	HPCDD146	OCDF	OCDD
	ITEQ				0.1	1	0.05	0.5	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	0.01	0.01	0.001	0.001
	WHO98				0.1	1	0.05	0.5	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	0.01	0.01	0.0001	0.0001
	Date	Sample	Volume	Oxygen																	
			[Rm^3]	[%]																	
1	10232000	Blank			24.57	2.46	49.14	4.91	2.46	24.57	24.57	24.57	24.57	24.57	24.57	24.57	245.71	245.71	245.71	24571.03	24571.03
1	10232000	T1OC	5.061	10.6	25.31	2.53	50.61	5.06	2.53	25.31	25.31	25.31	25.31	25.31	25.31	25.31	253.05	253.05	253.05	25305.00	25305.00
1	10242000	T2OC	5.085	10.7	25.43	2.54	50.85	5.09	2.54	25.43	25.43	25.43	25.43	25.43	25.43	25.43	254.25	254.25	254.25	25425.00	25425.00
1	10252000	T3OC	5.093	10.7	25.47	2.55	50.93	5.09	2.55	25.47	25.47	25.47	25.47	25.47	25.47	25.47	254.65	254.65	254.65	25465.00	25465.00
1	11192001	blankOC			26.47	2.65	52.93	5.29	2.65	26.47	26.47	26.47	26.47	26.47	26.47	26.47	264.67	264.67	264.67	26466.67	26466.67
1	11192001	T1OC	5.047	11.07	25.24	2.52	50.47	5.05	2.52	25.24	25.24	25.24	25.24	25.24	25.24	25.24	252.35	252.35	252.35	25235.00	25235.00
1	11202001	T2OC	5.388	11.17	26.94	2.69	53.88	5.39	2.69	26.94	26.94	26.94	26.94	26.94	26.94	26.94	269.40	269.40	269.40	26940.00	26940.00
1	11212001	T3OC	5.445	10.76	27.23	2.72	54.45	5.45	2.72	27.23	27.23	27.23	27.23	27.23	27.23	27.23	272.25	272.25	272.25	27225.00	27225.00
1	9232002	blankOC			30.77	3.08	61.54	6.15	3.08	30.77	30.77	30.77	30.77	30.77	30.77	30.77	307.68	307.68	307.68	30767.79	30767.79
1	9232002	T1OC	5.792	11.4	28.96	2.90	57.92	5.79	2.90	28.96	28.96	28.96	28.96	28.96	28.96	28.96	289.60	289.60	289.60	28960.00	28960.00
1	9242002	T2OC	5.82	11.6	29.10	2.91	58.20	5.82	2.91	29.10	29.10	29.10	29.10	29.10	29.10	29.10	291.00	291.00	291.00	29100.00	29100.00
1	9252002	T3OC	5.792	11.7	28.96	2.90	57.92	5.79	2.90	28.96	28.96	28.96	28.96	28.96	28.96	28.96	289.60	289.60	289.60	28960.00	28960.00
1	9232003	blankOC			25.88	2.59	51.75	5.18	2.59	25.88	25.88	25.88	25.88	25.88	25.88	25.88	258.77	258.77	258.77	25877.13	25877.13
1	9232003	T1OC	5.154	10.9	25.77	2.58	51.54	5.15	2.58	25.77	25.77	25.77	25.77	25.77	25.77	25.77	257.70	257.70	257.70	25770.00	25770.00
1	9242003	T2OC	5.145	11.3	25.73	2.57	51.45	5.15	2.57	25.73	25.73	25.73	25.73	25.73	25.73	25.73	257.25	257.25	257.25	25725.00	25725.00
1	9252003	T3OC	5.175	10.9	25.88	2.59	51.75	5.18	2.59	25.88	25.88	25.88	25.88	25.88	25.88	25.88	258.75	258.75	258.75	25875.00	25875.00
1	9202004	blankOC			23.66	2.37	47.33	4.73	2.37	23.66	23.66	23.66	23.66	23.66	23.66	23.66	236.64	236.64	236.64	23663.61	23663.61
1	9202004	T1OC	4.825	10.9	24.13	2.41	48.25	4.83	2.41	24.13	24.13	24.13	24.13	24.13	24.13	24.13	241.25	241.25	241.25	24125.00	24125.00
1	9212004	T2OC	4.866	10.9	24.33	2.43	48.66	4.87	2.43	24.33	24.33	24.33	24.33	24.33	24.33	24.33	243.30	243.30	243.30	24330.00	24330.00
1	9222004	T3OC	4.794	10.6	23.97	2.40	47.94	4.79	2.40	23.97	23.97	23.97	23.97	23.97	23.97	23.97	239.70	239.70	239.70	23970.00	23970.00
1	10112005	blankOC			30.02	3.00	60.03	6.00	3.00	30.02	30.02	30.02	30.02	30.02	30.02	30.02	300.15	300.15	300.15	30015.33	30015.33
1	10112005	T1OC	5.461	12.1	27.31	2.73	54.61	5.46	2.73	27.31	27.31	27.31	27.31	27.31	27.31	27.31	273.05	273.05	273.05	27305.00	27305.00
1	10122005	T2OC	5.458	11.7	27.29	2.73	54.58	5.46	2.73	27.29	27.29	27.29	27.29	27.29	27.29	27.29	272.90	272.90	272.90	27290.00	27290.00
1	10132005	T3OC	5.453	11.9	27.27	2.73	54.53	5.45	2.73	27.27	27.27	27.27	27.27	27.27	27.27	27.27	272.65	272.65	272.65	27265.00	27265.00
2	20021219	blankOC			15.12	1.51	30.23	3.02	1.51	15.12	15.12	15.12	15.12	15.12	15.12	15.12	151.16	151.16	151.16	15116.16	15116.16
2	20021217	T1OC	3.75	8.05	18.75	1.88	37.50	3.75	1.88	18.75	18.75	18.75	18.75	18.75	18.75	18.75	187.50	187.50	187.50	18750.00	18750.00
2	20021218	T2OC	4.23	7.8	21.15	2.12	42.30	4.23	2.12	21.15	21.15	21.15	21.15	21.15	21.15	21.15	211.50	211.50	211.50	21150.00	21150.00
2	20021219	T3OC	3.89	7.98	19.45	1.95	38.90	3.89	1.95	19.45	19.45	19.45	19.45	19.45	19.45	19.45	194.50	194.50	194.50	19450.00	19450.00
2	20040622	blankOC			20.04	2.00	40.07	4.01	2.00	20.04	20.04	20.04	20.04	20.04	20.04	20.04	200.37	200.37	200.37	20037.15	20037.15
2	20040622	T1OC	3.538	13.54	17.69	1.77	35.38	3.54	1.77	17.69	17.69	17.69	17.69	17.69	17.69	17.69	176.90	176.90	176.90	17690.00	17690.00
2	20040623	T2OC	3.445	11.37	17.23	1.72	34.45	3.45	1.72	17.23	17.23	17.23	17.23	17.23	17.23	17.23	172.25	172.25	172.25	17225.00	17225.00
2	20040624	T3OC	3.663	11.49	18.32	1.83	36.63	3.66	1.83	18.32	18.32	18.32	18.32	18.32	18.32	18.32	183.15	183.15	183.15	18315.00	18315.00
2	20050906	blankOC			19.86	1.99	39.72	3.97	1.99	19.86	19.86	19.86	19.86	19.86	19.86	19.86	198.58	198.58	198.58	19857.89	19857.89
2	20050906	T1OC	3.667	10.48	18.34	1.83	36.67	3.67	1.83	18.34	18.34	18.34	18.34	18.34	18.34	18.34	183.35	183.35	183.35	18335.00	18335.00
2	20050907	T2OC	4.438	10.59	22.19	2.22	44.38	4.44	2.22	22.19	22.19	22.19	22.19	22.19	22.19	22.19	221.90	221.90	221.90	22190.00	22190.00
2	20050908	T3OC	4.243	10.85	21.22	2.12	42.43	4.24	2.12	21.22	21.22	21.22	21.22	21.22	21.22	21.22	212.15	212.15	212.15	21215.00	21215.00
3	20031031	blank			21.15	2.12	42.31	4.23	2.12	21.15	21.15	21.15	21.15	21.15	21.15	21.15	211.53	211.53	211.53	21152.58	21152.58
3	20031031	Run1	4.484	10.8	22.42	2.24	44.84	4.48	2.24	22.42	22.42	22.42	22.42	22.42	22.42	22.42	224.20	224.20	224.20	22420.00	22420.00
3	20031103	Run2	4.458	10.6	22.29	2.23	44.58	4.46	2.23	22.29	22.29	22.29	22.29	22.29	22.29	22.29	222.90	222.90	222.90	22290.00	22290.00
3	20031104	Run3	4.476	9.9	22.38	2.24	44.76	4.48	2.24	22.38	22.38	22.38	22.38	22.38	22.38	22.38	223.80	223.80	223.80	22380.00	22380.00
3	20050802	blank			31.99	3.20	63.98	6.40	3.20	31.99	31.99	31.99	31.99	31.99	31.99	31.99	319.90	319.90	319.90	31990.30	31990.30
3	20050802	Run1	5.893	12.4	29.47	2.95	58.93	5.89	2.95	29.47	29.47	29.47	29.47	29.47	29.47	29.47	294.65	294.65	294.65	29465.00	29465.00
3	20050803	Run2	5.51	10.9	27.55	2.76	55.10	5.51	2.76	27.55	27.55	27.55	27.55	27.55	27.55	27.55	275.50	275.50	275.50	27550.00	27550.00
3	20050804	Run3	5.917	12.6	29.59	2.96	59.17	5.92	2.96	29.59	29.59	29.59	29.59	29.59	29.59	29.59	295.85	295.85	295.85	29585.00	29585.00
4	20060502	blank			23.32	2.33	46.63	4.66	2.33	23.32	23.32	23.32	23.32	23.32	23.32	23.32	233.15	233.15	233.15	23315.23	23315.23
4	20060502	Run1	3.2492	14	16.25	1.62	32.49	3.25	1.62	16.25	16.25	16.25	16.25	16.25	16.25	16.25	162.46	162.46	162.46	16246.00	16246.00
4	20060503	Run2	3.1964	14.3	15.98	1.60	31.96	3.20	1.60	15.98	15.98	15.98	15.98	15.98	15.98	15.98	159.82	159.82	159.82	15982.00	15982.00
4	20060504	Run3	3.116	14.1	15.58	1.56	31.16	3.12	1.56	15.58	15.58	15.58	15.58	15.58	15.58	15.58	155.80	155.80	155.80	15580.00	15580.00
5	20021023	blank			29.58	2.96	59.16	5.92	2.96	29.58	29.58	29.58	29.58	29.58	29.58	29.58	295.82	295.82	295.82	29581.79	29581.79
5	20021023	Run1	4.075	13.9	20.38	2.04	40.75	4.08	2.04	20.38	20.38	20.38	20.38	20.38	20.38	20.38	203.75	203.75	203.75	20375.00	20375.00
5	20021024	Run2	3.894	13.9	19.47	1.95	38.94	3.89	1.95	19.47	19.47	19.47	19.47	19.47	19.47	19.47	194.70	194.70	194.70	19470.00	19470.00
5	20021025	Run3	4.043	14.8	20.22	2.02	40.43	4.04	2.02	20.22	20.22	20.22	20.22	20.22	20.22	20.22	202.15	202.15	202.15	20215.00	20215.00

