STACK EMISSIONS MONITORING REPORT

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Operator & Address:
Energy Pyrolosis West Factory Bale Store Great Coates Industrial Estate Moody Lane Grimsby DN31 2SS

Permit:
EPR Permit: EP20140001

Release Point:
Main Process Exhaust

Sampling Date(s):
28th - 29th September 2015

ESG Job Number:	LNO 12607
Report Date:	23rd October 2015
Version:	1
Report By:	Keith Bird
MCERTS Number:	MM 07 825
MCERTS Level:	MCERTS Level 2 - Team Leader
Technical Endorsements:	1, 2 3 & 4
Report Approved By:	Scott Wilson
MCERTS Number:	MM 03 327
Business Title:	MCERTS Level 2 - FTIR Manager
Technical Endorsements:	1, 2, 3 & 4
Signature:	

UKAS TESTING
1015

mCERTS
THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME

CONTENTS

EXECUTIVE SUMMARY

MONITORING OBJECTIVES

Energy Pyrolosis operates a rubber recycling process at Grimsby which is subject to EPR Permit EP20140001, under the Environmental Permitting Regulations 2010.

ESG were commissioned by Mabbett & Associates Ltd to carry out stack emissions monitoring to determine the release of prescribed pollutants from the following Plant under normal operating conditions.

The results of these tests shall be used to demonstrate compliance with a set of emission limit values for prescribed pollutants as specified in the Plant's EPR Permit, EP20140001.

Plant

Main Process Exhaust

Operator

Energy Pyrolosis
West Factory Bale Store
Great Coates Industrial Estate
Moody Lane
Grimsby
DN31 2SS

EPR Permit: EP20140001

Stack Emissions Monitoring Test House

ESG - Stockport Laboratory
Unit 5 Crown Industrial Estate
Kenwood Road
Stockport
SK5 6PH
UKAS and MCERTS Accreditation Number: 1015

EXECUTIVE SUMMARY

EMISSIONS SUMMARY					
Parameter	**Units**	**Result**	**Calculated Uncertainty +/-**	**Limit**	**MCERTS accredited result**
Total Particulate Matter	mg/m³	3.3	0.31	30	✓
Particulate Emission Rate	g/hr	3.1	0.28	-	
Dioxins & Furans - UPPER Limits					
Dioxins & Furans (NATO I-TEQ)	ng/m³	0.02	0.004	0.1	✓
Dioxins & Furans (NATO I-TEQ) Emission Rate	µg/hr	0.02	0.003	-	
Dioxins & Furans (WHO TEQ Humans / Mammals)	ng/m³	0.02	0.004	-	✓
Dioxins & Furans (WHO TEQ H / M) Emission Rate	µg/hr	0.01	0.003	-	
Dioxins & Furans (WHO TEQ Fish)	ng/m³	0.02	0.004	-	✓
Dioxins & Furans (WHO TEQ Fish) Emission Rate	µg/hr	0.02	0.003	-	
Dioxins & Furans (WHO TEQ Birds)	ng/m³	0.04	0.009	-	✓
Dioxins & Furans (WHO TEQ Birds) Emission Rate	µg/hr	0.03	0.01	-	
Dioxins & Furans - LOWER Limits					
Dioxins & Furans (NATO I-TEQ)	ng/m³	0.02	0.004	-	✓
Dioxins & Furans (NATO I-TEQ) Emission Rate	µg/hr	0.02	0.003	-	
Dioxins & Furans (WHO TEQ Humans / Mammals)	ng/m³	0.01	0.003	-	✓
Dioxins & Furans (WHO TEQ H / M) Emission Rate	µg/hr	0.01	0.003	-	
Dioxins & Furans (WHO TEQ Fish)	ng/m³	0.02	0.004	-	✓
Dioxins & Furans (WHO TEQ Fish) Emission Rate	µg/hr	0.02	0.003	-	
Dioxins & Furans (WHO TEQ Birds)	ng/m³	0.04	0.009	-	✓
Dioxins & Furans (WHO TEQ Birds) Emission Rate	µg/hr	0.03	0.01	-	
Cadmium & Thallium	mg/m³	0.01	0.002	0.05	✓
Cadmium & Thallium Emission Rate	g/hr	0.01	0.001	-	
Heavy Metals	mg/m³	0.15	0.03	0.5	✓
Heavy Metals Emission Rate	g/hr	0.13	0.03	-	
Mercury	mg/m³	0.005	0.001	0.05	✓
Mercury Emission Rate	g/hr	0.004	0.001	-	
Hydrogen Chloride	mg/m³	0.82	0.10	20	✓
Hydrogen Chloride Emission Rate	g/hr	0.75	0.09	-	
Hydrogen Fluoride	mg/m³	***0.11***	0.01	2	✓
Hydrogen Fluoride Emission Rate	g/hr	***0.10***	0.01	-	
Sulphur Dioxide	mg/m³	9.2	1.1	100	✓
Sulphur Dioxide Emission Rate	g/hr	8.4	1.0	-	
Moisture	%	15.8	0.44	-	✓
Stack Gas Temperature	°C	45	-	-	
Stack Gas Velocity	m/s	6.0	0.16	-	
Gas Volumetric Flow Rate (Actual)	m³/hr	1055	55	-	✓
Gas Volumetric Flow Rate (STP, Wet)	m³/hr	913	47	-	
Gas Volumetric Flow Rate (STP, Dry)	m³/hr	768	40	-	
Gas Volumetric Flow Rate at Reference Conditions	m³/hr	913	47	-	

ND = None Detected,

Results at or below the limit of detection are highlighted by bold italic text.

The above volumetric flow rate is calculated using data from the preliminary survey. Mass emissions for non isokinetic tests are calculated using these values. For all isokinetic testing the mass emission is calculated using test specific flow data and not the above values.

Reference conditions are 273K, 101.3kPa without correction for water vapour

EXECUTIVE SUMMARY

MONITORING TIMES			
Parameter	**Sampling Date(s)**	**Sampling Times**	**Sampling Duration**
Total Particulate Matter Run 1	29 September 2015	19:05 - 20:05	60 minutes
Dioxins & Furans Run 1	29 September 2015	11:40 - 17:40	360 minutes
Cadmium & Thallium Run 1	29 September 2015	17:55 - 18:55	60 minutes
Heavy Metals Run 1	29 September 2015	17:55 - 18:55	60 minutes
Mercury Run 1	29 September 2015	17:55 - 18:55	60 minutes
Hydrogen Chloride Run 1	28 September 2015	12:35 - 13:35	60 minutes
Hydrogen Fluoride Run 1	28 September 2015	13:45 - 14:45	60 minutes
Sulphur Dioxide Run 1	28 September 2015	14:55 - 15:55	60 minutes
Preliminary Stack Traverse	29 September 2015	11:00	-

EXECUTIVE SUMMARY

PROCESS DETAILS

Parameter	Process Details
Description of process	Rubber recycling
Continuous or batch	Batch
Product Details	Diesel and Carbon
Part of batch to be monitored (if applicable)	When operating at temperature
Normal load, throughput or continuous rating	Normal Load
Fuel used during monitoring	LPG and recycled process gas
Abatement	None
Plume Appearance	Plume Visible

EXECUTIVE SUMMARY

Monitoring Methods

The selection of standard reference / alternative methods employed by ESG is determined, wherever possible by the hierarchy of method selection outlined in Environment Agency Technical Guidance Note (Monitoring) M2. i.e. CEN, ISO, BS, US EPA etc.

