

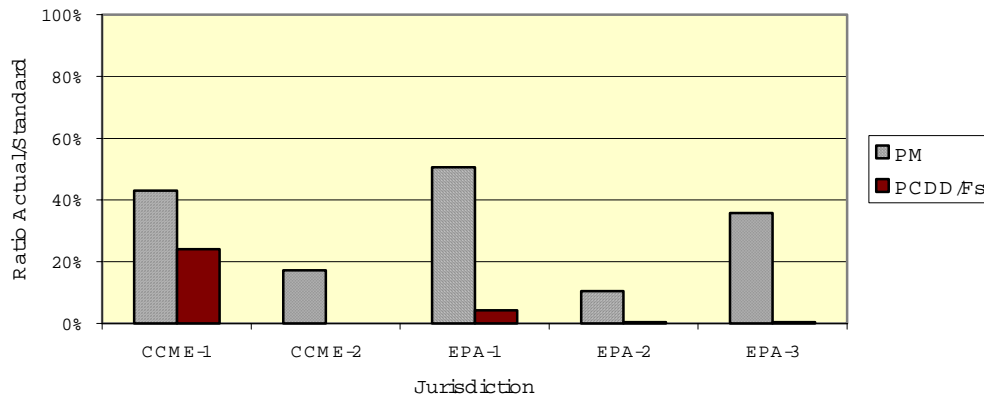
Westland CY-50-CA Thermal Oxidizer: Emissions of Chlorinated Dioxins/Furans and Particulate Matter



The system was initially developed in a joint venture to meet the criteria of simplicity (low cost) and robustness to comply with standards for conventional pollutants. A control system was then added to automate operation with any waste composition. The latest development involved energy recovery for hot water generation and “fine-polishing” air pollution system for meeting standards for all pollutants.

Emissions of particulate matter (PM) and chlorinated dioxins and furans (PCDD/Fs) from Westland’s CY-50-CA Thermal Oxidizer comply with standards in Canada and in the U.S. for large incinerators for municipal and biomedical wastes.

Compliance with Canadian and US Standards



CCME (Canadian)-1: Municipal & Biomedical (new, >200 kg/h); 2: Biomedical (old or <200 kg/h) – no standard for PCDD/Fs; **EPA** (U.S.) -1: Municipal (1.5 - 9 tonnes/h); 2: Biomedical (< 100 kg/h); 3: Biomedical (> 100 kg/h)

The capacity during the test was 34- 42 kg/h, with waste containing 19-24% plastics and 2.2-2.4% rubber - higher than those found in typical biomedical waste (14% and 0.7%).

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System Description

Figure I shows a schematic diagram of the system tested and the sampling location.