Table 9.5 Stack Testing Data Total Emission as Toxic Equivalency Various Methods [pg/Rm^3 @ 11% Oxygen]

Facility	Date	Sample Specifics			Alternative Calculation Regimes					
		Sample	Volume [Rm^3]	Oxygen [%]	ITEQ <LOQ = O	WHO98 <LOQ = O	ITEQ LOQ Sub	WHO98 LOQ Sub	ITEQ DL	WHO98 DL
1	10232000	Blank			0.00	0.00	41.77	41.77	4.49	4.98
1	10232000	T1OC	5.061	10.6	485.62	537.84	495.74	547.96	488.99	540.25
1	10242000	T2OC	5.085	10.7	371.44	411.52	381.61	421.69	374.40	413.48
1	10252000	T3OC	5.093	10.7	228.31	253.08	241.04	265.81	237.35	261.38
1	11192001	blankOC			0.00	0.00	44.99	44.99	1.11	1.28
1	11192001	T1OC	5.047	11.07	6.09	9.88	46.46	47.73	18.32	20.02
1	11202001	T2OC	5.388	11.17	3.21	3.21	46.31	46.31	8.98	9.60
1	11212001	T3OC	5.445	10.76	0.00	0.00	46.28	46.28	5.65	6.07
1	9232002	blankOC			0.00	0.00	52.31	52.31	3.11	3.48
1	9232002	T1OC	5.792	11.4	0.00	0.00	49.23	49.23	5.27	5.70
1	9242002	T2OC	5.82	11.6	0.00	0.00	49.47	49.47	4.01	4.46
1	9252002	T3OC	5.792	11.7	0.00	0.00	49.23	49.23	6.20	6.78
1	9232003	blankOC			0.00	0.00	43.99	43.99	1.45	1.63
1	9232003	T1OC	5.154	10.9	0.00	0.00	43.81	43.81	5.55	5.99
1	9242003	T2OC	5.145	11.3	0.00	0.00	43.73	43.73	5.29	5.86
1	9252003	T3OC	5.175	10.9	0.00	0.00	43.99	43.99	4.80	5.24
1	9202004	blankOC			0.00	0.00	40.23	40.23	5.77	6.88
1	9202004	T1OC	4.825	10.9	0.00	0.00	41.01	41.01	8.31	9.62
1	9212004	T2OC	4.866	10.9	0.00	0.00	41.36	41.36	6.76	7.75
1	9222004	T3OC	4.794	10.6	0.00	0.00	40.75	40.75	10.14	11.21
1	10112005	blankOC			0.00	0.00	51.03	51.03	1.84	2.10
1	10112005	T1OC	5.461	12.1	0.00	0.00	46.42	46.42	3.59	4.03
1	10122005	T2OC	5.458	11.7	0.00	0.00	46.39	46.39	4.87	5.40
1	10132005	T3OC	5.453	11.9	0.00	0.00	46.35	46.35	4.12	4.55
2	20021219	blankOC			0.00	0.00	25.70	25.70	3.42	3.82
2	20021217	T1OC	3.75	8.05	0.00	0.00	31.88	31.88	4.25	4.65
2	20021218	T2OC	4.23	7.8	0.00	0.00	35.96	35.96	5.62	6.21
2	20021219	T3OC	3.89	7.98	0.00	0.00	33.07	33.07	6.49	7.32
2	20040622	blankOC			0.00	0.00	34.06	34.06	4.57	5.65
2	20040622	T1OC	3.538	13.54	0.00	0.00	30.07	30.07	6.51	7.76
2	20040623	T2OC	3.445	11.37	0.00	0.00	29.28	29.28	4.25	5.27
2	20040624	T3OC	3.663	11.49	0.00	0.00	31.14	31.14	4.55	5.12
2	20050906	blankOC			0.00	0.00	33.76	33.76	0.63	0.72
2	20050906	T1OC	3.667	10.48	0.00	0.00	31.17	31.17	1.84	1.91
2	20050907	T2OC	4.438	10.59	0.00	0.00	37.72	37.72	2.33	2.38
2	20050908	T3OC	4.243	10.85	0.00	0.00	36.07	36.07	1.86	1.91
3	20031031	blank			0.00	0.00	35.96	35.96	1.98	2.39
3	20031031	Run1	4.484	10.8	5.68	8.09	39.31	41.72	15.92	18.12
3	20031103	Run2	4.458	10.6	2.80	6.90	38.47	40.33	13.25	15.06
3	20031104	Run3	4.476	9.9	2.82	5.23	38.62	38.80	12.15	13.15
3	20050802	blank			0.00	0.00	54.38	54.38	2.70	3.55
3	20050802	Run1	5.893	12.4	0.00	0.00	50.09	50.09	5.24	6.38
3	20050803	Run2	5.51	10.9	0.00	0.00	46.84	46.84	4.02	4.85
3	20050804	Run3	5.917	12.6	0.00	4.03	50.29	51.37	6.95	8.93
4	20060502	blank			0.00	0.00	39.64	39.64	4.29	5.20
4	20060502	Run1	3.2492	14	33.12	37.98	55.86	60.72	40.39	45.23
4	20060503	Run2	3.1964	14.3	255.10	309.07	264.69	318.66	257.84	311.74
4	20060504	Run3	3.116	14.1	78.73	87.84	92.75	101.86	80.86	89.96
5	20021023	blank			0.00	0.00	50.29	50.29	0.78	1.14
5	20021023	Run1	4.075	13.9	2.81	2.81	35.41	35.41	10.48	11.05
5	20021024	Run2	3.894	13.9	28.04	30.62	51.40	52.03	36.23	37.03
5	20021025	Run3	4.043	14.8	65.22	69.12	81.40	85.29	71.54	74.96

Table 9.6 Percentage Increase Produced by Using WHO98-TEF

Facility	Date	Sample	Impact of TEF Scheme [% Increase]		
			LOQ = 0	LOQ Sub	DL
1	10232000	Blank		0	11
1	10232000	T1OC	11	11	10
1	10242000	T2OC	11	11	10
1	10252000	T3OC	11	10	10
1	11192001	blankOC		0	16
1	11192001	T1OC	62	3	9
1	11202001	T2OC	0	0	7
1	11212001	T3OC		0	8
1	9232002	blankOC		0	12
1	9232002	T1OC		0	8
1	9242002	T2OC		0	11
1	9252002	T3OC		0	9
1	9232003	blankOC		0	12
1	9232003	T1OC		0	8
1	9242003	T2OC		0	11
1	9252003	T3OC		0	9
1	9202004	blankOC		0	19
1	9202004	T1OC		0	16
1	9212004	T2OC		0	15
1	9222004	T3OC		0	11
1	10112005	blankOC		0	15
1	10112005	T1OC		0	12
1	10122005	T2OC		0	11
1	10132005	T3OC		0	10
2	20021219	blankOC		0	11
2	20021217	T1OC		0	10
2	20021218	T2OC		0	10
2	20021219	T3OC		0	13
2	20040622	blankOC		0	24
2	20040622	T1OC		0	19
2	20040623	T2OC		0	24
2	20040624	T3OC		0	12
2	20050906	blankOC		0	15
2	20050906	T1OC		0	3
2	20050907	T2OC		0	2
2	20050908	T3OC		0	3
3	20031031	blank		0	21
3	20031031	Run1	42	6	14
3	20031103	Run2	146	5	14
3	20031104	Run3	86	0	8
3	20050802	blank		0	32
3	20050802	Run1		0	22
3	20050803	Run2		0	21
3	20050804	Run3		2	28
4	20060502	blank		0	21
4	20060502	Run1	15	9	12
4	20060503	Run2	21	20	21
4	20060504	Run3	12	10	11
5	20021023	blank		0	47
5	20021023	Run1	0	0	5
5	20021024	Run2	9	1	2
5	20021025	Run3	6	5	5

9.2 Affect of Applying Different Treatments for Low Concentration Data

A review of Table 9.5 shows that, for most of the test data, the substitution of zero for the less than detect values effectively reduces PCDD/F emissions to zero. Comparing these values to those determined with the DL values substituted shows that all the tests that would be reported as zero using the zero value for the LOQ substitution would have been listed as being below the Environment Canada LOQ and thus would not have to be reported as part of the NPRI reporting function. This would clearly address much of the confusion that arises in the minds of the public when they see variations in the reported concentrations at this level and try to read some significance into the changes. Given the uncertainty in any of the data at this concentration level, there is no statistically significant difference in the reported values. For those tests that returned high concentrations, there is little difference between the LOQ zero substitution and the DL substitution values. The minor difference results from high LOQ values for some of the higher chlorinated species due to their lower TEF values. HPCDF149 and OCDD and OCDF are the congeners affected by this switch in the data for facility 1 in 2000.

