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**MONITORING OF EMISSIONS FROM
COVENTRY CREMATORIUM
10 – 13 October, 2006**

For Coventry Crematorium

Prepared for:

Coventry Crematorium
The Lodge
Cannon Hill Road
Coventry
CV4 7DF

Prepared by:

REC Ltd
Unit 19
Bordesley Trading Estate
Birmingham
B8 1BZ
Tel : 0121 326 7007
Fax : 0121 328 1689
E-mail : sales@recltd.co.uk

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Prepared by : _____
M Edwards, Env. Technician

Reviewed by : _____
P. Furmston, Director

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EXECUTIVE SUMMARY

Resource & Environmental Consultants (REC) Ltd was commissioned by Coventry Crematorium to monitor emissions of pollutants released from the cremation process at their site.

In accordance with the requirements of their site authorisation, monitoring has been undertaken for the following pollutants:-

- Combustion Gases including O₂ and CO
- Total Particulate Matter
- Hydrogen Chloride (HCl)
- Volatile Organic Compounds (VOCs)

The following results were obtained from the emission monitoring survey and are compared with the current authorisation limit:-

Species	Accreditation Status	Average Emission Concentration (mg/Nm ³)				PG 5/2 Limit (mg/Nm ³)
		Crem 1	Crem 2	Crem 3	Crem 4	
Total VOCs as C	A	<1	<1	<1	<1	20
Carbon Monoxide	A	10	28	<1	2	100
Particulate Matter	A	68	67	76	40	80
Hydrogen Chloride	B	44	65	45	23	200

NOTE 1: All data are expressed in mg/Nm³ at 273K, 101.3kPa, dry gas, corrected to 11% oxygen content.

NOTE 2: UKAS status:- (A) REC Ltd accredited for sampling and analysis. (B) REC Ltd accredited for sampling only, UKAS accredited analysis conducted by SAL Ltd. (C) REC Ltd not accredited for sampling, UKAS accredited analysis conducted by SAL Ltd. (D) REC Ltd not accredited for sampling, analysis not UKAS accredited.

1. INTRODUCTION

1.1 Background

Coventry Crematorium commissioned REC Ltd to conduct an emission monitoring survey on their cremation process at their site. There are 4No. gas fired cremators operating at the crematorium.

1.2 Scope of the Survey

An emission monitoring survey was required to determine the release concentrations of various pollutants from the cremation process. Concentrations of the following pollutants were quantified during the survey:

- Combustion Gases including O₂ and CO
- Total Particulate Matter
- Hydrogen Chloride (HCl)
- VOCs

Ancillary measurements of stack dimensions, temperature and velocity were also made.

Sampling for combustion gases was carried out on a continuous basis with measured concentrations being data-logged at 1 minute intervals over the sampling period. All other pollutants were sampled in duplicate.

All results were to be reported at 273K, 101.3kPa, dry gas corrected to an oxygen content of 11% by volume.

1.3 Sampling Personnel

Monitoring was conducted by the following REC Ltd permanent staff:-

- Dave Burns - MCERTS Level 1
- Michelle Edwards - MCERTS Trainee

2. METHODOLOGY

2.1 Species and Techniques

The following table shows the reference methods used for the emission monitoring survey:

Species	Accreditation Status	Method	Uncertainty $\pm\%$	Limit of Detection
Moisture	A	In house method MM0010 based on BS EN 14790	20	0.1%
Particulate Matter	A	In house method MM0009 based BS ISO 9096	10	1
Hydrogen Chloride	B	In house method MM0006 based on BS EN 1911	15	0.1
Carbon Monoxide	A	In house method MM0002 based on ISO 12039	10	1
Oxygen	A	In house method MM0002 based on ISO 12039	10	0.1%
Total VOCs (as C)	A	In house method MM0002 based on BS EN 13526/12619	10	1

NOTE: UKAS Status:- (A) REC Ltd accredited for sampling and analysis. (B) REC Ltd accredited for sampling only, UKAS accredited analysis conducted by SAL Ltd. (C) REC Ltd not accredited for sampling, UKAS accredited analysis conducted by SAL Ltd. (D) REC Ltd not accredited for sampling, analysis not UKAS accredited.