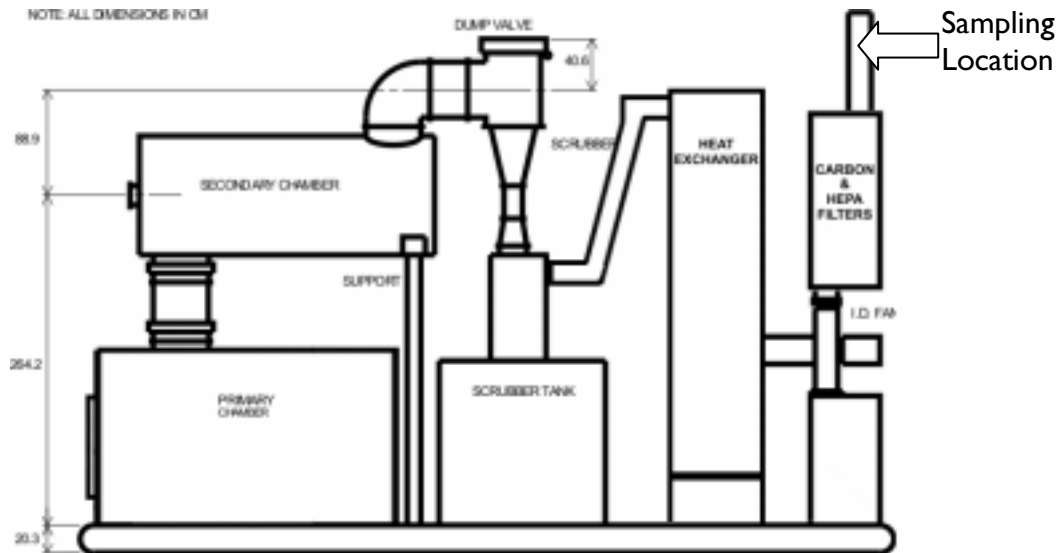


Figure I. Diagram of the System Tested and Sampling Location

The system consists of two main components:

- (A) A dual-chamber, starved-air combustion system followed by a venture scrubbing system, where the waste is oxidized and the flue gas is rapidly quenched and air pollutants removed;
- (B) A heat exchanger and a “fine-polishing” air pollution control system, where energy is recovered and further removal of air pollutants occurs.

The system is modeled after the Alberta Research Council’s pilot plant¹, and the design, operation and performance of component (A) were described previously.² The emissions of PM, HCl, SO₂, NO_x and CO met the standards for large incinerators in Canada and the U.S.

Waste is charged batch-wise into the primary chamber after preheating of the primary and secondary chambers. Under-fire air is fed into the primary chamber, where starved-air conditions are initially maintained, thereby generating combustible gases and soot. These are completely combusted in the secondary chamber by introducing flame-port air, and if necessary,

¹ B. Pandompatam et al. *Waste incineration research at the Alberta Environmental Centre, Part 2: Facility design considerations*. In: *Hazardous Waste Detection, Control, Treatment*. Proceedings of the World Conference on Hazardous Waste. (Abbou, R., eds.), pp. 1421-1440. Elsevier Science Publishers B.V., Amsterdam, The Netherlands. October 25-31, 1987. Budapest, Hungary.

² A. Liem et al *Development of a small-scale, simple and robust medical waste incinerator system*. 9th International Pacific Basin Conference on Hazardous Waste. Manila, Philippines. April 10-14, 2000

using an auxiliary burner. A control system is used to automatically regulate the under-fire and flame-port air flow rates to ensure complete combustion and to minimize auxiliary fuel use.

The hot flue gas from the secondary chamber is *rapidly* quenched in a venturi scrubber, which acts also as a pollution control device. Cooling from 1200 to 80 °C (maximum) occurred “instantaneously”, which should prevent PCDD/F formation from gradual cooling of flue gas.³

The latent heat of the moisture in the cooled flue gas is recovered in a condensing heat exchanger to generate hot water. An induced draft fan is used to draw the flue gas and to discharge it to the atmosphere via HEPA and activated carbon filters. These filters act as “fine-polishing” air pollution control device.

The sampling for PCDD/Fs and particulate matter was taken from the stack downstream of all the pollution control devices [see Figure 1].