MONITORING METHODS						
Species	**Method** Standard Reference Method / Alternative Method	**ESG Technical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Method**	**Limit of Detection (LOD)**	**Calculated MU +/- %**
TPM	SRM - BS EN 13284-1	AE 104	1015	Yes	0.15 mg/m³	9.2 %
PCDD/PCDF	SRM - BS EN 1948-1	AE 109	1015	Yes	0.002 ng/m³	20.2 %
Cd & Tl	SRM - BS EN 14385	AE 108	1015	Yes	0.00357 mg/m³	20.2 %
Heavy Metals	SRM - BS EN 14385	AE 108	1015	Yes	0.022 mg/m³	20.2 %
Mercury	SRM - BS EN 13211 / MID 14385	AE 107/AE 108	1015	Yes	0.0006 mg/m³	20.2 %
Hydrogen Chloride	SRM - BS EN 1911	AE 111	1015	Yes	0.01 mg/m³	12.1 %
Hydrogen Fluoride	SRM - BS ISO 15713	AE 113	1015	Yes	0.04 mg/m³	12 %
Sulphur Dioxide	SRM - BS EN 14791	AE 112	1015	Yes	0.11 mg/m³	12.1 %
H_2O	SRM - BS EN 14790	AE 105	1015	Yes	0.01%	2.76%
Velocity	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	5 Pa	2.7 %
Volumetric Flow Rate	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	-	5.2 %

EXECUTIVE SUMMARY

Analytical Methods

The following tables list the analytical methods employed together with the custody and archiving details:

SAMPLING METHODS WITH SUBSEQUENT ANALYSIS							
Species	**Analytical Technique**	**Analytical Procedure**	**UKAS Lab Number**	**UKAS Accredited Lab Analysis**	**Analysis Lab (ESG or Subcontract)**	**Sample Archive Location**	**Archive Period**
TPM	Gravimetric	AE 106	1015	Yes	ESG Stockport	ESG Stockport	3 months
PCDD/PCDF	Gas Chromatography - High Resolution Mass Spectometry	ANU/SOP/3007	1549	Yes	SAL	SAL	3 months
Cd & Tl	Inductively coupled Plasma - Mass Spectrometry	ANU/SOP/117, 101,102	1015	Yes	ESG Bretby	ESG Bretby	3 months
Heavy Metals	Inductively coupled Plasma - Mass Spectrometry	ANU/SOP/117, 101,102	1015	Yes	ESG Bretby	ESG Bretby	3 months
Mercury	Inductively coupled Plasma - Mass Spectrometry	ANU/SOP/117, 101,102	1015	Yes	ESG Bretby	ESG Bretby	3 months
Hydrogen Chloride	Ion Chromatography	ASC/SOP/110/10	1015	Yes	ESG Bretby	ESG Bretby	3 months
Hydrogen Fluoride	Ion Chromatography	ASC/SOP/110/10	1015	Yes	ESG Bretby	ESG Bretby	3 months
Sulphur Dioxide	Ion Chromatography	ASC/SOP/110/10	1015	Yes	ESG Bretby	ESG Bretby	3 months

ON-SITE TESTING							
Species	**Analytical Technique**	**Analytical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Analysis**	**Laboratory**	**Data Archive Location**	**Archive Period**
H_2O	Gravimetric	AE 105	1015	Yes	ESG Stockport	-	-

EXECUTIVE SUMMARY

SAMPLING LOCATION					
Sampling Plane Validation Criteria	**Value**	**Units**	**Requirement**	**Compliant**	**Method**
Lowest Differential Pressure	25	Pa	>= 5 Pa	Yes	BS EN 15259
Lowest Gas Velocity	6.0	m/s	-	-	-
Highest Gas Velocity	6.0	m/s	-	-	-
Ratio of Gas Velocities	1.0	: 1	< 3 : 1	Yes	BS EN 15259
Mean Velocity	6.0	m/s	-	-	-
Maximum angle of flow with regard to duct axis	<15	°	< 15°	Yes	BS EN 15259
No local negative flow	Yes	-	-	Yes	BS EN 15259

DUCT CHARACTERISTICS		
	Value	**Units**
Shape	Circular	-
Depth	0.25	m
Width	-	m
Area	0.05	m^2
Port Depth	60	mm

SAMPLING LINES & POINTS		
	Isokinetic	**Non-Iso & Gases**
Sample port size	4 inch BSP	2 inch BSP
Number of lines used	1	1
Number of points / line	1	1
Duct orientation	Vertical	Vertical
Filtration	Out Stack	Out Stack
Filtration for TPM	In Stack	-

SAMPLING PLATFORM	
General Platform Information	
Permanent / Temporary Platform / Ground level / Floor Level / Roof	Permanent
Inside / Outside	Inside

M1 Platform requirements	
Is there a sufficient working area so work can be performed in a compliant manner	Yes
Platform has 2 levels of handrails (approximately 0.5 m & 1.0 m high)	No
Platform has vertical base boards (approximately 0.25 m high)	No
Platform has removable chains / self closing gates at the top of ladders	No
Handrail / obstructions do not hamper insertion of sampling equipment	Yes
Depth of Platform = >Stack depth / diameter + wall and port thickness + 1.5m	No

Sampling Platform Improvement Recommendations (if applicable)

The platform does not meet the requirements of EA Guidance Note M1.

EXECUTIVE SUMMARY

Sampling & Analytical Method Deviations

In this instance there were no deviations from the sampling and analytical methods employed.

APPENDICES

CONTENTS

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

MONITORING SCHEDULE					
Species	**Method** Standard Reference Method / Alternative Method	**ESG Technical Procedure**	**UKAS Lab Number**	**MCERTS Accredited Method**	**Number of Samples**
TPM	SRM - BS EN 13284-1	AE 104	1015	Yes	1
PCDD/PCDF	SRM - BS EN 1948-1	AE 109	1015	Yes	1
Cd & Tl	SRM - BS EN 14385	AE 108	1015	Yes	1
Heavy Metals	SRM - BS EN 14385	AE 108	1015	Yes	1
Mercury	SRM - BS EN 13211 / MID 14385	AE 107/AE 108	1015	Yes	1
Hydrogen Chloride	SRM - BS EN 1911	AE 111	1015	Yes	1
Hydrogen Fluoride	SRM - BS ISO 15713	AE 113	1015	Yes	1
Sulphur Dioxide	SRM - BS EN 14791	AE 112	1015	Yes	1
H_2O	SRM - BS EN 14790	AE 105	1015	Yes	1
Velocity	SRM - BS EN ISO 16911-1	AE 154	1015	Yes	1

APPENDIX 1 - Monitoring Schedule, Calibration Checklist & Monitoring Team

CALIBRATEABLE EQUIPMENT CHECKLIST

Extractive Sampling		Instrumental Analyser/s		Miscellaneous	
Equipment	**Equipment I.D.**	**Equipment**	**Equipment I.D.**	**Equipment**	**Equipment I.D.**
Control Box DGM	LNO 13-01	Horiba PG-250 Analyser	-	Laboratory Balance	LNO 00-12 / 00-13
Box Thermocouples	LNO 03-01	FT-IR	-	Tape Measure	LNO 24-KB
Meter In Thermocouple	LNO 10-01A	FT-IR Oven Box	-	Stopwatch	LNO 17-KB
Meter Out Thermocouple	LNO 10-01B	Bernath 3006 FID	-	Protractor	-
Control Box Timer	LNO 17-01	Signal 3030 FID	-	Barometer	LNO 08-KB
Oven Box	LNO 09-12	Servomex	-	Digital Micromanometer	LNO 01-KB
Probe	LNO 11-05	JCT Heated Head Filter	-	Digital Temperature Meter	LNO 03-KB
Probe Thermocouple	LNO 10-05	Thermo FID	-	Stack Thermocouple	-
Probe	LNO 11-06	Stackmaster	-	Mass Flow Controller	LNO 29-66
Probe Thermocouple	LNO 10-06	FTIR Heater Box for Heated Line	-	MFC Display module	LNO 29-09
S-Pitot	LNO 06-KB	Anemometer	-	1m Heated Line (1)	-
L-Pitot	-	Ecophysics NOx Analyser	-	1m Heated Line (2)	-
Site Balance	LNO 14-KB	Chiller (JCT/MAK 10)	-	1m Heated Line (3)	-
Last Impinger Arm	-	Heated Line Controller (1)	-	5m Heated Line (1)	-
Dioxins Cond. Thermocouple	LNO 10-89	Heated Line Controller (2)	-	10m Heated Line (1)	-
Callipers	LNO 31-KB	Site temperature Logger	LNO 12-KB	10m Heated Line (2)	-
Small DGM	-		-	15m Heated Line (1)	-
Heater Controller	LNO 03-40		-	20m Heated Line (1)	-
Inclinometer (Swirl Device)	LNO 23-KB		-	20m Heated Line (2)	-

NOTE: If the equipment I.D is represented by a dash (-), then this piece of equipment has not been used for this test.