The LOQ substitution results in an increase in the TEQ values under both TEF schemes when compared to the existing reporting procedure. Single digit concentration values now are reported in the range of 50 pg with the LOQ substitution, significantly raising the concentrations reported. Two observations on this apparent flaw in the approach. Because the LOQ substitution has the same impact on the Blank Train data as it does on the actual sampled concentrations, the Blank Train values are similar to the train values and it may be necessary to look at correcting the sampling results for the background that might be present in all the samples. Secondly, increasing the sampling time would reduce the LOQ value so operators would have a way of reducing the reported concentrations.

Clearly, the LOQ substitution has both advantages and disadvantages and adopting a revised protocol would require some explanation of why the changes are required.

9.3 Affect of Applying WHO_{98}-TEF

Table 9.6 shows that for a majority of tests there is little difference in the reported values when the zero substitution is used for low concentration values. The blank cells are created because both values were zero for these tests. The range of changes in the LOQ=0 column vary over a large range. The first series of tests for facility 1 show an 11% increase, but individual increases in this column are as large as 146%. This occurs because of the changes in the TEF factor for PCDD1. Facility 4 shows an average increase of 16%, facility 5 increased by 5%.

The affect of the change in TEF protocols when the LOQ substitution is used is similar to that seen in the LOQ=0 column. One trend that is not evident in the LOQ Sub column is the rather sharp changes introduced by the change in TEF factors in the LOQ=0 column. With the exception of one test, all the percentage increases are less than 11%.

The impact of the TEF change on the data produced with the DL substitutions shows that the changes range from 2 - 28% excluding the blank train data. The averages for the various tests are generally in the range of 10% however on change in the second series at facility 3 was 24% and several test series changed by 14 - 18%. These results seem to confirm, that if the DL substitution is used the impact of the change in TEF factors will be less than 15%.

Of course, if there is a desire to change the TEF factor approach, the Environment Canada LOQ will need to be changed to agree with the new approach, or conversely, the EN1948 approach could be adopted. The latter might have the effect of driving a demand for longer sampling periods and thus lower substitution values.

10.0 FINDINGS and CONCLUSIONS

The Canada Wide Standard for Dioxins and Furans focussed upon anthropogenic sources of PCDD/F emissions to the Canadian environment and set standards so the country could move towards the target of virtual elimination of these substances. In the late 1990s, testing data from a limited number of waste incinerators suggested that the sector could be contributing a significant portion of the total PCDD/F released in Canada. Thus, the incinerator sector was targeted as one of six priority sectors under the Standard. Included in that Standard was a requirement that progress towards the goal of reducing PCDD/F be evaluated on a periodic basis. This report forms part of that progress review and addresses:

- the national inventory of incinerator sources and their emissions;
- the CWS PCDD/F standard with respect to regulations in other jurisdictions; and,
- whether alternative ways of expressing emission criteria are required and the potential effect such changes might have on operating sources.

In the course of preparing information to complete the review, it was necessary to document:

- the incineration and air pollution control equipment employed by the operators;
- the contribution of waste streams other than air emissions on PCDD/F emissions;
- the methods that are used to judge performance of sources in other jurisdictions and their potential limitations; and,
- the implications of alternative thermal processes for waste destruction.

Furthermore, it was necessary to collect information concerning operating incinerators to assemble an up to date inventory of incinerator sources. It was found that, of the 188 incinerators operating in 2000, 80 had been removed from service. This includes 67 hospital incinerators that were shutdown, the majority in Ontario where they were replaced by one new, state-of-the-art facility. Two MSW incinerators were shutdown, because the local government in both cases decided the units were too old to refurbish to meet the new CWS standard. One of these units accounted for a significant portion of the estimated emissions from that sector. A sewage sludge incinerator was shut down in Toronto as the City moved towards a 100% beneficial use program. Many incinerators located at federal establishments have ceased operation, and information suggests that others in this category have had their throughput severely curtailed. However, this study identified additional incinerators operating at federal establishments. It appears that the net reduction in the number of incinerators operated by federal entities is 32.

During the course of the study, it was identified that 22 new incinerators had been installed at remote mining and exploration camps to address the need for safe waste disposal in these areas. Most of these are located in northern Canada where landfilling is not a practical option for waste management. These units, some servicing relatively large camps, dispose of considerable amounts of waste on a daily basis. Another group of incinerators were identified as being installed to service various industrial and commercial interests in Alberta, but it was not ascertained whether this trend has occurred in other provinces. Most of these new units are batch

type incinerators designed with a primary and secondary chamber the latter being equipped with a temperature controlled secondary burner. None are equipped with HRSGs and few have been installed with APC equipment. Regardless of the lack of APC equipment on these units, limited test data suggests that their emissions would meet the CWS standard. Good combustion control in these units and an afterburner ensure minimal quantities of products of incomplete combustion are released. High stack temperatures, well in excess of the *de novo* synthesis window, limit the possibility of this reaction increasing emissions.

Clearly, with the number of older units in the incinerator population being reduced, and control measures being introduced on other systems, most provinces have experienced a reduction in PCDD/F emissions from incinerators. The addition of newly identified facilities in some provinces has raised their total emissions. In Manitoba, where it appears that most of the hospital incinerator population is still operating, there has been less change than in the other provinces.

Commercial waste incinerators, those burning MSW and medical waste, have been upgraded to meet the CWS. Most of this occurred shortly after the Standard was adopted, and monitoring data consistently shows most of these facilities to be recording emission concentrations that are below the 32 pg I-TEQ/Rm^3 @ 11% O_2 level of quantification standard defined by Environment Canada as satisfactorily proving virtual elimination for that source. Large commercial hazardous waste incinerators did not meet the CWS standard as early as the MSW incinerators. Three of the 6 major hazardous waste incinerators listed in a September 2004 report had test data below the CWS target. Further data is yet to be evaluated.

This review has shown that there is uncertainty in the reported PCDD/F values but even assuming the worst case, commercial MSW and medical waste incinerators are below the CWS standard. If the reported data were assumed to be subject to a positive bias, the hazardous waste incinerator performance might be satisfactory to meet the CWS.

The sampling and analysis methods used in Canada are comparable to those used in Europe. The latter methods were recently updated by the European Normalisation Commission and can be assumed to reflect the best available techniques for ensuring representative emission concentrations are reported. The methods provide an alternative way of determining the level of quantification in a sample based upon reviewing the congener data provided by the analytical laboratory. With this approach the contribution of specific congeners is included or omitted depending upon the quantity determined in the analysis and the calculation of the I-TEQ values is determined on two different distributions. This clearly shows the potential impact of using detection limit/quantification limit values in the equivalency calculation and overcomes some of the inconsistencies with the way the results are presented.

Similar regulatory standards are applied to incinerators in most jurisdictions. These standards are applied regardless of the waste the incinerator is burning, or the size of the incinerator, with the exception of some low volume cut-off points for application of the regulations. Exceptions to this finding are found in the United States of America where different types of incinerators are

subject to different standards, and in Japan where a sliding scale of allowable emissions based upon size is applied. In the United States, the standards were set on the basis of the MACT protocol where the best 12% of the existing population were used to set the standard. In Japan, there appears to be a recognition of the cost effectiveness of adding more sophisticated controls to larger facilities as the allowable concentration is reduced as the size increases.

Canada's Canada-wide Standards for PCDD/F are the most stringent in any national legislation. To date, it does not appear that any country has moved towards adoption of the WHO_{98} TEF factors in their national legislation; however, given the uncertainty in PCDD/F measurements, and the limited impact that the revised TEFs would have on the total WHO_{98}-TEQ value for most operating facilities, its implementation should have little repercussion on operating facilities.

Large facilities in Canada are required to routinely monitor the stack emissions of PCDD/F according to the CWS. Provinces have the option to allow testing frequency to be changed after a considerable period of reported concentrations below the 32 pg I-TEQ/Rm^3 LOQ level defined by Environment Canada. The CWS requires that this value be determined using detection level values for congeners that are not quantified during the analytical procedure. The CWS defines a different approach to testing small facilities. These are classified as those burning less than 26 Mg per year. These units are required to "make determined efforts" to achieve the CWS targets, and it is suggested that this should include a one time test to show that they indeed do meet these standards (see *Determined Efforts*). This requirement is particularly onerous for operators who have smaller incinerators located at sites that are frequently only accessible by float or ski equipped aircraft. As such there is little available emission data from these types of incinerators.

The division between large and small incinerators included in the existing CWS was chosen to encourage that more attention be paid to the larger incinerators that had the potential for higher annual emissions. As can be seen by the data in Chapter 8, the large incinerators seem to have lowered their emissions significantly.

Unfortunately, the existing designation 26 Mg/year throughput cut-off has the potential to leave 17 incinerators in camps located on federal lands, 14 incinerators in hospitals, and 10 incinerators operated by federal entities in the group requiring annual testing. While those at hospitals and at federal establishments are readily accessible, those in mining camps are not. The cost of testing a facility is on the order of $25,000 each per year, provided the testing contractor is located in the same town. Travel costs add to the testing budget and, when travel requires the testing crew to fly into a remote mining site, costs could easily double to $50,000 per year.

Small MSW incinerators typically operate for between 80-90% of the hours in a year. At this rate, a 3 Mg/day unit could process between 875 and985 Mg/year of waste. This would serve a population of 3,000 people given the typical per capita waste generation rates, although if the location was rural and disproportionate quantities of packaging were also found in the waste stream, this size might be too small. At a testing cost of $25,000 per year translates to adding approximately $25/Mg of waste disposed annually, more if the site is remote and travel costs are

high. This would appear to be very expensive for many small communities. If this practice were required, and enforced, communities might think twice about installing incinerators to dispose of their waste. Since burning is the most viable way for remote northern communities to dispose of waste, this requirement could see communities continue to use open burning as their only viable option. Open burning has the potential to generate much higher PCDD/F emissions than controlled incineration and must be discouraged. This suggests that other options for addressing good operation of incinerators should be considered.