Sampling and Analytical Methods

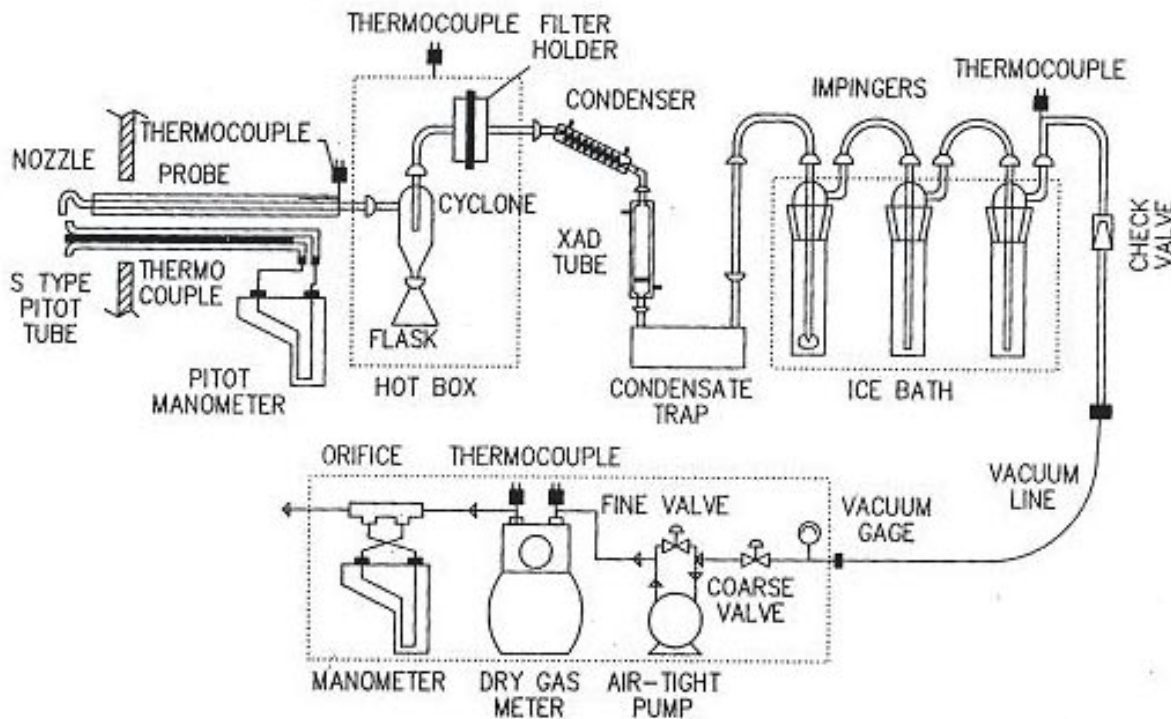


Figure 2. Diagram of Sampling Train

³ Patrick F. Mahoney et al. *Minimum Dioxin with Maximum Resource Recovery*. 17th International Symposium on Chlorinated Dioxins and Related Compounds, Indianapolis, IN, August, 1997.

The semi-volatile organics (MM5) sampling train, as shown in Figure 2, and the reference methods for sampling, recovery and analysis were used.⁴ Flue gas was sampled isokinetically⁵ through a nozzle connected to a heated probe and a heated box to prevent moisture condensation. In this case, only a filter was used to capture PM due to its expected low concentration. The sample was then condensed and passed through an XAD tube to adsorb PCDD/Fs. In case of incomplete adsorption, an impinger containing an ethylene glycol solution was used. The sample then was passed through an empty impinger to remove carried-over droplets and an impinger containing silica gel to adsorb moisture in it. The sampling flow rate was controlled by a series of valves, and measured by an orifice meter (instantaneous value) and a dry gas meter (cumulative volume) located downstream of the pump. About 3 m³ of sample was withdrawn.

Prior to sampling, oxygen and carbon dioxide measurements were made to determine the molecular weight of the dry flue gas, and to correct the emission results to the specified reference oxygen (or carbon dioxide) concentration. The moisture content in the flue gas was measured by weighing the condensate collected during the sampling period.

PM was measured by weighing oven-dried materials collected on the filter and the rinsing of the nozzle and the probe after sampling. PCDD/Fs were recovered by solvent extraction of the filter and the materials on it, the XAD tube and the ethylene glycol solution. The solvent was then “cleaned-up” to remove analytically-interfering compounds, and concentrated by vacuum evaporation prior to analysis.

The recovery and processing for PCDD/Fs are very complex and error-prone, thus it is necessary to use “surrogate compounds” for quality assurance. These are compounds with behaviour *similar* to the target compounds of interest, but are *analytically distinguishable*. Known quantities of surrogates are added to the XAD tube, and comparison between the measured and added quantities provides estimates of recovery efficiencies and detection limits.