CALIBRATION GASES

Gas (traceable to ISO 17025)	Cylinder I.D Number	Supplier	ppm	%	Analytical Tolerance +/- %
-	-	-	-	-	-

STACK EMISSIONS MONITORING TEAM

MONITORING TEAM								
Personnel	**MCERTS Number**	**MCERTS**		**TE / H&S Qualifications and Expiry Date**				
		Level	**Expiry**	**TE1**	**TE2**	**TE3**	**TE4**	**H&S**
Keith Bird	MM 07 825	MCERTS Level 2	Apr-17	Dec-18	Dec-19	Sep-20	Sep-19	Apr-17
Gary Orley	MM 13 1233	MCERTS Level 2	Apr-18	Feb-19	May-19	Nov-19	-	Apr-18

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER SUMMARY					
Parameter	Sampling Times	Concentration mg/m³	Uncertainty mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	19:05 - 20:05 29 September 2015	3.3	0.31	30	3.1
Blank	-	0.15	-	-	-

Reference conditions are 273K, 101.3kPa without correction for water vapour

Acetone Blank Value mg/l	Acceptable Value mg/l
2.0	10

FILTER INFORMATION

SAMPLES								
Test	Filter & Probe Rinse Number	Filter Start Weight g	Filter End Weight g	Mass Gained on Filter g	Probe Rinse Start Weight g	Probe Rinse End Weight g	Mass Gained on Probe g	Combined Total Mass Gained g
Run 1	G3942	0.10355	0.10447	0.00092	188.92380	188.92790	0.00410	0.00502

If total mass gained is less than the LOD then the LOD is reported

BLANKS								
Test	Filter & Probe Number	Filter Start Weight g	Filter End Weight g	Mass Gained Filter g	Probe Start Weight g	Probe End Weight g	Mass Gained Probe g	Combined Total Mass Gained g
Run 1	G3941	0.10402	0.10389	-0.00013	130.68300	130.68260	-0.00040	0.00022

If total mass gained is less than the LOD then the LOD is reported

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 1 — TPM

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	765.01
Stack static pressure, P_{static}	mm H_2O	1.02
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	765.08
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	191.9
$V_{wstd} = (0.001246)(V_{lc})$	m^3	0.2391074
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		1.350
Gas meter correction factor, Y_d		0.995
Mean dry gas meter temperature, T_m		19.125
Mean pressure drop across orifice, DH	mmH_2O	59.851
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$		1.270
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	1.5095
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No
% oxygen measured in gas stream, act%O_2		20.9
% oxygen reference condition		21
O_2 Reference Factor O_2 Ref $= \frac{21.0 - act\%O_2}{21.0 - ref\%O_2}$		No O2 Ref
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\,Ref})$	m^3	No O2 Ref
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1584
	%	15.84
Moisture by FTIR	%	-
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.86
Mean of velocity heads, DP_{avg}	mm H_2O	2.67
Mean square root of velocity heads, ÖDP		1.63
Mean stack gas temperature, T_s	°C	45
$V_s = \frac{(K_p)(C_p)(ÖDP)(Ö(T_s + 273))}{(M_s)(P_s)}$	m/s	6.08

Molecular weight of dry gas, M_d		
CO_2	%	0.03
O_2	%	20.90
Total	%	20.93
N_2 (100 -Total)	%	79.07
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.84
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.12
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.05
$Q_a = (60)(A_s)(V_s)$	m^3/min	17.9
Total flow of stack gas, Q		
Conversion factor (K/mm.Hg)		0.3592
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	13.0
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O_2ref	No O2 Ref
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	15.47
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	9.98
Nozzle area, A_n	mm^2	78.24
Total sampling time, q	min	60
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	102.1
Acceptable isokinetic range 95% to 115%		Yes
Particulate Concentration, C		
Mass collected on filter, M_f	g	0.00092
Mass collected in probe, M_p	g	0.00410
Total mass collected, M_n	g	0.00502
$C_{wet} = \frac{M_n}{V_{mstw}}$	mg/m³	3.326
$C_{dry} = \frac{M_n}{V_{mstd}}$	mg/m³	3.951
$C_{dry@X\%O2} = \frac{M_n}{V_{mstd@X\%oxygen}}$	mg/m³	No O2 Ref
Particulate Emission Rates, E		
$E = [(C_{wet})(Q_{stw})(60)] / 1000$		3.09

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

TOTAL PARTICULATE MATTER QUALITY ASSURANCE CHECKLIST

LEAK RATE						
Run	Mean Sampling Rate litre/min	Pre-sampling Leak Rate litre/min	Post-sampling Leak Rate litre/min	Maximum Vacuum mm Hg	Acceptable Leak Rate litre/min	Leak Tests Acceptable?
Run 1	22.4	0.14	0.17	-431.8	0.45	Yes

ISOKINETICITY		
Run	Isokinetic Variation %	Acceptable Isokineticity
Run 1	102.1	Yes

Acceptable isokinetic range 95% to 115%

WEIGHING BALANCE UNCERTAINTY			
Run	Result mg/m³	5% ELV mg/m³	LOD < 5% ELV
Run 1	0.15	1.5	Yes

The above is based on both the Filter and rinse uncertainty

BLANK VALUE				
Run	Overall Blank Value mg/m^3	Daily Emission Limit Value mg/m^3	Acceptable Blank Value mg/m^3	Overall Blank Acceptable mg/m^3
Blank 1	0.15	30	3.0	Yes

FILTERS					
Run	Filter Material	Filter Size mm	Max Filtration Temperature °C	Pre-use Filter Conditioning Temperature °C	Post-use Filter Conditioning Temperature °C
Run 1	GF	47	46	180	160

GF = Glass Fibre

QF = Quartz Fibre

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DIOXINS & FURANS SUMMARY - UPPER LIMIT

NATO I-TEQ					
Test	Sampling Times	Concentration ng/m³	LOD ng/m³	Limit ng/m³	Emission Rate µg/hr
Run 1	11:40 - 17:40 29 September 2015	0.02	0.002	0.1	0.02
Field Blanks Run 1	-	0.006	-	-	-

WHO TEQ (Humans / Mammals)					
Test	Sampling Times	Concentration ng/m³	LOD ng/m³	Limit ng/m³	Emission Rate µg/hr
Run 1	11:40 - 17:40 29 September 2015	0.02	0.002	-	0.01
Field Blanks Run 1	-	0.006	-	-	-

WHO TEQ (Fish)					
Test	Sampling Times	Concentration ng/m³	LOD ng/m³	Limit ng/m³	Emission Rate µg/hr
Run 1	11:40 - 17:40 29 September 2015	0.02	0.003	-	0.02
Field Blanks Run 1	-	0.006	-	-	-

WHO TEQ (Birds)					
Test	Sampling Times	Concentration ng/m³	LOD ng/m³	Limit ng/m³	Emission Rate µg/hr
Run 1	11:40 - 17:40 29 September 2015	0.04	0.003	-	0.03
Field Blanks Run 1	-	0.01	-	-	-

Reference conditions are 273K, 101.3kPa without correction for water vapour

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DIOXINS & FURANS SUMMARY - LOWER LIMIT

NATO I-TEQ					
Test	Sampling Times	Concentration ng/m³	LOD ng/m³	Limit ng/m³	Emission Rate µg/hr
Run 1	11:40 - 17:40 29 September 2015	0.02	-	0.1	0.02
Field Blanks Run 1	-	0.006	-	-	-