This study has identified that a major limitation in the data available from many of the facilities that do not charge a tipping fee is the lack of consistency in defining how much waste is charged to the furnace. This leads many facilities to try to rationalize their status as a small facility, <26 Mg/year, on the basis of that the facilities are used infrequently, even though the incinerator's rated capacity would suggest that the facility could burn considerably more than 26 Mg/yr or 500 kg/week or 70 kg/day.

Typically, small batch incinerators, designated by their hourly burn capacity, will accept between 70 and 210 kg of waste per batch, operate for 2 -3 hours on each batch, and can be cycled anywhere from 3 to 6 times per day. This suggests that these systems could process 26 Mg/yr if the smallest unit was run once daily throughout the year but the same unit could process up to 156 Mg/yr if run at the maximum frequency. Considering the smallest unit is rated at 50 lb or 22 kg/hr burn rate, it is clear that many of these incinerators have the potential to exceed the "small" incinerator designation in the CWS.

The recommendations that follow provide, among others, suggestions to address alternatives to testing small incinerators to prove they are meeting the CWS.

11.0 RECOMMENDATIONS

11.1 Numerical Standard

As noted elsewhere in this report, large fee charging, commercial incinerators operating in the country currently meet, or are moving towards meeting the CWS PCDD/F emission standard. Given that the Canada-wide Standards for PCDD/F set the world's most stringent emission target:

> It is recommended that no further adjustment to the CWS PCDD/F numerical emission standards is necessary.

Furthermore, no changes need to be made in the definitions of waste incineration incorporated in the standard.

11.2 Applicability

To clearly enunciate the requirements defined by the standard, given the waste incineration definition:

> It is recommended that any system that thermally treats wastes for the purpose of disposal be subject to the Canada-wide Standards for PCDD/F.

Internationally new thermal destruction technologies are being employed in various countries. Japan has a number of gasification/melting furnace installations handling MSW. Each of these installations has an APC system similar to those currently employed in Canadian MSW incineration facilities. This results in the new systems being capable of meeting the same emission standards as conventional incinerators. To alleviate any misconceptions that new systems might be able to avoid installing air pollution control equipment:

> It is recommended that any new thermal destruction technology only be approved if the proponent can demonstrate that the system will meet the emission standard, either through the application of a suitable air pollution control system, or by submitting validated test data from a full scale facility operating in another jurisdiction. Full scale facilities are typically deemed to be in commercial operation, that is they are not large scale pilot facilities, or even proof of concept demonstration units.

The implementation of the CWS for PCDD/F from incinerators has been effective in reducing emissions to the atmosphere from large facilities, and has forced the closure of many smaller facilities that could not be viably upgraded to meet the standards. However, this study has identified a number of issues related to how the standard is currently implemented.

11.3 Annual Throughput Calculations

There is evidence that most small incinerator operators do not routinely record waste loads to their furnaces and thus the total waste processed in their facility is poorly defined. This results incinerators not being tested in the manner prescribed in the standard. While recommendations later in this chapter suggest weigh scales should be installed at all facilities, if this is not done, there is a need to standardise the way annual waste throughput is determined at facilities so facilities cannot slide under the criteria in the standards. Thus, in the absence of recorded weight information:

> It is recommended that the waste throughput used to classify the size of any small batch incinerator be based upon the design rated capacity of the specific incinerator.
>
> Furthermore, it is recommended that the number of batches assumed to be charged to the unit be based upon 24 divided by twice the manufacturer's cycle time for the unit in hours.

To clarify this approach, consider the typical small batch units that are designed to burn a batch in 2 -3 hours. These may require 1 hour to cool sufficiently after the burn to allow ash removal. After ash removal they can be recharged and the burn process is repeated. Larger batch units can have a burn time of 8 - 12 hours and require 5 - 8 hours before they have cooled down sufficiently to allow ash to be removed and a new charge loaded. Under the recommendations above, a unit rated at 70 kg/batch operating on a 4 hours cycle, could be run up to 6 times per day, but realistically it would be unlikely that it would be run more than 3 -4 times in any 24 hours. The total annual capacity would thus be: (24/4/2 = 3 batches/day x 365 days x 70 kg/batch = 767 Mg/year. A larger unit, burning say 1 Mg on a 14 hour cycle, could process (24/14/2 = 0.857 ≈ 1 batch/day or 365 Mg/year).

Larger incinerators, providing a disposal service based upon a tipping fee, should be classified on the basis of their annual waste receipts as recorded on the incoming scales used to bill the clients.

11.4 Site Disposal Capacity

The survey conducted for this study identified some sites that have installed several smaller incinerators to handle waste disposal. While these measures might respond to the need to transport such equipment to remote locations in a timely fashion, or provide more flexibility to their operation, the size of individual units should not used to categorise what measures are required to reduce incinerator emissions on a site. Rather the total disposal capacity installed on the site should be used. Thus:

> It is recommended that, for the purposes of defining the steps that an operator must take to ensure that the facility meets all the requirements of the CWS for PCDD/F, the total

installed incineration capacity on a given property be used.

This will result in new installations comprised of numerous small incinerators not being able to avoid the provisions of the CWS by claiming the units were below the 26 Mg/year threshold.

11.5 Implementation Measures

In Annex 1 of the CSW it is stated that there is a need to ensure that there is a level playing field that leads to the uniform application of the numeric standard across the country. Given the experiences over the intervening years, it is clear that this has been difficult to achieve. The current requirements under the CWS specify annual testing of all incinerators processing more than 26 Mg/year of waste. Furthermore, under the determined efforts clause, it is suggested that a one time proof of effectiveness testing should be conducted for smaller incinerators. As discussed in the Findings and Conclusions such testing could impose excessive operating costs on smaller installations. Such costs would only increase the further the community is located from the testing contractor's home base. As such, virtually no test data has been generated over the past five year for facilities other than the fee for service, commercial large facilities. Indeed, little information is available on the measures that have been taken to reduce PCDD/F emissions at smaller facilities that were identified in the 2000 inventory.

The limited amount of test data for new equipment presented in this report has shown that these two stage combustion systems can meet the CWS requirements without the installation of air pollution control equipment if they are operated in an appropriate manner. This provides an opportunity to encourage the use of good incineration practices which will have minimal impacts on the environment, provided such equipment is operated appropriately. To this end:

> It is recommended that jurisdictions explore opportunities to employ up to date incineration equipment to replace existing systems that would otherwise need to be upgraded with complex air pollution control systems to meet the CWS.
>
> Furthermore, it is recommended that jurisdictions allow such equipment to be operated without the annual testing requirements provided the operator takes appropriate measures to ensure good operation and provides adequate records of such operation.

To reinforce this recommendation a series of sub-recommendations address the implementation of alternative approaches to ensuring low PCDD/F emissions from operating systems.

11.5.1 Batch Equipment Certification

Designating equipment that has been shown, through third party testing, to be capable of meeting the CWS emission standards when operated according to the manufacturer's instructions is a first step in the process. To accomplish this:

> It is recommended that any manufacturer selling a batch incinerator in Canada obtain third party certification that the unit meets the Canada wide standards for PCDD/F when burning the type of waste intended for a specific installation.

This implies that certification would not be available for continuously fed two stage units, the smallest of which would be capable of handling in excess of 250 Mg/year of waste if operated at typical utilisation levels.

Such certification will require PCDD/F testing of the various units in the manufacturer's range to prove that the performance is suitable. The testing would be conducted with waste representative of that specified in the certification. If an application could include wastes not certified for the specific equipment, either the owner would have to undertake sampling at their site, or the manufacturer would need to obtain additional third party verification of the equipment performance.

There are issues that will need to be addressed in establishing such certification, and particularly the testing program that should be undertaken on specific equipment. To facilitate the development of these procedures:

> It is recommended that a multi-stakeholder committee consisting of regulators, manufacturers, and testing companies be convened to commence the development of a certification procedure for batch incineration equipment.

11.5.2 Continuous Monitoring of Batch Systems

While the foregoing ensures that new batch type equipment is capable of meeting the standards, the question becomes, what other measures do we need to ensure this performance is maintained? Given the nature of these systems, there are two further recommendations:

> Equipment that achieves certification can only be sold with a monitoring package capable of recording pertinent operating parameters that ensure the system is being used in the manner it was intended to be used.

> All installations using a certified incinerator shall install weigh scales to record the weight of each load charged to the incinerator.

The intent of the recommended monitoring package is to record those operating parameters that affect good combustion. Given that most batch incinerators incorporate a secondary burner designed to maintain temperatures in the secondary chamber under all operating conditions, and this is an important aspect of ensuring low PCDD/F emissions, fuel flow, temperatures, and differential pressures in the system should be measured. These monitors would be connected to a computer which will continuously log data from the operating incinerator. The software in the computer should be capable of logging the waste charge data too. The data from this system will

be available to environmental inspectors who will be able to check the performance of the system. Since the system will log charges to the furnace, and operating time of the incinerator, should the owner choose to operate the unit less than assumed under the Annual Calculation recommendation, these data can be used to justify lower annual emission totals.

Where possible:

> It is recommended that the computer monitoring equipment be integrated with all the operating controls of the facility in a manner that would facilitate remote access to the data to enable the manufacturer to assist the operator with trouble shooting the operation of the unit.
>
> Furthermore, it is recommended that arrangements be made so the appropriate regulatory or jurisdictional authority can access the data remotely for the purposes of monitoring the operation.

11.5.3 Operator Training

The cornerstone of ensuring good operation of any incinerator is that the staff understand how the system operates and take appropriate steps to ensure the continued good operation of the equipment. Since the design heat release rate in the furnace is an important parameter in ensuring proper operation, it is also recommended that:

> Operators be trained, either through an appropriate site specific training program or through a certification program provided by a qualified body, on the operation of the unit.
>
> Operators be instructed to distinguish between broad categories of waste, say packaging versus food waste, and be given clear instructions on how much of each component it is suitable to charge the furnace with on each load.