⁴ Environment Canada. *Reference method for source testing: Measurements of Releases of selected semi-volatile organic compounds from stationary sources*. Report EPS 1/RM/2. 1989

⁵ Isokinetic means that the sampling velocity through the nozzle is the same as the flue gas velocity. This makes the nozzle “invisible” which is necessary to ensure representative sampling of particulate matter.

The analysis was conducted only at the homologue level, not for each specific congener.⁶ This is a *screening* method to determine whether under the *worst-case scenario*, certain emission standards are met.

Results

The sampling was conducted on August 9 and September 4 in 2002.

Waste Composition and Capacity

A mixture of wood waste, plastics and rubber was used to provide consistency in waste composition and to simulate biomedical waste in terms of plastic and rubber contents. A summary of the waste composition and the capacity during sampling is shown in Table I, and the waste feeding “profiles” are shown in Figure 3, together with the start and stop times of the sampling, which lasted about three hours.

Table I. Summary of Waste Composition and Capacity During Sampling

Date (2002)	Composition (wt%)				Capacity kg/h	Thermal Capacity	
	Wood	Plastics	Rubber	Water		GJ/h	10 ⁶ Btu/h
Aug 9	72.5%	18.8%	2.2%	6.6%	42.4	0.63	0.60
Sept 4	73.2%	24.4%	2.4%	2.4%	33.9	0.56	0.53

The plastic and rubber contents in the mixture were higher than those found in typical biomedical waste in the U.S., which are 14.2% and 0.7%, respectively.⁷ These components are responsible for “black smoke” generation, and hence the results show the robustness of the control system used. Notice that the mass capacity is dependent on the heating value of the feed, decreasing with higher heating values.

⁶ Congeners with the *same number of Cl atom* form a homologue; a congener has the *locations* of Cl atoms specified

⁷ R.G. Barton et al. *State-of-the-Art Assessment of Medical Waste Incinerators*. US EPA Report (Draft). EPA Contract 68-03-3365. 1991. Table 1.