2.2 Sampling & Analytical Methodology

Total Particulate Matter

To determine the concentration of particulate matter in the emissions, isokinetic stack sampling equipment satisfying the BS ISO 9096. In house method MM0009 was followed.

The Standard describes the methodology for measuring particulate matter under defined conditions and at discrete locations in the duct. Sampling is carried out under isokinetic sampling conditions i.e. the flowrate through the sampling nozzle is adjusted to equal the flowrate in the duct at the sampling positions. Velocity pressures were recorded throughout the monitoring period by means of an 'S' type pitot integral to the sampling probe and nozzle assembly.

A sample of the exhaust stream was removed from the stack via a titanium nozzle and titanium lined heated probe. It was then passed through a quartz fibre filter contained in a heated oven compartment. The temperature of the probe and filter box were maintained at 160°C i.e. above the dew point of the stack gases, to ensure moisture did not condense on the filter.

The impinger train was seated in a water bath to cool the gas stream and condense out less volatile gases and water vapour.

The first three impingers encountered by the gas stream contained deionised water. The fourth impinger was left empty and the fifth contained anhydrous silica gel which was used to dry the gas stream before passing it through a dry gas meter (DGM) to measure the volume of gas sampled.

All the impingers were weighed before and after the sampling run in order to determine the mass of water condensed by the impinger train (in house Method MM00010).

Upon completion of sampling, the filter was removed to a clean petri dish, labelled and sealed. The probe and filter housing were rinsed with acetone and water. The washings were collected in a container and submitted for analysis along with the filter.

HCl

To determine the concentration of HCl in the emissions, isokinetic stack sampling equipment satisfying the requirements of BS EN 1911. In house method MM0006 was followed.

A sample of the exhaust stream was removed from the stack via a titanium nozzle and titanium lined heated probe. It was then passed through a quartz fibre filter contained in a heated oven compartment. The temperature of the probe and filter box were maintained above 160°C in accordance with MM0006. On leaving the filter, the sampled exhaust gas was passed into a series of impingers.

The first three impingers encountered by the gas stream contained deionised water to capture and absorb the volatile chloride (Cl). The fourth impinger was left empty and the fifth contained anhydrous silica gel which was used to dry the gas stream before passing it through a dry gas meter (DGM) to measure the volume of gas sampled.

Upon completion of sampling, the contents of the first three impingers were transferred to a sealed, labelled container, which was subsequently analysed for Cl via an ion chromatographic technique.

Combustion Gases

To determine the concentration of combustion gases (CO, and O₂) in emissions, a Testotherm Model 350XL multigas analyser was used. The analyser incorporates a gas conditioner to enable the gas stream to be presented to the electrochemical cells on a dry gas basis. In house method MM0002 was followed.

The analyser satisfies the requirements of the following Standards:-

CO & O₂ - ISO 12039

For each parameter the measured value (m.v.) and accuracy associated with this type of measurement using the Testo 350XL is:

O ₂	±	0.8% of full scale deflection
CO	±	2ppm (0-39.9ppm), ± 5% of m.v. (40 - 500ppm).

The analyser was calibrated against traceable test gases prior to the survey.

The Standards describe the methodology for measuring the combustion gases listed above under defined conditions in the duct. Sampling is carried out under anisokinetic sampling conditions as it is assumed that the gas is homogenous across the sample plane.

Total VOCs

To determine the concentration of VOCs in emissions, a Signal 3030 portable flame ionisation detector (FID) was employed. The analyser consists of a sintered filter, to remove particulate matter, a heated sampling line and heated FID block. This equipment satisfies the requirements of BS ENs 13526 and 12619 (in house method MM0002).

The instrument is calibrated over a number of ranges against a traceable propane (C_3H_8) standard prior to and on completion of each test.

VOCs are detected by the FID with the output being proportional to the number of carbon atoms present in the sample. The readout displays a VOC figure expressed in ppm as carbon which is converted to mg/Nm^3 as carbon.

Stack Temperature and Velocity

To determine the stack temperature, a calibrated thermocouple and digital indicator were employed. The exhaust gas velocity was investigated using a pitot static probe (to MM0009) and digital manometer.

3. SAMPLING AND OPERATIONAL DETAILS

3.1 Process Description

The operation of the process at Coventry Crematorium is classified as a Part B process under the Environmental Protection (Prescribed Process and Substances) Regulations. The process is therefore under Local Authority regulation and must demonstrate compliance with the standards published under PG 5/2 (2004). Monitoring is carried out over a whole cremation cycle from 2 minutes after loading to prior to raking.