11.5.4 Incinerators Equipped with Heat Recovery Systems

The provisions for equipment certification that avoid the need for annual testing, and the suggestion that certain systems do not need APC systems to meet the CWS only applies to systems that vent directly to the atmosphere at temperatures in excess of $600^{O}C$. Data available suggests that systems equipped with heat recovery boilers could produce higher PCDD/F emissions. Remember, the release of PCDD/F has been related to the time that exhaust gases are exposed to temperatures in the *de novo* synthesis temperature window. Should the potential for PCDD/F formation be raised due to the configuration of the incineration system, it is clear that it will be necessary to take additional measures to minimise such emissions. Thus:

> It is recommended that any owner contemplating the installation of a boiler on a waste incinerator be required to install an APC system to remove PCDD/F from the exhaust gas

stream.

Newer, simpler systems have become available and can be used to limit emissions while not unduly increasing the complexity of the system (See ADIOX in Chapter 4).

11.6 Existing Incinerator Installations

Incinerators that were included in the 2000 inventory, are still operating, and have not been tested to prove that they are meeting the CWS PCDD/F need to be addressed in the spirit of ensuring the application of the level playing field. Many of these incinerators have produced little data to enable their emissions to be estimated. Indeed, annual waste throughput data was not available for most of these systems. Therefore:

> It is recommended that all facilities install scales and start recording the amount of waste charged to their incinerator along with the date and time of the start and completion of each operating cycle.

Records should be recorded electronically to facilitate analysis of annual throughput.

Since most of these systems are small, batch incinerators, for which the cost of annual testing may be prohibitive, if it is deemed appropriate to allow new batch installations without PCDD/F testing requirements, existing small batch incinerators should meet similar requirements. Thus:

> It is recommended that these facilities be required to install temperature, pressure and auxiliary fuel flow monitoring equipment to confirm the incinerator is operated appropriately.
>
> Furthermore, it is recommended that all records, monitoring data and reports required shall be maintained at the site for a minimum period of at least two (2) years from the date of their creation in a hard copy format and as an electronic record and shall be made available for inspection by regulatory staff.

11.7 PCDD/F Incinerator Inventory

There are uncertainties in the inventory developed during this project. These relate to the limited amount of data available from many of the smaller incinerators. Furthermore, there is a lack of data concerning the concentration of PCDD/F in residues and the quantity of residues generated. In order to improve the inventory several recommendations are offered:

> It is recommended that all facilities be required to file, with the appropriate regulatory

authority, their annual waste throughput data, by the end of March in the following year starting in March 2008. This filing should include details on the quantity and disposition of residues discharged from the facility.

It is recommended that various regulatory authorities encourage a limited amount of residue collection and testing for PCDD/F content following appropriate procedures.

Residue sampling and analysis to determine PCDD/F levels should follow the procedures outlined by the IAWG[109]. By following the sampling recommendations representative samples can be collected for triplicate analyses. Samples should be cooled quickly and stored at temperatures below 4^{O}C. Residues should be processed on an as received basis and results should be expressed in a manner that accounts for the moisture present in the residue stream. Should it be deemed necessary to dry the samples, this should be conducted at temperatures below 50^{O}C. The extraction of residue samples is facilitated by decomposition of the matrix using hydrochloric acid, after which the solution should be neutralised and lyophilised prior to conventional organic extraction. The object of the testing is to determine **total** concentrations, expressed as toxic equivalents, not to determine the quantity of PCDD/F in leachates from the residue streams.

In 2008, when the throughput and residue data is available, the inventory can be refined.

It is recommended that the PCDD/F inventory developed as part of this study be updated in 2008 by the incorporation of waste throughput and residue generation data along with the results of the residue testing programs.

Based upon the results of this update:

It is recommended that suitable default factors for air emissions and PCDD/F in residues be developed to aid in preparing the annual emission estimates from all incinerators.

[109] International Ash Working Group, 1997. Municipal Solid Waste Incinerator Residues. Published by Elsevier, ISBN 0-444-82563-0. See Chapter 6 for sampling procedures and pp. 236-237 for analytical recommendations.

APPENDIX A

The Relationship between Analytical Results and Measurement Uncertainty

To ascertain the concentration of contaminants in a exhaust stream, sampling must be undertaken. Even the best of the sampling methods discussed in Chapter 5 can introduce unintended errors into the results. Moreover, the analytical procedures have the potential to add to the uncertainty of the final value. The issues of reproducibility, precision and uncertainty have been addressed in a number of studies, guidelines and even in legislation. This Appendix examines in more detail some of the issues raised in the Uncertainty section in Chapter 5 to assist the reader in understanding that a measurement result may not provide a "go/no go" decision on the suitability of emission data.

Those who have looked at extensive files of sampling data recognize that there is variability in the results. Typically this variability is attributed to differences in the process, but in reality in most situations it is a function not only of process variability, but also random and systematic errors that exist in any measurement. To understand the extent of such variability, and it's impact on the uncertainty of a specific measurement this appendix discusses a number of different issues. Initially, it looks at the variability that can exist in a laboratory measurement of an animal feed sample, because at least with this type of sample repetitive measurements can establish how accurate the results are. This discussion draws from published papers from the European Community regarding measurement of contaminants. The appendix goes on to draw upon the concepts introduced with respect to laboratory measurements and uncertainty to consider the uncertainty in stack measurements, and presents the results of two studies that tried to establish the range of uncertainty that might be present in such measurements.

Analytical Laboratory Results

The EC Directive[110] on contaminants in animal feed set limits on PCDD/F concentration in feed materials. To define the methods by which such samples were to be taken an analysed, the EC through the Director General Health and Consumer Protection, Food and Feed Safety Division issued regulations[111]. Essentially these rules suggest that the sample should consist of several

[110] EC Directive 2002/32/EC , 2002. Directive 2002/32/EC of the European Parliament and of the Council of 7, May 2002. As amended by COMMISSION DIRECTIVE 2003/57/EC of 17 June 2003 amending Directive 2002/32/EC of the European Parliament and of the Council on undesirable substances in animal feed (extend the list of feeds subject to PCDD/F I-TEQ limits) and by COMMISSION DIRECTIVE 2006/13/EC of 3 February 2006 amending Annexes I and II to Directive 2002/32/EC of the European Parliament and of the Council on undesirable substances in animal feed as regards dioxins and dioxin-like PCBs (to change the I-TEQ values to WHO_{98}-TEQ values.)

[111] EC Directive 2002/69/EC, 2002. COMMISSION DIRECTIVE 2002/69/EC of 26 July 2002 laying down the sampling methods and the methods of analysis for the official control of dioxins and the determination of

aliquots taken from the "lot" of material being sampled. The "lot" could represent a day's production, or a particular catch of fish, or even milk samples from one herd. The aliquots are combined and the combined sample is then split to provide sub-samples for various purposes including additional analyses by interested parties, and archiving. The resulting sub-samples are of sufficient size that they can be used to produce two individual samples for analysis should it be necessary. The rule goes on to provide guidance on the interpretation of the result.
Recognizing that such sampling is comparatively straight forward compared to sampling the exhaust of an incinerator, and that the implications of failures in the results can be grave, it is interesting to note that the Directive on Sampling was not the final word.
Subsequent to the issuance of the Sampling regulation, a committee provided a report on the interpretation of the results of such analyses[112]. The latest revision of that report was dated in January, 2005. While it deals with the important issue of food contamination, the principles apply to the presentation and evaluation of any analytical results so the following section quotes liberally from that source.

From the introduction to the Interpretation report:

> Before any specification is laid down ....., it must be understood that a specific parameter will depend on the procedures used to estimate it. In particular, an estimate of a specific value may be dependent upon the method of analysis used, but is always dependent on the method of sampling used to verify compliance with the specification. It is important for delegates ..... to appreciate the influence that methods of analysis and sampling may have on the judgements that may be made with regard to the compliance of ..... a sample.
>
> Without common and uniform criteria for methods of analysis and sampling procedures, and their common application and interpretation, different ..... parties will make different judgements as to whether a particular batch is in compliance with its ..... specifications.
>
> .... It should be appreciated that the issues involved are real rather than hypothetical. Decisions have been taken by some ..... jurisdictions which in a given situation were contrary to those which would have been taken by other ..... jurisdictions in the same situation.

Note: In the preceding quotation, specific references to EU parties have been removed .... and where additions are made to preserve the context they are shown in the basic font for this report.

The Interpretation report focuses on the role of analytical variability (normally known as "measurement uncertainty") in the interpretation of a specification. The introduction also notes

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dioxin-like PCBs in foodstuffs. Available at: http://europa.eu/smartapi/cgi/sga_doc?smartapi!celexapi!prod!CELEXnumdoc&lg=EN&numdoc=32002L0069&model=guichett

[112] EC DG Health and Consumer Protection, 2005. Reporth on the Relationship between Analytical Results, Measurement Uncertainty, Recovery Factors and the Provisions of EU Food and Feed Legislation. Available at: http://ec.europa.eu/food/food/chemicalsafety/contaminants/report-sampling_analysis_2004_en.pdf

that the concepts relate to quantitative analytical results, not qualitative results. The latter are more difficult to address, but it is noted in the report that they are currently being assessed.

The authors note that a number of assumptions can prevent the uniform implementation of legislative standards. These range from the apparently trivial issue of the number of significant figures that should be included in reported results, and their relation to limits to the use of recovery correction factors when calculating and reporting the analytical results. Between these two extremes is consideration of how analytical variability (or "measurement uncertainty") should be incorporated into the interpretation of a specification. These issues arise, not from concerns over the quality of analytical results, that is technical issues, but rather from administrative concerns related to increased emphasis on these issues in analytical circles[113].

Rather than reproducing the discussion in the report on significant figures, it is worth reiterating the conclusion:

> "where this is appropriate for the precision of the result, the analyst should report to one more significant figure than is indicated in the specification, assuming that the analyst is using an appropriate method."

When interpreting the results of a sampling program rounding the last significant figure of the result to produce a number that can be compared to the standard will clearly show that 0.081 ng would meet a 0.08 ng or 80 pg standard.