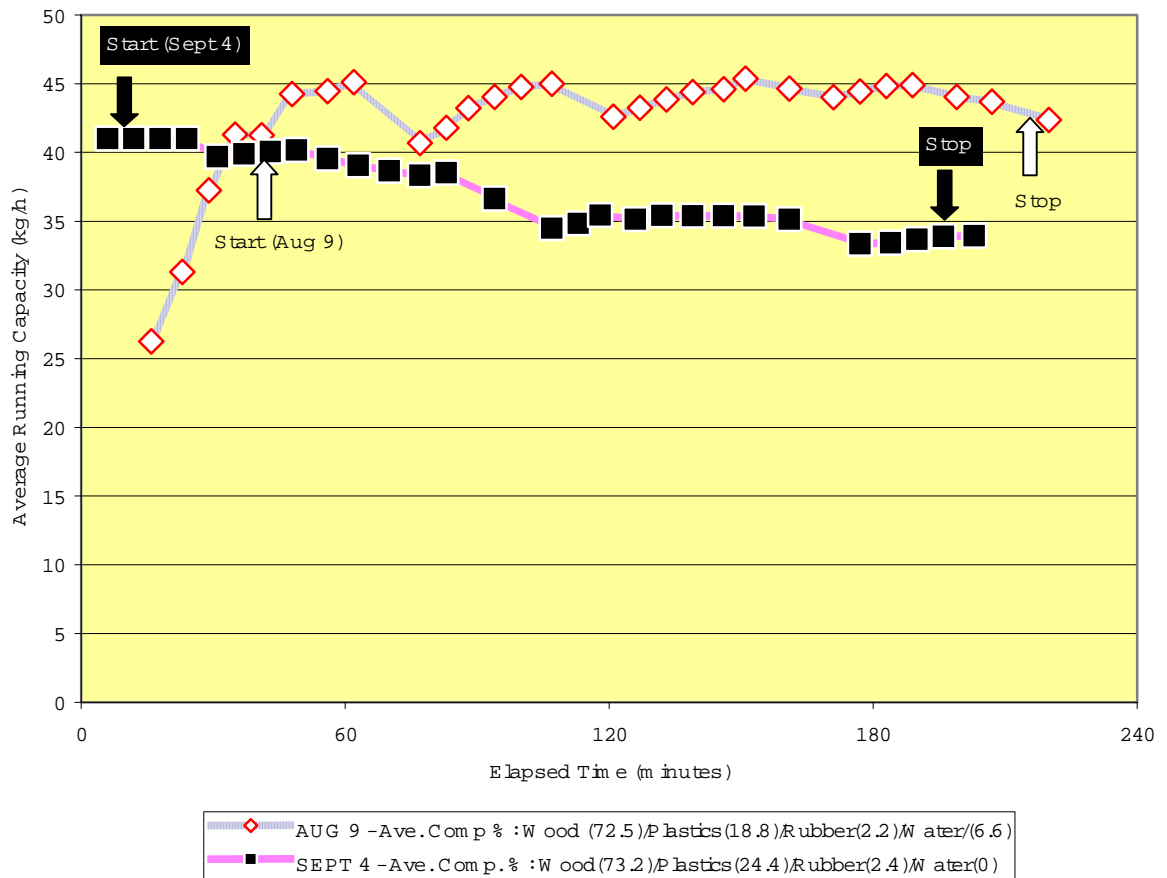


Figure 3. Waste Loading During Sampling and Capacity

The average running capacity W_n [kg/h] is defined as:

$$W_{n+1} = \frac{\sum_{i=1}^{n+1} L_i}{t_{n+1} - t_1} \quad n=1,2,\dots$$

where L_i [kg] is the mass of the i^{th} batch and $(t_{n+1} - t_1)$ [h] is the elapsed time between the first and the $(n+1)^{\text{th}}$ batches fed into the primary chamber. W_n thus represents the *average over the indicated elapsed time after the first batch is loaded*.

The thermal capacity is computed based on the average mass capacity at the end of sampling, the average composition and the published heating value of each component.

Flue Gas Sampling

The details are given in Appendix A, and a summary is given in Table II. Several points to be noted from the results:

- Sampling was conducted until 100 ft³, as read in the dry gas meter, of sample was collected. The inlet and outlet temperatures and the barometric pressure were measured and used, with the measured oxygen concentration, to compute the referenced volume collected.
- The oxygen concentration was not indicative of the combustion process. In order to reduce the relative humidity of the air entering the “fine-polishing” device, ambient air was “bled in” upstream of the induced draft fan at the heat exchanger outlet.
- The isokineticity results met the acceptable range ($\pm 10\%$) specified in the reference method.

Table II. Summary of Sampling Results

Sampling Date 2002	Composition, %		Volume sampled, m ³		Isokineticity
	H ₂ O	O ₂ ^a	DGM ^b	Referenced ^c	%
Aug 9	8.9	16.5	2.80	1.10	98.3
Sept 4	4.5	17.5	2.80	0.87	97.1

Notes: **a:** Air “bled in” after heat exchanger; **b:** Dry gas meter reading at measured inlet and outlet temperature and pressure; **c:** corrected to 25 °C, 101.3 kPa, dry basis, corrected to 11% (vol) O₂

Detection Limits

As will be shown later, PCDD/Fs were not detectable. The relevant question is therefore “What are the detection limits?”. In this case, the detection limits are *not unique*, determined *only* by the sensitivity of the analytical equipment used. Instead, they are determined by the recovery efficiency, the extent of solvent concentration and the volume of the gas sample collected. The following equation shows the relationship:

$$DL_M = \frac{DL_{AE}}{V_R \times F}$$

where DL_M is the *method* detection limit [say, pg/Rm³]; DL_{AE} is the *equipment* detection limit [pg] which is a function of equipment operation and sensitivity *and* the recovery efficiency of the target compound, as determined by the surrogate analysis; V_R is the referenced volume of sample collected [m³, see Table II]; and F is the ratio of the volume injected to the analytical equipment to the volume of the concentrated solvent [dimensionless].