3.2 Sampling Positions

On all Cremators only a single 4" BSP sampling ports was installed due to access restrictions. The sampling points provided were at least 5 x hydraulic diameters from any flow disturbance both upstream and downstream from the sampling plane. Access was via a ladder to a permanent platform.

The present sampling arrangements do not meet the requirements stated in Environment Agency Technical Guidance Note M1 in that only one port is provided instead of two and the platform size is smaller than that recommended.

3.3 Uncertainty

Due to the absence of a second port, sampling could only be conducted through one sampling port. This will degrade the accuracy of the particulate concentrations presented from the standard $\pm 10\%$ to no better than $\pm 20\%$.

It is unlikely that the concentrations of other determinants measured (HCl, CO, O₂ and VOC) are considered to be affected, as they exist in a gaseous phase, thus are considered to be homogenous across the sample plane of each cremator.

3.3 Emission Monitoring Survey Details

The emission monitoring survey was carried out on the four cremators over the period 10-13 October, 2006. The table below summarises the actual sampling periods.

SAMPLING PERIODS

Stack	Parameter	Sample Time & Date
Cremator No. 1	Particulates, HCl, VOCs, CO, O ₂ Run 1	12:05 -13:45 (10/10/06)
	Particulates, HCl, VOCs, CO, O ₂ Run 2	13:55 -15:00 (10/10/06)
	Particulates, HCl, VOCs, CO, O ₂ Run 3	09:08 -10:28 (11/10/06)
Cremator No. 2	Particulates, HCl, VOCs, CO, O ₂ Run 1	12:05 -13:25 (11/10/06)
	Particulates, HCl, VOCs, CO, O ₂ Run 2	13:50 -15:00 (11/10/06)
	Particulates, HCl, VOCs, CO, O ₂ Run 3	09:06 -10:26 (12/10/06)
Cremator No. 3	Particulates, HCl, VOCs, CO, O ₂ Run 1	11:02 -12:12 (12/10/06)
	Particulates, HCl, VOCs, CO, O ₂ Run 2	13:07 -14:27 (12/10/06)
	Particulates, HCl, VOCs, CO, O ₂ Run 3	14:35 -15:35 (12/10/06)
Cremator No. 4	Particulates, HCl, VOCs, CO, O ₂ Run 1	09:13 -10:30 (13/10/06)
	Particulates, HCl, VOCs, CO, O ₂ Run 2	11:46 -12:56 (13/10/06)
	Particulates, HCl, VOCs, CO, O ₂ Run 3	13:54 -14:54 (13/10/06)

4. RESULTS AND DISCUSSION

4.1 Initial Velocity and Temperature Traverse

An initial pitot-static pressure and temperature traverse was carried out on each emission source. From this data stack velocity, expressed in metres per second (m/s), and volumetric flowrates expressed in cubic metre per hour (m³/hr) have been calculated.

The results are reported at actual stack conditions and the volumetric flowrate is further expressed at the standard reference conditions of 273K, 101.3kPa i.e. standard temperature and pressure (STP). The results are summarised in Table 1.

4.2 Particulate Matter

The results of the particulate sampling runs are summarised in Tables 2-5. From the mass of particulate matter on the filter and in the acetone/water wash residue and volume sampled an emission concentration was calculated.

The results are expressed in mg/m³ at 273K, 101.3kPa, on a dry gas basis at measured and 11% O₂ content.

4.3 Hydrogen Chloride

The results of the volatile chloride sampling runs are summarised in Tables 2-5. From the concentration of Cl⁻ and the measured volume of absorbing solution a total mass of HCl in microgram (µg) was determined. From the molecular weight, an equivalent weight of HCl was then calculated. From the measured sample volume, an emission concentration and mass emission was calculated.

The results are expressed in mg/m³ at 273K, 101.3kPa, on a dry gas basis at measured and 11% O₂ content.

4.4 Combustion Gases

The results of the combustion gas monitoring tests are summarised in Table 6. This table presents the averages of measurements collected throughout the sample periods.