The use of recovery factors for PCDD/F analyses was an issue reviewed in 1987 during the validation of the NITEP PEI Testing. At that time the recommendation of the reviewers was that recoveries should be reported, as a QA/QC measure, but that results should not be recovery corrected. As noted in the discussion of sampling methods, the use of isotope dilution techniques with a high resolution gas chromatograph/high resolution mass spectrometer [HRGC/HRMS] relies upon quantifying the $^{13}C_{12}$-labelled standard substances, which are added to different steps of the overall procedure as internal standards. The response for the target compounds is scaled against the response for the isotope directly. Recovery rates in the PCDD/F analysis procedures are treated as QA/QC criteria and if they are out of range, additional analyses need to be undertaken. For the purpose of this report and the CWS standard, recovery correction is NOT to be used.

By far, the interpretation report treats the issue of uncertainty in the most depth. Several appendices address the various aspects of this issue. The explanation of the basics of the issue are easily understood, and for that reason it is repeated in the following paragraphs.

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[113] Thompson, Michael, Stephen L R Ellison, Ales Fajgelj, Paul Willetts and Roger Wood, 1999. "Harmonised Guidelines for The Use of Recovery Information in Analytical Measurement", Pure Appl. Chem., 1999, 71, 337 – 348

> All analytical results actually take the form "a ± 2u" or "a ± U" where "a" is the best estimate of the true value of the concentration of the measurand (the analytical result) and "u" is the standard uncertainty and "U" (equal to 2u) is the expanded uncertainty. "4u" is the range within which the true value is estimated, with a high probability, to fall. The value of "U" or "2u" is the value which is normally used and reported by analysts and is hereafter referred to as "measurement uncertainty" and may be estimated and expressed by analyst in a number of different ways.
>
> With the introduction of ISO and other guidelines on uncertainty estimation, the accuracy available from analytical methods is increasingly characterised in terms of "measurement uncertainty", which takes into account both the "trueness" (average departure from a true value) and the "precision" (the degree to which successive results tally). The range within which "a" is likely to fall – i.e. the uncertainty in "a" – depends on the inherent "trueness" and precision of the analytical method as used in the laboratory.

Most laboratories performing PCDD/F analyses are formally accredited, participate in proficiency testing schemes, use internal quality-control procedures and use appropriately validated methods of analysis. These laboratories are generally considered by practitioners to be "in control".

If, as is often the case with stack emission data in North America, the results are accepted as the true value of the concentration in the stack, and the measurement uncertainty is not included, comparison of the results to the standard may lead to erroneous conclusions. The interpretation report provides a graphic example of the situation for sample results where the true value of the concentration is at different levels compared to the limit value, Figure 1. The figure clearly suggests that samples I and II fail to meet the standard. However, if one considers the uncertainty on the measured values, there are other possible interpretations of the significance of the results, as shown in Figure 1. Clearly, measurement uncertainty must be recognized.

Furthermore, the interpretation report suggests that the uncertainty becomes more and more important as the regulatory levels are reduced. Again, using a food sample, the interpretation report provides numerical estimates of the level of uncertainty based upon collaborative trials. The values represent the (expanded) uncertainties that might be reported by laboratories.

Table A1 Expanded Uncertainty Range of Acceptable Concentrations*

Concentration	Expanded Uncertainty [%]	Range of Acceptable Concentrations*
100 g / 100 g	4	96 to 104 g / 100 g
10 g / 100 g	5	9.5 to 10.5 g / 100 g
1 g / 100 g	8	0.92 to 1.08 g / 100 g
1 g / kg	11	0.89 to 1.11 g / kg
100 mg / kg	16	84 to 116 mg / kg
10 mg / kg	22	7.8 to 12.2 mg / kg
1 mg / kg	32	0.68 to 1.32 mg / kg
<100 ug / kg	44	56 to 144 ug / kg

* this effectively means that values falling within these ranges may be regarded as being of the same analytical population.

Figure A1 Diagrammatic Illustration of the Effect of Measurement Uncertainty and the Limit (from the Interpretation Report)

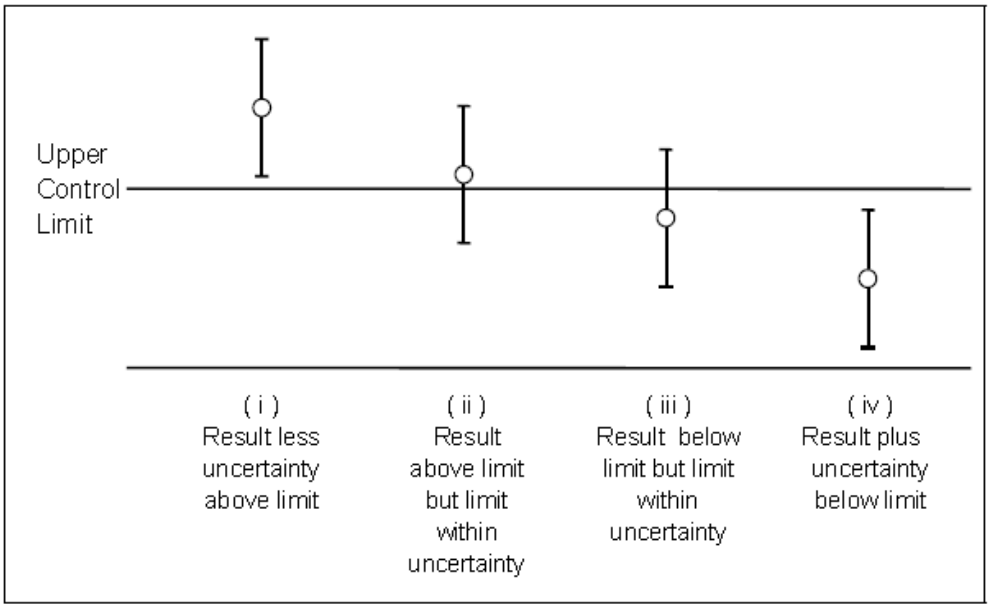
If one represents the best estimate by the circle on the vertical lines in the diagram below, and the measurement uncertainty by the lines, the diagram provides an illustration of four different situations which could be interpreted in different ways.

Situation I
The analytical result together with the measurement uncertainty exceeds the maximum level. All enforcement authorities would consider the sample to be non-compliant with the specification.

Situation II
The analytical result exceeds the maximum level by less than the measurement uncertainty. Some enforcement authorities would accept the sample as being compliant with the specification if they take account of the measurement uncertainty. Others would ignore the measurement uncertainty and refuse to accept the sample.

Situation III
The analytical result is below the maximum level by less than the measurement uncertainty. In general, enforcement authorities would consider the sample to be compliant with the specification, but would probably be wary of future samples.

Situation IV
The analytical result is below the maximum value by an amount greater than the measurement uncertainty. All enforcement authorities would consider the sample to be compliant without any hesitation.



The uncertainties provided in Table 1 were derived from taking the Horwitz or modified Horwitz predicted σ_R values and doubling to obtain the equivalent expanded uncertainty. This is but one of several ways to determine the uncertainty as summarized in Annex II of the interpretation report. Among the methods discussed in that report are those listed in the following box.

RECOMMENDED PROCEDURES FOR THE ESTIMATION OF MEASUREMENT UNCERTAINTY

It is recommended that food and feed control laboratories use information derived from the following procedures to help in estimating the measurement uncertainty of their results:

Annex II.1	ISO guide to the expression of measurement uncertainty
Annex II.2	EURACHEM Guide to quantifying uncertainty in analytical measurement: A. component-by-component approach B. use of collaborative trial data
Annex II.3	Use of collaborative trial: data – ISO 5725 critical differences
Annex II.4	Draft ISO TS 21748 – Guide to the Use of Repeatability, Reproducibility and Trueness Estimates in Measurement Uncertainty Estimation
Annex II.5	Concept established by Commission Decision 2002/657/EC implementing Council Directive 96/23/EC concerning the performance of analytical methods and the interpretation of results
Annex II.6	AOAC INTERNATIONAL approach
Annex II.7	Internal quality control approach
Annex II.8	NMKL (Nordic Committee on Food Analysis) approach
Annex II.9	Microbiological Analyses
Annex II.10	Useful references

The AOAC discussion in Annex II.6 is particularly enlightening on the issue of uncertainty and how to assess it. The following excerpts were taken from Annex II.6.

> "The idea is very simple – what variability can one expect from one's measurements. But the concept was introduced initially into the analytical laboratory from metrology, which required an examination of all possible sources of error, adding them vectorially, and expanding the resulting total error statistically to arrive at a result with an attached 95% probability statement. Analytical chemists, however, had long ago realized that by performing an interlaboratory study on a standard method using a group of typical laboratories analysing a set of typical matrixes, they could reproduce almost all the uncertainty that nature could create. This practical aspect is now being incorporated into the discussion of uncertainty.
>
> The official definition of measurement uncertainty (from the NIST Web site http://physics.nist.gov/cuu/Uncertainty/glossary.html) is:
>
> • *Uncertainty (of measurement)*: parameter, associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be

attributed to the measurand.

• The parameter may be, for example, a standard deviation (or a given multiple of it), or the half-width of an interval having a stated level of confidence.

• Uncertainty of measurement comprises, in general, many components. Some of these components may be evaluated from the statistical distribution of the results of a series of measurements and can be characterized by experimental standard deviations. The other components, which also can be characterized by standard deviations, are evaluated from assumed probability distributions based on experience or other information.

• It is understood that the result of the measurement is the best estimate of the value of the measurand, and that all components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion.

Considerable confusion about this term will be swept away immediately if you note that *the term "UNCERTAINTY" is attached to a RESULT, not to a method*; i.e., *measurement uncertainty* is being discussed, not *method uncertainty*. We will see how the method gets into the discussion later.

The introductory chapter to practically every textbook of quantitative analysis discusses the variability of analytical results and often advises reporting results in terms of the mean of a series of replicates and an interval within which you expect most (i.e. 95%) of your future results to fall if future analyses were conducted in an identical manner. However, the economics of chemical analysis dictates that only a few analyses are conducted on a test sample ("the results are usually good enough for government work"), so this theoretical admonition has been largely ignored until recently. Now, for accreditation purposes, laboratories are required to attach a statement of *measurement uncertainty* to their analytical results.

To obtain that halo of uncertainty surrounding your reported result, you have essentially four options:

(1) The option of calculating the equivalent of a confidence interval from the "*t*" factor applied to the standard deviation of replicates.