WHO TEQ (Humans / Mammals)					
Test	Sampling Times	Concentration ng/m³	LOD ng/m³	Limit ng/m³	Emission Rate µg/hr
Run 1	11:40 - 17:40 29 September 2015	0.02	-	-	0.01
Field Blanks Run 1	-	0.006	-	-	-

WHO TEQ (Fish)					
Test	Sampling Times	Concentration ng/m³	LOD ng/m³	Limit ng/m³	Emission Rate µg/hr
Run 1	11:40 - 17:40 29 September 2015	0.02	-	-	0.02
Field Blanks Run 1	-	0.006	-	-	-

WHO TEQ (Birds)					
Test	Sampling Times	Concentration ng/m³	LOD ng/m³	Limit ng/m³	Emission Rate µg/hr
Run 1	11:40 - 17:40 29 September 2015	0.04	-	-	0.03
Field Blanks Run 1	-	0.01	-	-	-

Reference conditions are 273K, 101.3kPa without correction for water vapour

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DIOXINS & FURANS ANALYSIS SUMMARY - RUN 1

NATO I-TEQ & WHO TEQ (Humans / Mammals)					
Congener	Result	NATO I-TEQ	WHO TEQ Humans / Mammals	Extraction Recovery	
				Actual	Permitted
	ng	ng	ng	%	%
Dioxins					
2378 Tetra CDD	0.0071	0.0071	0.0071	76	50 - 130
12378 Penta CDD	0.029	0.0145	0.029	124	50 - 130
123478 Hexa CDD	0.019	0.0019	0.0019	88	50 - 130
123678 Hexa CDD	0.035	0.0035	0.0035	83	50 - 130
123789 Hexa CDD	0.019	0.0019	0.0019		
1234678 Hepta CDD	0.1	0.001	0.001	86	50 - 130
OCDD Octa CDD	0.15	0.00015	0.000045	72	20 - 150
Total -Dioxins	**0.3591**	**0.03005**	**0.044445**		
Furans					
2378 Tetra CDF	0.11	0.011	0.011	83	50 - 130
12378 Penta CDF	0.052	0.0026	0.00156	0	>=50
23478 Penta CDF	0.085	0.0425	0.0255	126	50 - 130
123478 Hexa CDF	0.089	0.0089	0.0089	79	50 - 130
123678 Hexa CDF	0.076	0.0076	0.0076	79	50 - 130
234678 Hexa CDF	0.082	0.0082	0.0082	82	50 - 130
123789 Hexa CDF	0.018	0.0018	0.0018	0	>=50
1234678 Hepta CDF	0.17	0.0017	0.0017	84	20 - 150
1234789 Hepta CDF	0.014	0.00014	0.00014	0	>=50
OCDF Octa CDF	0.055	0.000055	0.0000165	77	20 - 150
Total -Furans	**0.751**	**0.084495**	**0.0664165**		
Mean Recoveries (%)				**88**	
Total Isomers	**1.1101**	**0.11455**	**0.11086**		
Total ITEQ (<LOD = 0)		**0.11455**	**0.11086**		

NOTE: The Total Isomers result includes all isomers below the limit of detection. This gives a "worst case" Dioxins & Furans result.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DIOXINS & FURANS ANALYSIS SUMMARY - RUN 1

WHO TEQ (Fish) & WHO TEQ (Birds)					
Congener	Result	WHO TEQ Fish	WHO TEQ Birds	Extraction Recovery	
				Actual	Permitted
	ng	ng	ng	%	%
Dioxins					
2378 Tetra CDD	0.0071	0.0071	0.0071	76	50 - 130
12378 Penta CDD	0.029	0.029	0.029	124	50 - 130
123478 Hexa CDD	0.019	0.0095	0.00095	88	50 - 130
123678 Hexa CDD	0.035	0.00035	0.00035	83	50 - 130
123789 Hexa CDD	0.019	0.00019	0.00019		
1234678 Hepta CDD	0.1	0.0001	0.0001	86	50 - 130
OCDD Octa CDD	0.15	-	-	72	20 - 150
Total -Dioxins	**0.3591**	**0.04624**	**0.03769**		
Furans					
2378 Tetra CDF	0.11	0.0055	0.11	83	50 - 130
12378 Penta CDF	0.052	0.0026	0.00052	0	>=50
23478 Penta CDF	0.085	0.0425	0.085	126	50 - 130
123478 Hexa CDF	0.089	0.0089	0.0089	79	50 - 130
123678 Hexa CDF	0.076	0.0076	0.0076	79	50 - 130
234678 Hexa CDF	0.082	0.0082	0.0082	82	50 - 130
123789 Hexa CDF	0.018	0.0018	0.0018	0	>=50
1234678 Hepta CDF	0.17	0.0017	0.0017	84	20 - 150
1234789 Hepta CDF	0.014	0.00014	0.00014	0	>=50
OCDF Octa CDF	0.055	0.0000055	0.0000055	77	20 - 150
Total -Furans	**0.751**	**0.0789455**	**0.2238655**		
Mean Recoveries (%)				**88**	
Total Isomers	**1.1101**	**0.1251855**	**0.2615555**		
Total ITEQ (<LOD = 0)		**0.1251855**	**0.2615555**		

NOTE: The Total Isomers result includes all isomers below the limit of detection. This gives a "worst case" Dioxins & Furans result.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DIOXINS & FURANS ANALYSIS SUMMARY - FIELD BLANK RUN 1

NATO I-TEQ & WHO TEQ (Humans / Mammals)					
Congener	Result	NATO I-TEQ	WHO TEQ Humans / Mammals	Extraction Recovery	
				Actual	Permitted
	ng	ng	ng	%	%
Dioxins					
2378 Tetra CDD	0.0025	0.0025	0.0025	93	50 - 130
12378 Penta CDD	0.0087	0.00435	0.0087	127	50 - 130
123478 Hexa CDD	0.0073	0.00073	0.00073	85	50 - 130
123678 Hexa CDD	0.019	0.0019	0.0019	84	50 - 130
123789 Hexa CDD	0.012	0.0012	0.0012		
1234678 Hepta CDD	0.07	0.0007	0.0007	90	50 - 130
OCDD Octa CDD	0.099	0.000099	0.0000297	81	20 - 150
Total -Dioxins	**0.2185**	**0.011479**	**0.0157597**		
Furans					
2378 Tetra CDF	0.021	0.0021	0.0021	92	50 - 130
12378 Penta CDF	0.017	0.00085	0.00051	0	>=50
23478 Penta CDF	0.023	0.0115	0.0069	105	50 - 130
123478 Hexa CDF	0.029	0.0029	0.0029	78	50 - 130
123678 Hexa CDF	0.021	0.0021	0.0021	76	50 - 130
234678 Hexa CDF	0.022	0.0022	0.0022	80	50 - 130
123789 Hexa CDF	< 0.012	0.0012	0.0012	0	>=50
1234678 Hepta CDF	0.071	0.00071	0.00071	87	20 - 150
1234789 Hepta CDF	0.011	0.00011	0.00011	0	>=50
OCDF Octa CDF	0.046	0.000046	0.0000138	87	20 - 150
Total -Furans	**0.273**	**0.023716**	**0.0187438**		
Mean Recoveries (%)				**90**	
Total Isomers	**0.4915**	**0.035195**	**0.0345035**		
Total ITEQ (<LOD = 0)		**0.033995**	**0.0333035**		

NOTE: The Total Isomers result includes all isomers below the limit of detection. This gives a "worst case" Dioxins & Furans result.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DIOXINS & FURANS ANALYSIS SUMMARY - FIELD BLANK RUN 1