Concentrations are expressed in mg/m³ at the standard reference conditions of 273K, 101.3kPa, dry gas, referenced to 11% oxygen content.

4.5 Total VOC Emission Data

The results of the VOC monitoring tests are also summarised in Table 6. This table presents the averages of measurements collected throughout the sample periods. Concentrations are expressed in mg/m³ at the standard reference conditions of 273K, 101.3kPa, dry gas, referenced to 11% oxygen content.

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TABLES

TABLE 1**FLOW DATA**

Stack Ref.	Stack Temp (°C)	Av. Pitot (Pa)	Duct Area (m ²)	Velocity (m/s)	Vol. Flow (m ³ /hr)	
					actual	@ ntp
Cremator 1	710	19	0.126	10.3	4,653	1,293
Cremator 2	778	32	0.163	13.8	8,079	2,100
Cremator 3	631	12	0.129	7.8	3,635	1,098
Cremator 4	787	18	0.119	10.4	4,470	1,152

TABLE 2

PARTICULATE/HCl EMISSIONS - CREMATOR No.1

12:05 - 13:45 13:55 - 15:00 09:08 - 10:28

Sampling Data	Run 1	Run 2	Run 3
Run Time (min)	100	65	80
Total mass H ₂ O collected (g)	66.3	40.2	65.9
Pitot tube constant, Cp	0.84	0.84	0.84
Dry gas meter (DGM) volume (litres)	1219.00	840.00	1194.00
Temperature DGM (°C)	22	24	26
Temperature stack (°C)	736	734	737
Mean pitot tube pressure drop, delta P (cm H ₂ O)	0.19	0.20	0.28
Orifice meter pressure drop, delta H (cm H ₂ O)	1.54	1.60	2.28
Barometric Pressure (kPa)	102.9	102.9	101.5
X-sectional area of stack (m ²)	0.126	0.126	0.126
Nozzle size (mm)	10.73	10.73	10.73
Flow Data			
Velocity, actual (m/s)	8.7	8.9	10.7
Velocity, ntp (m/s)	2.4	2.4	2.9
Vol. Flow, actual (m ³ /hr)	3945	4013	4825
Vol. Flow, ntp (m ³ /hr)	1075	1096	1305
Volume sampled, ntp, dry gas (m ³)	1.164	0.796	1.110
Volume sampled, ntp, wet gas (m ³)	1.247	0.850	1.197
Analytical Data			
Filter Weight Gain (mg)	121.5	38.1	13.0
Acetone Wash Residue Weight (mg)	25.3	6.0	29.3
Total Particulates (mg)	143.4	40.7	37.1
Mass HCl Impingers 1+2 (ug)	78454	39958	18825
Mass HCl Impinger 3 (ug)	80	61	53
Partics Field Blank (mg)	3	3.4	5.2
HCl Field Blank (mg/l)	0.06	0.06	0.06
HCl in Impingers 1+2 (%)	100	100	100
Emission Data			
O ₂ (%vol)	10.7	10.6	11.7
H ₂ O (% vol)	6.6	6.3	7.3
Percentage Isokinetic	96.6	99.4	95.5
Particulates (mg/m ³) @ 11% O ₂	119.6	49.1	36.0
HCl (mg/m ³) @ 11% O ₂	65.5	48.3	18.3