The results are summarized in Table III and chromatograms of the analytical results are given in Appendix B. The detection limits for total PCDD/Fs are computed by summing the

detection limit of each homologue. Therefore, this represents the *worst-case scenario* since it is statistically unlikely that all the homologues are present at their detection limits. The results are presented in terms of both toxicity equivalence (TEQ) and actual, where TEQ is computed by multiplying each detection limit with its Toxicity Equivalency Factors (TEF).

Table III. Surrogate Recoveries and Detection Limits

Surrogate	TEF ⁸	Aug 9/02				Sept 4/02			
		Rec Eff	AE	Method, pg/Rm ³		Rec Eff	AE	Method, pg/Rm ³	
		%	pg	TEQ	Actual	%	pg	TEQ	Total
¹³ C ₁₂ – 2378 TCDD	1	48	5.2	47.3	47.3	52	4.9	56.3	56.3
¹³ C ₁₂ – 2378 TCDF	0.1	54	3.7	3.4	33.6	57	3.5	4.0	40.2
¹³ C ₁₂ – 12378 PeCDD	0.5	64	4.7	21.4*	42.7*	66	4.5	25.9*	51.7*
¹³ C ₁₂ – 123478 HxCDD	0.1	71	5.6	5.1	50.9	78	5.1	5.9*	58.6*
¹³ C ₁₂ – 123678 HxCDD	0.1	63	4.7	4.3	42.7	67	4.5	5.2	51.7
¹³ C ₁₂ – 234678 HxCDD	0.1	70	5.7	5.2*	51.8*	81	4.9	5.6	56.3
¹³ C ₁₂ – 1234678 HpCDD	0.01	73	5.5	0.5*	50.0*	83	4.8	0.5*	55.2*
¹³ C ₁₂ – OCDD	0.001	80	7.5	0.1*	68.2*	90	6.7	0.1*	77.0*
TOTAL PCDD/Fs (worst-case)				<105	<506			<125	<582

Surrogates: PCDD=dioxins; PCDF=furans; No. of Cl atoms: T=4; Pe=5; Hx=6; Hp=7; O=8; **TEF:** Toxicity Equivalency Factors **RecEff:** Recovery Efficiency; **AE:** Analytical Equipment Detection Limit (DL_{AE}); **Method :** method detection limit; **TEQ** = TEF * DL_{AE} /V_R /0.1, where V_R= referenced volume of gas sampled [see Table II], and 0.1 is the fraction of the concentrated solvent used in the analysis; **Actual** = DL_{AE}/V_R/0.1; **TOTAL PCDD/Fs :** worst-case scenario based on homologue analysis results; each homologue assumed at its detection limit; **bolded numbers** used in the summation, and * used for the corresponding furan homologues.

Compliance with Emission Standards

Particulate matter

The PM concentrations are shown in Table IV, together with the Canadian and U.S. Standards. Notice, therefore, that emission standards in Canada and the U.S. for *large municipal and biomedical waste incinerators* are readily met.

⁸ CCME. *Operating and Emission Guidelines for Municipal Solid Waste Incinerators*. Report CCME-TS/WM-TRE003. June 1989. Appendix B.