WHO TEQ (Fish) & WHO TEQ (Birds)					
Congener	Result	WHO TEQ Fish	WHO TEQ Birds	Extraction Recovery	
				Actual	Permitted
	ng	ng	ng	%	%
Dioxins					
2378 Tetra CDD	0.0025	0.0025	0.0025	93	50 - 130
12378 Penta CDD	0.0087	0.0087	0.0087	127	50 - 130
123478 Hexa CDD	0.0073	0.00365	0.000365	85	50 - 130
123678 Hexa CDD	0.019	0.00019	0.00019	84	50 - 130
123789 Hexa CDD	0.012	0.00012	0.00012		
1234678 Hepta CDD	0.07	0.00007	0.00007	90	50 - 130
OCDD Octa CDD	0.099	-	-	81	20 - 150
Total -Dioxins	**0.2185**	**0.01523**	**0.011945**		
Furans					
2378 Tetra CDF	0.021	0.00105	0.021	92	50 - 130
12378 Penta CDF	0.017	0.00085	0.00017	0	>=50
23478 Penta CDF	0.023	0.0115	0.023	105	50 - 130
123478 Hexa CDF	0.029	0.0029	0.0029	78	50 - 130
123678 Hexa CDF	0.021	0.0021	0.0021	76	50 - 130
234678 Hexa CDF	0.022	0.0022	0.0022	80	50 - 130
123789 Hexa CDF	< 0.012	0.0012	0.0012	0	>=50
1234678 Hepta CDF	0.071	0.00071	0.00071	87	20 - 150
1234789 Hepta CDF	0.011	0.00011	0.00011	0	>=50
OCDF Octa CDF	0.046	0.0000046	0.0000046	87	20 - 150
Total -Furans	**0.273**	**0.0226**	**0.0534**		
Mean Recoveries (%)				**90**	
Total Isomers	**0.4915**	**0.0379**	**0.0653**		
Total ITEQ (<LOD = 0)		**0.0367**	**0.0641**		

NOTE: The Total Isomers result includes all isomers below the limit of detection. This gives a "worst case" Dioxins & Furans result.

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS - RUN 1 — Dioxins & Furans

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	765.01
Stack static pressure, P_{static}	mm H_2O	1.02
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	765.08
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	-
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		5.23
Gas meter correction factor, Y_d		0.99
Mean dry gas meter temperature, T_m		16.81
Mean pressure drop across orifice, DH	mmH_2O	25.71
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$		4.94
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	5.8756
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No
% oxygen measured in gas stream, act%O_2		20.90
% oxygen reference condition		21
O_2 Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$		No O2 Ref
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	No O2 Ref
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1584
	%	15.84
Moisture by FTIR	%	-

Molecular weight of dry gas, M_d		
CO_2	%	0.03
O_2	%	20.90
Total	%	20.93
N_2 (100 -Total)	%	79.07
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.84
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.12
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.86
Mean of velocity heads, DP_{avg}	mm H_2O	1.85
Mean square root of velocity heads, ÖDP		1.36
Mean stack gas temperature, T_s	°C	46
$V_s = \frac{(K_p)(C_p)(ÖDP)(Ö(T_s + 273))}{(M_s)(P_s)}$	m/s	5.07
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.05
$Q_a = (60)(A_s)(V_s)$	m^3/min	14.9
Total flow of stack gas, Q		
Conversion factor (K/mm.Hg)		
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	10.9
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O2ref	No O2 Ref
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	13
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	8.9
Nozzle area, A_n	mm^2	61.8
Total sampling time, q	min	360.0
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	100.6
Acceptable isokinetic range 95% to 115%		Yes

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

DIOXINS & FURANS QUALITY ASSURANCE CHECKLIST

Leak Test Results	Mean Sampling Rate litre/min	Pre-sampling Leak Rate litre/min	Post-sampling Leak Rate litre/min	Maximum Vacuum mm Hg	Acceptable Leak Rate litre/min	Leak Tests Acceptable litre/min
Run 1	14.5	0.07	0.12	-330.2	0.72	Yes

Isokinetic Criterion Compliance	Isokinetic Variation %	Acceptable Isokineticity
Run 1	100.6	Yes

Acceptable isokinetic range 95% to 115%

Filtration	Filter Material	Filter Size mm	Maximum Filtration Temperature °C
Run 1	QF	90	120

GF = Glass Fibre

QF = Quartz Fibre

Critical Sampling Requirement	Maximum Temperature at Condenser / Adsorber °C	Maximum Temperature during storage / transit °C	Acceptable Temperature?
Run 1	15	15	Yes

Acceptable < 25°C

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HEAVY METALS SOLID & VAPOUR PHASES COMBINED

CADMIUM & THALLIUM COMBINED					
Test	**Sampling Times**	**Concentration mg/m³**	**LOD mg/m³**	**Limit mg/m³**	**Emission Rate g/hr**
Run 1	17:55 - 18:55 29 September 2015	0.008	0.004	0.05	0.01
Field Blank	-	0.003	-	-	-
TOTAL HEAVY METALS COMBINED					
Test	**Sampling Times**	**Concentration mg/m³**	**LOD mg/m³**	**Limit mg/m³**	**Emission Rate g/hr**
Run 1	17:55 - 18:55 29 September 2015	0.15	0.02	0.5	0.13
Field Blank	-	0.01	-	-	-

Reference conditions are 273K, 101.3kPa without correction for water vapour

INDIVIDUAL METALS SUMMARY - SOLID & VAPOUR PHASES COMBINED

Metals	LOD mg/m³	Concentration mg/m³	Emission Rate g/hr
Cadmium	0.00173	0.00285	0.00239553
Thallium	0.00297	0.00522	0.004387093
Cadmium & Thallium	0.00357	0.00807	0.006782623

Metals	LOD mg/m³	Concentration mg/m³	Emission Rate g/hr
Arsenic	0.00301	0.00554	0.004657751
Antimony	0.00273	0.00498	0.004185109
Chromium	0.00229	0.01438	0.012087733
Cobalt	0.00137	0.00285	0.00239553
Copper	0.00229	0.00419	0.003521591
Lead	0.00285	0.01075	0.009032725
Manganese	0.00313	0.09518	0.079997789
Nickel	0.00273	0.01165	0.009794205
Vanadium	0.00205	0.00373	0.003138832
Total Other Heavy Metals	0.02244	0.15326	0.128811266

Reference conditions are 273K, 101.3kPa without correction for water vapour

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HEAVY METALS - RUN 1 SUMMARY

Metals	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³
Cadmium	0.001	0.50	0.001	0.001	1.87	0.002
Thallium	0.001	0.60	0.001	0.002	3.74	0.004
Cadmium & Thallium	0.001	1.10	0.001	0.002	5.62	0.01
Volume Sampled m^3		0.8322			0.8322	

Reference conditions are 273K, 101.3kPa without correction for water vapour

Metals	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³
Arsenic	0.00048	0.40000	0.00048	0.00253	4.21200	0.00506
Antimony	0.00048	0.40000	0.00048	0.00225	3.74400	0.00450
Chromium	0.00060	8.90000	0.01069	0.00169	3.06900	0.00369
Cobalt	0.00024	0.50000	0.00060	0.00112	1.87200	0.00225
Copper	0.00060	1.30000	0.00156	0.00169	2.18700	0.00263
Lead	0.00060	5.20000	0.00625	0.00225	3.74400	0.00450
Manganese	0.00060	75.00000	0.09012	0.00253	4.21200	0.00506
Nickel	0.00048	1.40000	0.00168	0.00225	8.29800	0.00997
Vanadium	0.00036	0.30000	0.00036	0.00169	2.80800	0.00337
Total Other Heavy Metals	0.00445	93.40000	0.11223	0.01800	34.14600	0.04103
Volume Sampled m^3		0.8322			0.8322	

Reference conditions are 273K, 101.3kPa without correction for water vapour

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HEAVY METALS - BLANK SUMMARY

Metals	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³
Cadmium	0.00060	0.5	0.00060	0.00112	0.50000	0.00060
Thallium	0.00060	0.6	0.00072	0.00225	1.00000	0.00120
Cadmium & Thallium	0.00120	1.1	0.00132	0.00225	1.50000	0.00180
Volume Sampled m^3		0.8322			0.8322	