TABLE 3

PARTICULATE/HCl EMISSIONS - CREMATOR No.2

12:05 - 13:25 13:50 - 15:00 09:06 - 10:26

Sampling Data	Run 1	Run 2	Run 3
Run Time (min)	80	70	80
Total mass H ₂ O collected (g)	50.6	38.9	67.1
Pitot tube constant, C _p	0.84	0.84	0.84
Dry gas meter (DGM) volume (litres)	1203.00	1158.00	1261.00
Temperature DGM (°C)	28	24	23
Temperature stack (°C)	753	734	770
Mean pitot tube pressure drop, delta P (cm H ₂ O)	0.30	0.35	0.38
Orifice meter pressure drop, delta H (cm H ₂ O)	2.39	2.78	2.99
Barometric Pressure (kPa)	102.0	102.0	101.5
X-sectional area of stack (m ²)	0.163	0.163	0.163
Nozzle size (mm)	10.73	10.73	10.73
Flow Data			
Velocity, actual (m/s)	11.1	11.8	12.6
Velocity, ntp (m/s)	3.0	3.2	3.3
Vol. Flow, actual (m ³ /hr)	6489	6904	7355
Vol. Flow, ntp (m ³ /hr)	1732	1878	1926
Volume sampled, ntp, dry gas (m ³)	1.113	1.087	1.182
Volume sampled, ntp, wet gas (m ³)	1.176	1.139	1.272
Analytical Data			
Filter Weight Gain (mg)	51.3	22.5	36.7
Acetone Wash Residue Weight (mg)	38.6	27.5	44.6
Total Particulates (mg)	84.7	44.8	80.4
Mass HCl Impingers 1+2 (ug)	52175	77776	64972
Mass HCl Impinger 3 (ug)	34	375	268
Partics Field Blank (mg)	5	5.2	0.9
HCl Field Blank (mg/l)	0.06	0.06	0.06
HCl in Impingers 1+2 (%)	100	100	100
Emission Data			
O ₂ (%vol)	11.6	12.8	11.4
H ₂ O (% vol)	5.4	4.6	7.0
Percentage Isokinetic	91.5	93.5	89.0
Particulates (mg/m ³) @ 11% O ₂	81.0	50.4	70.9
HCl (mg/m ³) @ 11% O ₂	49.9	87.8	57.5

TABLE 4

PARTICULATE/HCl EMISSIONS - CREMATOR No.3

11:02 - 12:12 13:07 - 14:27 14:35 -15:35

Sampling Data	Run 1	Run 2	Run 3
Run Time (min)	80	80	60
Total mass H ₂ O collected (g)	63.0	25.6	50.3
Pitot tube constant, C _p	0.84	0.84	0.84
Dry gas meter (DGM) volume (litres)	761.00	880.00	632.00
Temperature DGM (°C)	21	23	25
Temperature stack (°C)	843	777	885
Mean pitot tube pressure drop, delta P (cm H ₂ O)	0.15	0.14	0.14
Orifice meter pressure drop, delta H (cm H ₂ O)	1.32	1.47	1.28
Barometric Pressure (kPa)	102.9	102.9	102.9
X-sectional area of stack (m ²)	0.129	0.129	0.129
Nozzle size (mm)	10.73	10.73	10.73
Flow Data			
Velocity, actual (m/s)	8.1	7.5	7.9
Velocity, ntp (m/s)	2.0	2.0	1.9
Vol. Flow, actual (m ³ /hr)	3754	3489	3681
Vol. Flow, ntp (m ³ /hr)	926	914	874
Volume sampled, ntp, dry gas (m ³)	0.729	0.836	0.597
Volume sampled, ntp, wet gas (m ³)	0.807	0.871	0.664
Analytical Data			
Filter Weight Gain (mg)	31.7	10.7	13.6
Acetone Wash Residue Weight (mg)	45.8	49.1	22.7
Total Particulates (mg)	76.6	58.9	35.4
Mass HCl Impingers 1+2 (ug)	44359	1400	46186
Mass HCl Impinger 3 (ug)	67	1695	1465
Partics Field Blank (mg)	1	0.9	0.9
HCl Field Blank (mg/l)	0.06	0.06	0.06
HCl in Impingers 1+2 (%)	100	45	97
Emission Data			
O ₂ (%vol)	11.6	10.4	9.2
H ₂ O (% vol)	9.7	3.9	10.1
Percentage Isokinetic	93.1	101.7	108.0
Particulates (mg/m ³) @ 11%O ₂	111.9	66.4	50.3
HCl (mg/m ³) @ 11% O ₂	64.9	3.5	67.6