Run sufficient replicates on the specific test sample under consideration to obtain a fairly good idea of how the results will scatter in routine work. If you manufacture a product to a specification of 20% fat day in and day out, with the help of a statistician, you would soon be able to know the typical uncertainty of the fat content of the product, of the sampling, and of the analysis. But if you are called upon to provide an *estimate of uncertainty* from a set of duplicates from a material you will never see again, you will have to multiply the standard deviation calculated from that pair of results by a factor of 12! Such an estimate is essentially useless because experience

shows that future analysis from even a moderately experienced analyst will rarely approach the expected extreme.

Incidentally, running more replicates will not change the "true value" of the mean or of the standard deviation. More replicates provide more confidence in the interval estimate bracketing the true concentration and the true standard deviation.

(2) The theoretical "bottom-up" approach recommended by the bible on uncertainty, rubber stamped by nine international organizations.

Sit down and think about everything that might possibly affect the result and estimate the expected variation that each factor will contribute to the final value. These will include uncertainties, expressed as standard deviations. When you have thought of everything that might possibly influence your reaction, separation, and measurement, and assigned a standard deviation to each factor, calculate the square root of the linear combination of the variances to obtain the final standard deviation that you attach to your measurement as the measurement uncertainty. Then multiply this final standard deviation by a coverage factor (k) of 2 to ensure a probability of 95%, i.e., only a 5% chance that the true value lays outside the expanded uncertainty limits. Incidentally, do not forget lot and analytical sampling, which are unique for every lot and which, therefore, require individual estimation by replication of these components for completeness. "Practical" examples can be found in a EURACHEM guide.

This absurd and budget-busting approach (for analytical chemistry) arose from metrological chemists taking over in entirety the concepts developed by metrologists for physical processes measured with 5-9 significant figures (gravitational constant, speed of light, etc.) and applying them to analytical chemistry measurements with 2 or 3 significant figures. This approach also ignores the fact that some chemical methods are influenced by numerous factors, some positive and some negative, that tend to cancel out, and that often other chemical methods are influenced by a few factors that overwhelm the weight and volume uncertainty calculations presented in the published examples.

(3) The practical "top-down" approach from the relative standard deviation derived from an interlaboratory study by the Harmonized IUPAC/AOAC protocol or ISO 572521.

The approach, which is becoming generally accepted in Europe, is to conduct an interlaboratory study utilizing the Harmonized IUPAC/AOAC or ISO 5725 protocol (which utilizes an identical statistical model except for outlier removal). The protocols require a sample of at least 8 typical laboratories analysing a minimum set of 5 matrices covering the range of materials of interest. Then relate the standard deviation among laboratories (S_R) as being proportional to measurement uncertainty. By utilizing a sample of presumably typical laboratories operating in different environments on at least 5 materials covering the range of interest, it is very likely that most of the potential error factors that are likely to be encountered in practice will have been introduced. Therefore, if we equate this S_R to measurement uncertainty and call it

standard measurement uncertainty (standard uncertainty for short), we are at least about 70% certain that our result plus and minus S_R will encompass the "true" value. If we multiply S_R by a coverage factor of 2, we obtain the "expanded measurement uncertainty" (expanded uncertainty for short); we are now at least 95% certain that our result plus and minus $2S_R$ will encompass the "true" value.

When using this collaborative study approach, which results in a "standard method" as used by ISO 17025, be sure that all of the important variables are specified or understood (*see Definition of Terms and Explanatory Notes* section of the *Official Methods of Analysis of AOAC INTERNATIONAL*) with assigned limits. Under such conditions, S_R derived from the supporting collaborative study in the same units as the reported result with the accompanying number of significant figures, usually 2 or 3, may be used as the standard uncertainty, assuming the laboratory has demonstrated that it operates within the performance limits for that method.

(4) The estimate obtained by applying the Horwitz formula relating the relative standard deviation to concentration, as a mass fraction, $RSD_R = 2C^{(-0.15)}$, which is based upon a review of over 10 000 interlaboratory results, primarily published in the *Journal of AOAC INTERNATIONAL*.

[Alternative formula are: $\sigma_H = 0.02c^{0.8495}$ and $RSD_R = 2^{(1-0.5\log C)}$]

As a last resort, or even before you start any analyses, you can make a rough calculation to determine if the expected uncertainty at the expected concentration will be fit for the intended purpose. Apply the Horwitz formula (or a suitably adjusted version of the Horwitz formula to account for special circumstances such as a single laboratory) to the anticipated concentration to obtain a within-laboratory Sr and multiply it by 2 to obtain the expanded uncertainty. The Horwitz formula as initially applied to among-laboratory reproducibility parameters in %, and with C expressed as a mass fraction, is RSD_R (in %) = $2C^{(-0.15)}$ or as a standard deviation $S_R = 0.02C^{(0.85)}$ To apply to within-laboratory repeatability parameters, divide by 2 and equate this to estimated standard uncertainty:

$$S_r = 0.01C^{(0.85)}$$

To obtain the expanded (repeatability) uncertainty, multiply by 2:

$$S_r = 0.02C^{(0.85)}$$

For example, if we are dealing with a pure compendial material, C expressed as a mass fraction is 1, so the anticipated expanded uncertainty, $2S_r$, is 0.04 or 4%. This is interpreted as 95% of anticipated results will fall between 96 and 104%. You can "improve" your uncertainty by running independent replicates. "Independent" means as a minimum "non-simultaneous" but again economics would not permit it, so the improvement would be considerably less than theoretical.

The Horwitz formula will tell you if your anticipated uncertainty is such that you will be

within the limits of the ballpark with a typical method. The maximum spread obtained by the top down approach will encompass the "true value" in almost all practical cases. It is usually easier to let nature slip in all the un-anticipatable tricks that can befall even the most careful analysts than to valiantly attempt to foresee them beforehand by the budget approach. This is how the uncertainty of the method becomes entangled with the uncertainty of the measurement.

Note 1: Some of these "unanticipatable tricks" are chaotic, like dropping the thermometer or missing a decimal point. They are not subject to statistical description. Such adventitious flaws are handled by quality control but they cannot be predicted in any quantitative way. Such flaws are not intrinsic to the method.

Note 2: The uncertainty of a method, its bias and variability, is revealed by the spread of the individual measurements, i.e., by the average and standard deviation of the set of measurements.

The theory envisions that an infinite set of concentration estimates is obtained for each true concentration but the hapless finite chemist is forced just to take a sampling from this infinite set at the given concentration, usually just one or two estimates. Outlier tests are applied to remove clearly extrinsic interferences with the proper application of the chemical method. Note also that the uncertainty components, both bias and variability, are functions of the true concentration, though variability is usually observed to be more concentration-dependent than the bias.

If a method is to be corrected for recovery (bias) the method will usually so indicate. Many regulatory methods do not require such a correction because the specification (tolerance) was established by the same method so the recovery is "built into" the specification.

Note 3: The analytical chemist usually ignores sampling uncertainty primarily because typically little or no information accompanies the laboratory sample as to whether or not the laboratory sample truly reflects the lot. It is usually left to "management" to coordinate the analytical information with the sampling information. However, if the sample has been collected according to statistical principles (a process that usually requires a very large number of increments) and if these increments have been analysed to provide the basis for an estimate of sampling uncertainty, then propagation of error considerations can provide an overall "sampling + analysis" uncertainty."

Note 3 is particularly important when considering stack sampling measurements. The uncertainty that might be associated with the sampling method is of great importance if one is to account for all the uncertainty in a given result.

Uncertainty in Stack Measurement Results

Identifying uncertainty in analytical results from food samples, the thrust of much of the

uncertainty discussion to this point in this section, is straight-forward. Laboratories, or regulators simply have to request that data from numerous analyses of relevant reference samples be provided. The same in not true for exhaust gas samples. There are not relevant reference materials for exhaust gas streams. Moreover, given the analytical requirements, it is not usual for laboratory samples to be split thereby eliminating the possibility of quantifying the differences in laboratory procedures by analysing the same sample catch in two different laboratories. Clearly, regulators and the scientific community need to be assured that the results that are being reported using different sampling methods or from different sampling teams, or even from different laboratories are comparable. Of course, as can be appreciated from the preceding discussion of uncertainty, comparable really implies that all reported results from a given facility will lie within the range of uncertainty.

Two studies of the uncertainty in PCDD/F measurements are available in the literature:

- EN 1948-3 1996 provides the details of validation trials conducted on the three European sampling methods discussed earlier in this section; and,
- The ASME sponsored ReMAP project[114] report looks at the results of paired train data to establish measurement precision estimates.

The latest version of EN 1948-3 2006 includes an Annex[115] that is more of a thought piece than an evaluation of data.

CEN Study

The CEN Validation study in EN-1948-3 (1996) presents the results of comparative validation trials at waste incinerators sponsored by the Commission of the European Communities, the European Free Trade Association and the German Federal Environment Agency. The precision and the performance characteristics for the method were determined during these trials.

There were three MSW incinerator facilities used for the study:

- facility A - equipped with a wet spray humidifier and dry scrubber and an activated carbon bed for mercury and PCDD/F control. The dust concentrations in the stack were below 15 mg/m^3.
- facility B - wet scrubber for acid gas control followed by an SCR for NO_x and

[114] Lanier, W. Steven and Charles D. Hendrix, 2001. Reference Method Accuracy and Precision (ReMAP): Phase 1. Precision of Manual Stack Emission Measurements. Prepared under the auspices of American Society of Mechanical Engineers, Research Committee on Industrial and Municipal Waste. Published as ASME Report CRTD Volume 60.

[115] EN 1948-3 2006. Annex B (informative) Estimation of the measuring uncertainty and precision of the determination of polychlorinated dibenzo-p-dioxins and dibenzofurans

PCDD/F control with dust emission concentrations below 3 mg/m^3.

- facility C - wet spray humidifier with lime and PAC addition followed by an ESP controlling dust levels to below 5 mg/m^3.