Reference conditions are 273K, 101.3kPa without correction for water vapour

Metals	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³	Stack LOD mg/m³	Laboratory Result ug	Concentration mg/m³
Arsenic	0.00048	0.40000	0.00048	0.00253	1.12500	0.00135
Antimony	0.00048	0.40000	0.00048	0.00225	1.00000	0.00120
Chromium	0.00060	0.50000	0.00060	0.00169	0.87500	0.00105
Cobalt	0.00024	0.20000	0.00024	0.00112	0.50000	0.00060
Copper	0.00060	0.50000	0.00060	0.00169	0.75000	0.00090
Lead	0.00060	0.40000	0.00048	0.00225	1.00000	0.00120
Manganese	0.00060	0.40000	0.00048	0.00253	1.12500	0.00135
Nickel	0.00048	0.40000	0.00048	0.00225	1.00000	0.00120
Vanadium	0.00036	0.30000	0.00036	0.00169	0.75000	0.00090
Total Other Heavy Metals	0.00445	3.50000	0.00421	0.01800	8.12500	0.00976
Volume Sampled m^3		0.8322			0.8322	

Reference conditions are 273K, 101.3kPa without correction for water vapour

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MERCURY SUMMARY - PARTICULATE & VAPOUR PHASES COMBINED

Test	Sampling Times	Concentration mg/m³	LOD mg/m³	Limit mg/m³	Emission Rate g/hr
Run 1	17:55 - 18:55 29 September 2015	0.005	0.00	0.05	0.004
Field Blank	-	0.002	-	-	-

Mercury	PARTICULATE PHASE			VAPOUR PHASE		
	Stack LOD mean mg/m³	Lab Result ug	Concentration mg/m³	Stack LOD mean mg/m³	Lab Result ug	Concentration mg/m³
Run 1	0.00060	0.50	0.00060	0.00004	3.81	0.005
Volume Sampled m^3		0.8322			0.8322	
Field Blank	-	0.50	0.00060	-	1.12	0.0013
Volume Sampled m^3		0.8322			0.8322	

Reference conditions are 273K, 101.3kPa without correction for water vapour

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

ISOKINETIC SAMPLING EQUATIONS RUN 1 — Cd, Tl, Heavy Metals & Mercury

Absolute pressure of stack gas, P_s		
Barometric pressure, P_b	mm Hg	765.0
Stack static pressure, P_{static}	mm H_2O	1.0
$P_s = \frac{P_b + (P_{static})}{13.6}$	mm Hg	765.1
Vol. of water vapour collected, V_{wstd}		
Moisture trap weight increase,Vlc	g	-
$V_{wstd} = (0.001246)(V_{lc})$	m^3	-
Volume of gas metered dry, V_{mstd}		
Volume of gas sample through gas meter, V_m		0.745
Gas meter correction factor, Y_d		0.9947
Mean dry gas meter temperature, T_m		18.29
Mean pressure drop across orifice, DH	mr	19.49
$V_{mstd} = \frac{(0.3592)(V_m)(P_b+(DH/13.6))(Y_d)}{T_m + 273}$		0.70
Volume of gas metered wet, V_{mstw}		
$V_{mstw} = V_{mstd} + V_{wstd}$	m^3	0.8322
Vol. of gas metered at O_2 Ref. Cond., $V_{mstd@X\%O2}$		
Is the process burning hazardous waste? *(If yes, no favourable oxygen correction)*		No
% oxygen measured in gas stream, act%O_2		20.9
% oxygen reference condition		21
O_2 Reference Factor $\frac{O2\ Ref = 21.0 - act\%O2}{21.0 - ref\%O2}$		No O2 Ref
$V_{mstd@X\%oxygen} = (V_{mstd})(O_{2\ Ref})$	m^3	No O2 Ref
Moisture content, B_{wo}		
$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$		0.1584
	%	15.84
Moisture by FTIR	%	-

Molecular weight of dry gas, M_d		
CO_2	%	0.03
O_2	%	20.90
Total	%	20.93
N_2 (100 -Total)	%	79.07
$M_d = 0.44(\%CO_2)+0.32(\%O_2)+0.28(\%N_2)$		28.84
Molecular weight of wet gas, M_s		
$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$	g/gmol	27.12
Velocity of stack gas, V_s		
Pitot tube velocity constant, K_p		34.97
Velocity pressure coefficient, C_p		0.86
Mean of velocity heads, DP_{avg}	mm H_2O	2.19
Mean square root of velocity heads, ÖDP		1.48
Mean stack gas temperature, T_s	°C	45
$V_s = \frac{(K_p)(C_p)(ÖDP)(Ö(T_s + 273))}{(M_s)(P_s)}$	m/s	5.51
Actual flow of stack gas, Q_a		
Area of stack, A_s	m^2	0.05
$Q_a = (60)(A_s)(V_s)$	m^3/min	16.2
Total flow of stack gas, Q		
Conversion factor (K/mm.Hg)		0.3592
$Q_{std} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})}{(T_s) +273}$	Dry	11.8
$Q_{stdO2} = \frac{(Q_a)P_s(0.3592)(1-B_{wo})(O_2REF)}{(T_s) +273}$	@O2ref	No O2 Ref
$Q_{stw} = \frac{(Q_a)P_s(0.3592)}{(T_s) +273}$	Wet	14.0
Percent isokinetic, %I		
Nozzle diameter, D_n	mm	7.89
Nozzle area, A_n	mm^2	48.90
Total sampling time, q	min	60
$\%I = \frac{(4.6398E6)(T_s+273)(V_{mstd})}{(P_s)(V_s)(A_n)(q)(1-B_{wo})}$	%	99.4
Acceptable isokinetic range 95% to 115%		Yes

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HEAVY METALS QA CHECKLIST

Leak Test Results	Mean Sampling Rate litre/min	Pre-sampling Leak Rate litre/min	Post-sampling Leak Rate litre/min	Maximum Vacuum mm Hg	Acceptable Leak Rate litre/min	Leak Tests Acceptable litre/min
Run 1	12.4	0.05	0.08	-254	0.25	Yes

Isokinetic Criterion Compliance	Isokinetic Variation %	Acceptable Isokineticity
Run 1	99.4	Yes

Filtration / Temp	Filter Material	Filter Size mm	Maximum Filtration Temperature °C	Maximum storage / transit Temperature °C
Run 1	QF	47	180	14

GF = Glass Fibre

QF = Quartz Fibre

Metals	Type of Absorbers - Metals	Absorption Solutions - Metals
Run 1	PTFE	3.3% Nitric Acid, 1.5% Hydrogen Peroxide

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HEAVY METALS ABSORBTION EFFICIENCY

Parameter		Total ug	3rd Absorber ug	Absorption Efficiency (%)	Required %	Pass / Fail
Cadmium	Run 1	2.37200	0.83	65	90	N/A <30% ELV
Thallium	Run 1	6.71600	1.66	75	90	N/A <30% ELV
Arsenic	Run 1	4.61200	ND	100	90	Pass
Antimony	Run 1	4.14400	ND	100	90	Pass
Chromium	Run 1	11.96900	ND	100	90	Pass
Cobalt	Run 1	2.37200	ND	100	90	Pass
Copper	Run 1	3.48700	ND	100	90	Pass
Lead	Run 1	8.94400	ND	100	90	Pass
Manganese	Run 1	79.21200	1.86	98	90	Pass
Nickel	Run 1	9.69800	ND	100	90	Pass
Vanadium	Run 1	3.10800	ND	100	90	Pass

Parameter		Total ug	5th Absorber ug	Absorption Efficiency	Required	Pass / Fail
Mercury	Run 1	4.31	0.04	99	95	N/A <30% ELV

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HYDROGEN CHLORIDE SUMMARY					
Test	**Sampling Times**	**Concentration mg/m³**	**LOD mg/m³**	**Limit mg/m³**	**Emission Rate g/hr**
Run 1	12:35 - 13:35 28 September 2015	0.82	0.01	20	0.75
Field Blank	-	0.04	-	-	-