TABLE 5

PARTICULATE/HCl EMISSIONS - CREMATOR No.4

	09:13 - 10:33	11:46 -12:56	13:54 - 14:54
Sampling Data			
	Run 1	Run 2	Run 3
Run Time (min)	90	70	60
Total mass H ₂ O collected (g)	47.7	39.8	46.1
Pitot tube constant, C _p	0.84	0.84	0.84
Dry gas meter (DGM) volume (litres)	1281.00	956.00	813.00
Temperature DGM (°C)	18	21	26
Temperature stack (°C)	762	767	797
Mean pitot tube pressure drop, delta P (cm H ₂ O)	0.35	0.30	0.31
Orifice meter pressure drop, delta H (cm H ₂ O)	2.58	2.24	2.26
Barometric Pressure (kPa)	102.9	102.9	102.9
X-sectional area of stack (m ²)	0.119	0.119	0.119
Nozzle size (mm)	10.73	10.73	10.73
Flow Data			
Velocity, actual (m/s)	11.9	11.0	11.4
Velocity, ntp (m/s)	3.2	2.9	2.9
Vol. Flow, actual (m ³ /hr)	5125	4735	4917
Vol. Flow, ntp (m ³ /hr)	1363	1252	1264
Volume sampled, ntp, dry gas (m ³)	1.237	0.915	0.765
Volume sampled, ntp, wet gas (m ³)	1.297	0.968	0.827
Analytical Data			
Filter Weight Gain (mg)	12.9	35.1	10.2
Acetone Wash Residue Weight (mg)	36.8	13.1	22.7
Total Particulates (mg)	45.7	44.2	28.9
Mass HCl Impingers 1+2 (ug)	8660	49030	6427
Mass HCl Impinger 3 (ug)	34	205	32
Partics Field Blank (mg)	4	4.0	4.0
HCl Field Blank (mg/l)	0.06	0.06	0.06
HCl in Impingers 1+2 (%)	100	100	100
Emission Data			
O ₂ (%vol)	10.4	11.3	9.9
H ₂ O (% vol)	4.6	5.5	7.4
Percentage Isokinetic	83.8	87.5	86.3
Particulates (mg/m ³)@ 11%O ₂	34.8	49.8	34.0
HCl (mg/m ³)@ 11% O ₂	6.6	55.5	7.6

TABLE 6**VOC, CO, & O₂ EMISSION CONCENTRATION DATA**

Cremator Ref	O₂ (% vol.)	CO (ppm)	CO (mg/m³) @ 11% O₂	VOC (ppm)	VOC (mg/m³) @ 11% O₂
Crem 1 Run 1	10.7	16	20	<1	<1
Crem 1 Run 2	10.6	2	2	<1	<1
Crem 1 Run 3	11.7	5	7	<1	<1
Crem 2 Run 1	11.6	30	40	<1	<1
Crem 2 Run 2	12.8	17	25	<1	<1
Crem 2 Run 3	11.4	14	19	<1	<1
Crem 3 Run 1	11.6	<1	<1	<1	<1
Crem 3 Run 2	10.4	<1	<1	<1	<1
Crem 3 Run 3	9.2	<1	<1	<1	<1
Crem 4 Run 1	10.4	<1	1	<1	<1
Crem 4 Run 2	11.3	2.7	3.4	<1	<1
Crem 4 Run 3	9.9	<1	<1	<1	<1

APPENDIX 1

Calculations

Conversion Factors

ppm @ mg/Nm ³ (at 273K, 101.3kPa: STP)			
CO	X	1.25	
SO ₂	X	2.86	
VOC's	X	0.53	(as total Carbon)
NO _x	X	2.05	(as NO ₂)

Oxygen Correction to Reference Value

Concentration at (STP) -> Concentration at 273K, 101.3kPa, reference O₂ and Dry Gas, i.e.

Concentration X ((20.9-O₂ ref)/(20.9-O₂ measured)) = Concentration at ref Oxygen state.

Example Calculation

SO ₂ concentration at STP	=	170.7 mg/Nm ³
Oxygen percentage in gas stream	=	13.8%
Reference Oxygen	=	11%
SO ₂ concentration at reference O ₂ conditions	=	170.7 ((20.9-11)/(20.9-13.8))
	=	238 mg/Nm ³ at 273K, 101.3kPa, 11% O ₂ and Dry Gas

Moisture Correction (Wet to Dry)

Concentration of Gas Dry = Concentration of x 100/100-Bws Gas Wet

Concentration of Gas Wet = Concentration of x 100-Bws/100 Gas Dry

Where Bws = moisture content of gas stream in percent (Vol/Vol).

Example

VOC concentration	=	25 mg/Nm ³ (Wet)
Moisture Content	=	27.1%
Concentration of VOC	=	25 (100/(100-27.1))

Carbon (C) to Trichloethylene (TCE)

ppm TCE = ppm C x 0.6715

TCE in mg/m³ = TCE ppm x 5.864 (Mol Wt/22.4)