At facilities A and B three sampling organisations simultaneously operated two identifical sampling trains in the stack for tests on each of 6 days. Thus each organisation, typically applying different collection methods, collected 12 samples over the period. The sample extraction procedures were conducted by the sampling organisations and the raw extracts were sent to laboratories for clean-up and analyses. A total of 7 laboratories were involved in the clean-up and analysis steps, six primary locations and a seventh used as a cross-check on split samples.

The procedure of having the sampling team extract the samples to a raw extract facilitates sample splitting for cross-checking, but this is less likely to be feasible in North America where, for the most part, the laboratories received the samples from the train and perform the extraction, clean-up and analysis all at the same facility.

The comparison of the methods and the results was carried out according to ISO 5725-2: 1994[116] by taking parallel duplicate samples. Since 5725 is a method for calculating the internal variability given the availability of a reference material, and emission sampling is time dependent and cannot be assumed to be constant, a different calculation approach was employed[117]. Essentially the confidence interval was calculated as:

$$I_C = t_{1-\frac{\alpha}{2}} \sqrt{\frac{\sum_{i=1}^{n} (y_{i1} - y_{i2})^2}{2n}}$$

Where:

I_c	=	internal confidence interval
$t_{1-\alpha/2}$	=	student t statistic at $\alpha = 0.05$ (95% confidence level)
n	=	number of tests

Essentially the square root of the average of half the sum of the squares of the differences for the each test times the t statistic.

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[116] ISO 5725-2:1994 Accuracy (trueness and precision) of measurement methods and results – Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method. International Standards Organisation.

[117] NFX 43-331:1996 Emissions de sources fixes – Détermination de l'intervalle de confiance d'une méthode de mesure en l'absence d'échantillon de référence par mesures parallèles simultanées. : AFNOR (Association Française de Normalisation -- French Standards Association).

The statistic, when applied to the results from one institute, provides the internal variability or repeatability of one team applying one method. It is an expression of the maximum difference that would be expected at the 95% confidence level for pairs of samples taken by the same team and analysed in the same laboratory.

The results of the validation tests were submitted the CEN committee for review. The committee checked all the results to ensure that all the requirements of the Standard had been met before the statistics were calculated. The results summarized in Table A2 are discussed below.

Out of the total of 36 possible samples from facility A, 33 samples were available for analysis at 3 different laboratories. In addition 3 cross check samples were submitted. Eighteen samples, including all those from one laboratory, were rejected as being outside the limits, even after the extraction limits were enlarged to a range of 10% to 180%. A total of 10 pairs remained for the calculation. With 36 possible samples from facility B, 34 were available for analysis at 5 laboratories and 2 cross-checks were submitted. Only 11 pairs were judged suitable for the calculation. For facility C only 4 days of testing were completed, producing 24 possible samples. All the samples were available and sent to a single laboratory. Only one pair of samples were judged to be unacceptable for calculation procedures.

By comparing the differences between test results generated by the different sampling contractors and laboratories an external variability can be determined. This provides an evaluation of the overall uncertainty attached to the results of an individual measurement. The external variability encompasses all factors that lead to differences in results including sampling procedures, the variations in the concentrations in the stack gases at different points in the stack, and the variability between laboratories.

To calculate the external variability the differences between pairs of measurements are taken. In other words if 2 sampling contractors (x and y) each generate 2 samples (1 and 2) from a given test, the differences are:

x1 - y1; x2 - y1; x1 - y2 and x2 - y2.

Thus for n tests there are 4n values of the differences. These can be used to calculate the standard deviation of the differences and the mean of the differences. These factors and the t statistic for 4n-1 degrees of freedom can be used to calculate the external variability:

$$e_v = d_{emean} + t_{4n-1}(\sigma_{de})$$

The calculation assumes that the distribution of the differences is gaussian, a condition that is generally satisfied if 20 - 25 data points are available.

Unfortunately, not all the test data was judged suitable for the evaluation of the external variability. The results from facility C were all analysed at one laboratory so these data were not available. At facility A, evaluation of the results determined that the sampling points were

sufficiently different that these data should not be used to determine external variability. Thus, external variabilty was calculated on the basis of facility B data.

Table A2 Summary Internal Variability Data from Validation Tests for CEN

Facility	Method	Number of Pairs	Average [ng I-TEQ/m^3]	Internal Variability [ng I-TEQ/m^3]
A	Dilution	5	0.19	±0.12
	Filter/Cooler	5	0.04	±0.06
B	Dilution	3	0.04	±0.016
	Filter/Cooler	5	0.03	±0.014
	Cooled Probe	3	0.041	±0.011
C	Dilution	4	0.13 (0.10)*	±0.21 (±0.08)*
	Cooled Probe	4	0.13	±0.02

Note: * indicates a single outlier point removed from the calculation

The external variability, and hence the uncertainty of the measurements of PCDD/F expressed as I-TEQ determined from these data was ±0.050 ng I-TEQ/m^3 at a mean value of 0.035 ng I-TEQ/m^3. This result has two implications:

- it suggests that the "real" value of the concentration could be a negative value, an apparently impossible conclusion; and,
- it suggests that any value less than 85 pg I-TEQ/m^3 is essentially the same value.

Some discussions of uncertainty note that negative values can be reported, simply because at the 95% confidence level values are likely to be found on both sides of the mean and if the mean is small enough there likely will be some negative values contributing to offset the high values. This sort of a situation is usually indicative of the distribution not fitting the "normal" curve, and with environmental data the distribution is typically log-normally distributed. That is the bulk of the data is close to the mean by high and low values are expected to be found in low numbers. Typically in the log-normal distribution the high number skew the distribution.

The second implication basically suggest that no conclusions on differences in emissions could be made if the results are less than 85 pg I-TEQ/m^3 because the data is within the range of the uncertainty.

ASME Study

The ASME study used available data to obtain estimates the precision of US EPA standard methods. While particulate matter, acid gases, metals and organics were all considered in the ReMAP study, this discussion will focus on the Method 23 results. These results are provided for data that is not corrected for diluent levels, but since most of the data came from MSW incinerators it can be assumed that this would have only a small impact on the overall conclusions.

The ReMAP methodology involved an assessment of the external variability as discussed in the previous section, because the data was collected from a number of projects undertaken by different sampling teams at different facilities and typically analysed by different laboratories. Some of the data includes the results of validation studies for different methods, other data were collected as part of specific research projects being undertaken for US EPA or other agencies.

Unlike the CEN study which determined the external variability on the basis of the standard deviation of the differences between paired data, the ReMAP study used the small sample bias corrected values of the standard deviation of the data pairs. The bias corrected standard deviation values and the average concentration data are then weighted for the number of degrees of freedom, transformed to the Log-Log plane given the data were found to fit a power curve, and subjected to a linear regression analysis to determine the parameters of the power law. The power law equation is then used to determine a predicted value of the standard deviation at each concentration point. Comparing the calculated and predicted average values of the standard deviation provides an appropriate value for a second bias correction factor. That factor is used to adjust the constant in the power law formula to provide an unbiased equation describing the relationship between the standard deviation and concentration. Using these data the 95% confidence intervals can be calculated for the range of the available data.

The data used for the original ReMap study included 19 paired samples collected from the mid-point in the air pollution control system of an MSW incinerator. The object of the tests was to examine the effects of lime and PAC addition to the gas stream at various ESP operating temperatures[118]. These samples were not collected at the stack, rather they were collected before the ESP but after the reagent injection. Also included in the data were 3 pairs of data, essentially simultaneous tests on a light weight aggregate kiln exhaust conducted for the US EPA by two different contractors. Subsequent to the preparation of the ReMAP report, simultaneous testing was conducted during compliance testing at another MSW incinerator in the United States. A total of 5 additional paired tests were included in a revision to the PCDD/F findings[119].

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[118] Rigo, H. Gregor and A.J. Chandler, 1997. Retrofitting ESP Equipped MWCs to meet the 1995 Emission Guidelines using Sensible Heat Exchanger Cooling and Dry Reagent Injection. A presentation at the 5th North American Waste to Energy Conference. RTP, North Carolina. Proceedings published by SWANA GR-WTE 0105.

[119] Hendrix, Charles D., 2006. Updating the Models. Precision of Manual Stack Emission Measurements. Draft document submitted for review to ASME committee.

While the original report provided an estimate on the uncertainty of the PCDD/F ITEQ concentration measurements, it was noted that there was no detectable relationship between the standard deviation and average measured concentration. That is the standard deviation was constant at all measured concentrations in the range of the data. The original report suggested that on the basis of the pooled variance of the data that measurement imprecision, uncertainty in the terminology of this report, was somewhere between ±68 pg ITEQ/m^3 and ±95 pg ITEQ/m^3 depending upon whether one accepted applied the 95% confidence bound to the value of the index in the power law function. Adding the additional data points established that there was a relationship between concentration and precision. Based upon the data available and the upper 95% confidence interval on the power law function, at 32 pg ITEQ/m^3 the uncertainty is ±18.6 pg ITEQ/m^3 and this rises to ±49.5 pg ITEQ/m^3 at an average concentration of 80 pg ITEQ/m^3. As Hendrix notes in the revised documents, it is important to recognize that since the model is a regression line the model improves if it contains more data near the extremes. At the present moment there is little data in the model to look at values in the region of the LOQ defined by Environment Canada, 32 pg ITEQ/Rm^3 @ 11% O_2.

Comparing the uncertainty provided by the CEN study with that at similar concentrations found in the ReMAP study suggests that the uncertainty shown by the ReMAP data is 40% of the value developed from the CEN study. Unlike the CEN study, where simultaneous sample pairs were analysed by different laboratories, each of the ReMAP studies reflects only the variability in one laboratory.

More importantly, the ReMAP values suggest that at the current CWS limit for incinerators, 80 pg ITEQ/Rm^3, the uncertainty in the measured value would extend from less than the LOQ to approximately 130 pg ITEQ/Rm^3.

The relationship between concentration and precision needs to have more study, mostly by encouraging more dual train sampling at the lower emission concentrations currently being achieved by some of the MSW incinerators in Canada.

Summary Uncertainty

From the discussion above, the reader can conclude that emission measurements are not absolute numbers that will pass or not pass a regulatory limit, but rather a value around which there is a considerable amount of uncertainty.