Reference conditions are 273K, 101.3kPa without correction for water vapour

HYDROGEN CHLORIDE QUALITY ASSURANCE CHECKLIST

Leak Test Results	Mean Sampling Rate l/min	Pre sampling leak rate l/min	Post sampling leak rate l/min	Acceptable leak rate l/min	Leak Tests Acceptable?
Run 1	2.0	0.02	0.0270	0.04	Yes

	Filter Material	Filter Size mm	Max. Filtration Temp. °C	Max. Storage / Transit Temp. °C	Type of Absorbers	Absorption Solutions
Run 1	QF	47	160	15	Glass	HPLC Water

GF = Glass Fibre

QF = Quartz Fibre

HYDROGEN CHLORIDE ABSORPTION EFFICIENCY

Parameter	**Total ug**	**IMP C ug**	**Absorption Efficiency %**	**Acceptable Absorption Efficiency %**	**Absorption Efficiency Acceptable ?**
Run 1	117.3	6.3	95	95	N/A- < 1mg/m³

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

HYDROGEN FLUORIDE SUMMARY					
Test	**Sampling Times**	**Concentration mg/m³**	**LOD mg/m³**	**Limit mg/m³**	**Emission Rate g/hr**
Run 1	13:45 - 14:45 28 September 2015	***0.11***	0.04	2	***0.10***
Field Blank	-	0.08	-	-	-

Please note figures in bold italic font are at the limit of detection
Reference conditions are 273K, 101.3kPa without correction for water vapour

HYDROGEN FLUORIDE QUALITY ASSURANCE CHECKLIST

Leak Test Results	Mean Sampling Rate l/min	Pre sampling leak rate l/min	Post sampling leak rate l/min	Acceptable leak rate l/min	Leak Tests Acceptable?
Run 1	3.0	0.03	0.04	0.06	Yes

	Filter Material	Filter Size mm	Max. Filtration Temp. °C	Max. Storage / Transit Temp. °C	Type of Absorbers	Absorption Solutions
Run 1	QF	47	160	15	Quartz	0.1N Sodium Hydroxide

GF = Glass Fibre
QF = Quartz Fibre

HYDROGEN FLUORIDE ABSORPTION EFFICIENCY

Parameter	**Total ug**	**IMP C ug**	**Absorption Efficiency %**	**Acceptable Absorption Efficiency %**	**Absorption Efficiency Acceptable ?**
Run 1	ND	ND	100	95	Yes

ND - None Detected

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

SULPHUR DIOXIDE SUMMARY					
Test	**Sampling Times**	**Concentration mg/m³**	**LOD mg/m³**	**Limit mg/m³**	**Emission Rate g/hr**
Run 1	14:55 - 15:55 28 September 2015	9.2	0.11	100	8.4
Field Blank	-	0.38	-	-	-

Reference conditions are 273K, 101.3kPa without correction for water vapour

SULPHUR DIOXIDE QUALITY ASSURANCE CHECKLIST

Leak Test Results	Mean Sampling Rate l/min	Pre sampling leak rate l/min	Post sampling leak rate l/min	Acceptable leak rate l/min	Leak Tests Acceptable?
Run 1	2.0	0.03	0.03	0.04	Yes

	Filter Material	Filter Size mm	Max. Filtration Temp. °C	Max. Storage / Transit Temp. °C	Type of Absorbers	Absorption Solutions
Run 1	QF	47	160	15	Glass	0.3% Hydrogen Peroxide

GF = Glass Fibre

QF = Quartz Fibre

SULPHUR DIOXIDE ABSORPTION EFFICIENCY

Parameter	**Total ug**	**IMP C ug**	**Absorption Efficiency %**	**Acceptable Absorption Efficiency %**	**Absorption Efficiency Acceptable ?**
Run 1	1305.6	57.6	96	95	Yes

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

MOISTURE CALCULATIONS

Moisture Determination - Isokinetic							
Test Number	Sampling Time and Date	Start Weight kg	End Weight kg	Total gain kg	Concentration %	LOD %	Uncertainty %
Run 1	19:05 - 20:05 29 September 2015	3.4025	3.5944	0.1919	15.8	0.008	2.8

Moisture Quality Assurance							
Test Number	Sampling Duration mins	Total Volume Sampled l	Sampling Rate l/min	Start Leak Rate l/min	End Leak Rate l/min	Acceptable Leak Rate l/min	Leak Tests Acceptable?
Run 1	60	1510	22.4	0.14	0.17	0.45	Yes

PRELIMINARY STACK SURVEY

Stack Characteristics		
Stack Diameter / Depth, D	0.25	m
Stack Width, W	-	m
Stack Area, A	0.05	m^2
Average stack gas temperature	45	^oC
Stack static pressure	0.1	kPa
Barometric Pressure	102	kPa

Stack Gas Composition & Molecular Weights								
Component	Molar Mass M	Density kg/m³ p	Conc Dry % Vol	Dry Volume Fraction r	Dry Conc kg/m³ pi	Conc Wet % Vol	Wet Volume Fraction r	Wet Conc kg/m³ pi
CO_2	44	1.963059	0.030000	0.000300	0.000589	0.025248	0.000252	0.000496
O_2	32	1.427679	20.900000	0.209000	0.298385	17.589484	0.175895	0.251121
N_2	28	1.249219	79.070000	0.790700	0.987758	66.545479	0.665455	0.831299
H_2O	18	0.803070	-	-	-	15.839789	0.158398	0.127205

Where: p = M / 22.41 pi = r x p

Calculation of Stack Gas Densities		
Determinand	Result	Units
Dry Density (STP), P_{STD}	1.2867	kg/m^3
Wet Density (STP), P_{STW}	1.2101	kg/m^3
Dry Density (Actual), P_{Actual}	1.1134	kg/m^3
Average Wet Density (Actual), $P_{ActualW}$	1.047	kg/m^3

Where:

P_{STD} = sum of component concentrations, kg/m^3 (not including water vapour)

P_{STW} = (P_{STD} + pi of H_2O) / (1 + (pi of H_2O / 0.8036))

P_{Actual} = P_{STD} x (Ts / Ps) x (Pa / Ta)

$P_{ActualW}$ = P_{STW} x (Ts / Ps) x (Pa / Ta)

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY

TRAVERSE 1

Date of Survey	29 September 2015
Time of Survey	11:00
Velocity Measurement Device:	S-Type Pitot

Sampling Line A								
Traverse Point	Distance into duct (m)	DP pt mmH_2O (average of 3 readings)	DP pt Pa (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m^3/s	O_2 % Vol	Angle of Swirl °
1	0.13	2.7	27	45	5.97	0.29	-	<15
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	2.7	27	45	5.97	0.29	-	

Sampling Line B								
Traverse Point	Distance into duct (m)	DP pt mmH_2O (average of 3 readings)	DP pt Pa (average of 3 readings)	Temp °C	Velocity m/s	Volumetric Flow Rate (actual) m^3/s	O_2 % Vol	Angle of Swirl °
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Mean	-	-	-	-	-	-	-	

PRELIMINARY STACK SURVEY QUALITY ASSURANCE CHECKLIST

PITOT LEAK CHECK								
Run	Pre Traverse Leak Rate				Post Traverse Leak Rate			
	Start Value mmH O	End Value mmH O	Difference %	Outcome	Start Value mmH O	End Value mmH O	Difference %	Outcome
Run 1	88	87	1.1	Pass	96	94	2.1	Pass

To complete a compliant pitot leak check a pressure of over 80 mmH O (or 800 Pa) is applied and the pressure drop monitored over 5 mins. A drop of ≤ 5% must be observed.