Table IV. Particulate Matter Concentrations and Compliance with Standards (mg/Rm³)

Date (2002)	Result	CCME-MSW ⁹	CCME-BW ¹⁰	US-MSW ¹¹	US-MWI ¹²
Aug 9	12.2	20	20 or 50	17	82 or 24
Sept 4	5.0				

CCME : Canadian Council of the Ministers of the Environment; **US**: US Environmental Protection Agencies; **MSW**: Municipal solid waste incinerator; **BW**: Biomedical waste incinerator for [new, > 200kg/h] or [old or smaller]; **MWI**: Medical waste incinerator for [< 500 lb/h] or [larger]. **R** (CCME); 25 °C, 101.3 kPa, 11% O₂; **R** (US): 20 °C, 101.3 kPa, 7% O₂ – but values shown have been converted to CCME reference conditions.

Chlorinated Dioxins and Furans

PCDD/Fs levels were below the detection limits. For comparison with emission standards, the *worst-case scenario* was assumed, where the concentration of each homologue was assigned the value of its detection limit. The results are shown in Table V. Notice, therefore, that current standards in Canada and the U.S. are readily met.

Table V. PCDD/F Concentrations and Compliance with Standards (ng/Rm³)

Date (2002)	TEQ		Actual		
	Result	CCME - MSW/BW	Result	US-MSW	US-MWI
Aug 9	<0.11	0.50	<0.51	13	125
Sept 4	<0.13		<0.58		

Concluding Remarks

- Smoke-free operation was attained with waste containing plastics and rubber at levels higher than those found in typical medical waste.
- With the use of the “fine-polishing” air pollution device, emissions of particulate matter and chlorinated dioxins and furans were *well below* current standards in Canada and U.S. for *large incinerators*.

⁹ Ref. 7, Table 4.2.

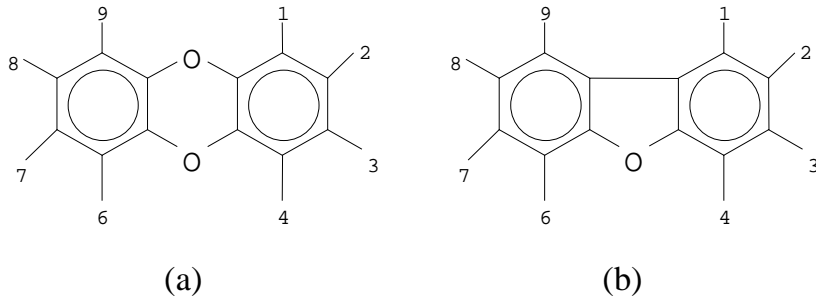
¹⁰ CCME. *Guidelines for the Management of Biomedical Waste in Canada*. .CCME-EPC-WM-42E. (February 1992).

¹¹ U.S. EPA. Federal Register. 40 CFR Part 60. *New Source Performance Standards for New Small Municipal Waste Combustion Units; Proposed Rule*. (August 30, 1999)

¹² U.S. EPA. Federal Register. 40 CFR Part 60. *Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Hospital/Medical/Infectious Waste Incinerators*. Volume 62, No. 178. (September 1997).

Glossary

Dioxin Nomenclature. The following diagram shows the structure of (a) dioxins and (b) furans and the numbering of the positions that could be taken up by up to 8 Cl atoms.



Weight units

Notation	Name	Value
pg	picogram	10^{-12} g
ng	nanogram	10^{-9} g
μ g	microgram	10^{-6} g
mg	milligram	10^{-3} g

Conversion from Actual to Reference, Dry Conditions

$$V_R = V_A \times \frac{T_R + 273}{T_A + 273} \times \frac{P_R}{P_A} \times \frac{20.9 - O_R}{20.9 - O_A} \times \frac{(100 - H_2O)}{100}$$

where **V**: volume; **T**: temperature ($^{\circ}$ C); **P**: pressure; **O**: oxygen concentration (vol.%); **H₂O**: moisture content (vol.%); and subscripts **R**: reference and **A**: actual or as measured. Any consistent units may be used for V and P.

Appendix A .Details of Sam pling Conditions

Appendix B. Chrom atogram s of Analytical Results