S-Type Pitot Stagnation Check				
Run	Stagnation (Pa)	Reference (Pa)	Difference (Pa)	Outcome (Permitted +/- 10 Pa)
Run 1	10	10	0.0	Pass

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

PRELIMINARY STACK SURVEY (CONTINUED)

Sampling Plane Validation Criteria				
EA Technical Guidance Note (Monitoring) M1	Result	Units	Requirement	Compliant
Lowest Differential Pressure	26.8	Pa	>= 5 Pa	Yes
Lowest Gas Velocity	6.0	m/s	-	-
Highest Gas Velocity	6.0	m/s	-	-
Ratio of Gas Velocities	1.0	-	< 3 : 1	Yes
Maximum angle of flow with regard to duct axis	0	°	< 15°	Yes
No local negative flow	Yes	-	-	Yes

Calculation of Stack Gas Velocity, V		
Velocity at Traverse Point, $V = K_{pt} \times (1\text{-}e) * \sqrt{(2 * DP_{pt} / P_{ActualW})}$		
Where: K_{pt} = Pitot tube calibration coefficient (1-e) = Compressibility correction factor, assumed at a constant 0.998		
Average Stack Gas Velocity, Va	**6.0**	m/s

Calculation of Stack Gas Volumetric Flowrate, Q			
Duct gas flow conditions	Actual	Reference	Units
Temperature	45	0	°C
Total Pressure	102.1	101.3	kPa
Oxygen	20.9	21	%
Moisture	15.84	15.84	%
Pitot tube calibration coefficient, K_{pt}	0.86		

Gas Volumetric Flowrate	Result	Units
Average Stack Gas Velocity (Va)	5.97	m/s
Stack Area (A)	0.05	m^2
Gas Volumetric Flowrate (Actual), Q_{Actual}	1055	m^3/hr
Gas Volumetric Flowrate (STP, Wet), Q_{STP}	913	m^3/hr
Gas Volumetric Flowrate (STP, Dry), $Q_{STP,Dry}$	768	m^3/hr
Gas Volumetric Flowrate (REF), Q_{Ref}	913	m^3/hr

Where:

Q_{Actual} = Va x A x 3600

Q_{STP} = Q (Actual) x (Ts / Ta) x (Pa / Ps) x 3600

$Q_{STP,Dry}$ = Q (STP) / (100 - (100 / Ma)) x 3600

Q_{Ref} = Q (STP) x ((100 - Ma) / (100 - Ms)) x ((20.9 - O_2a) / (20.9 - O_2s))

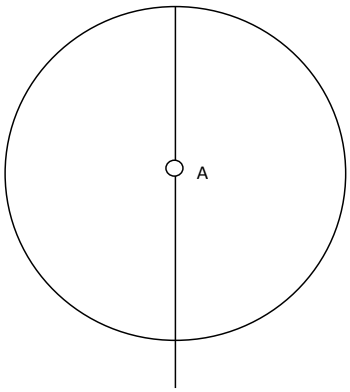
Nomenclature:

Ts = Absolute Temperature, Standard Conditions, 273 K
Ps = Absolute Pressure, Standard Conditions, 101.3 kPa
Ta = Absolute Temperature, Actual Conditions, K
Pa = Absolute Pressure, Actual Conditions, kPa
Ma = Water vapour, Actual Conditions, % Vol
Ms = Water vapour, Reference Conditions, % Vol
O_2a = Oxygen, Actual Conditions, % Vol
O_2s = Oxygen, Reference Conditions, % Vol

APPENDIX 2 - Summaries, Calculations, Raw Data and Charts

STACK DIAGRAM

	Value	Units
Stack Depth	0.25	m
Stack Width	-	m
Area	0.05	m^2



Sampling Line

Non-Isokinetic/Gases Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack	Units
A	%	50	m

Isokinetic Sampling			
Sampling Point	Distance (% of Depth)	Distance into Stack (m)	Swirl °
1	50.0	0.13	< 15
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
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-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-

○ Isokinetic sampling point
● Isokinetic sampling points not used
◎ Non Isokinetic/Gases sampling point

SAMPLING LOCATION

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - TOTAL PARTICULATE MATTER

Run	Sampled Volume	Sampled Gas Temp	Sampled Gas Pressure	Sampled Gas Humidity	Oxygen Content	Limit of Detection	Leak	Uncollected Mass
	m^3	K	kPa	% by volume	% by volume	% by mass	%	mg
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 5% of ELV**	**≤ 2%**	**≤ 10% of ELV**
Run 1	0.001	2.0	0.50	1.0	N/A	0.22	-	-
as a %	0.07	0.68	0.49	1.0	N/A	0.49	0.76	0.001
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**	**Yes**

Run	Volume (STP)	Mass of particulate	O_2 Correction	Leak	Uncollected Mass	Combined uncertainty
	m^3	mg	-	mg/m^3	mg	
Run 1	1.42	5.0	1.0	0.015	0.0001	-
MU as mg/m^3	0.04	0.15	-	0.015	0.0001	**0.15**
MU as %	1.31	4.4	-	0.44	0.003	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.31**	**mg/m^3**	**9.2**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - DIOXINS & FURANS

Run	Sampled Volume m³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Leak %
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 2%**
Run 1	0.001	2.0	0.50	1.0	N/A	-
as a %	0.02	0.69	0.49	1.0	N/A	0.83
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**

Run	Volume (STP) m³	O2 Correction -	Leak ng/m³	Laboratory analysis -	Combined uncertainty
Run 1	5.5737	1.0	0.0001	-	-
MU as ng/m³	0.0003	-	0.0001	0.0019	**0.0020**
MU as %	1.3103	-	0.4794	10.00	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.004**	**ng/m³**	**20.2**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - CADMIUM & THALLIUM

Run	Sampled Volume m³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Concentration in impinger mg	Leak %
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**<5%**	**<=2%**
Run 1	0.001	2.0	0.50	1.0	0.1	0.0004	-
as a %	0.12	0.69	0.49	1.0	-	3.00	0.65
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**

Run	Volume (STP) m³	O2 Correction -	Leak mg/m³	Lab Uncertainty mg	Combined uncertainty
Run 1	0.79	-	0.00003	-	-
MU as mg	0.0001	-	0.00003	0.0008	**0.0008**
MU as %	1.3	-	0.3740	10.0	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.002**	**mg/m³**	**20.2**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - HEAVY METALS

Run	Sampled Volume m^3	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Concentration in impinger mg	Leak %
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**<5%**	**<=2%**
Run 1	0.001	2.0	0.50	1.0	0.10	0.002	-
as a %	0.12	0.73	0.49	1.0	-	3.00	0.65
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**

Run	Volume (STP) m^3	O2 Correction -	Leak mg/m^3	Lab Uncertainty mg	Combined uncertainty
Run 1	0.8388	-	0.0006	-	-
MU as mg/m^3	0.0021	-	0.0006	0.01533	**0.0155**
MU as %	1.3382	-	0.3740	10	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.03**	**mg/m^3**	**20.2**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - MERCURY

Run	Sampled Volume m³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Concentration in impinger mg	Leak %
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**<5%**	**<=2%**
Run 1	0.001	2.0	0.50	1.0	0.1	0.0002	-
as a %	0.12	0.69	0.49	1.0	-	3.0	0.65
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**

Run	Volume (STP) m³	O2 Correction -	Leak mg/m³	Lab Uncertainty mg	Combined uncertainty
Run 1	0.79	-	0.00002	-	-
MU as mg/m³	0.0001	-	0.00002	0.0005	**0.0005**
MU as %	1.3	-	0.37	10	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.001**	**mg/m³**	**20**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - NON-ISOKINETIC HYDROGEN CHLORIDE

Run	Sampled Volume m³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Concentration in impinger mg	Limit of Detection % by mass	Leak %
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**<5%**	**≤ 5% of ELV**	**<=2%**
Run 1	0.00004	2.0	0.50	1.0	0.10	0.02	0.004	-
as a %	0.03	0.69	0.50	1.0	-	3.0	3.0	1.35
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**	**Yes**

Run	Volume (STP) m³	Mass of Hydrogen Chloride mg	O2 Correction -	Leak mg/m³	Lab Uncertainty mg	Combined uncertainty
Run 1	0.13	0.12	-	0.0064	-	-
MU as mg/m³	0.01	0.02	-	0.0064	0.04	**0.05**
MU as %	1.3	3.0	-	0.78	5.0	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.10**	**mg/m³**	**12.1**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - NON-ISOKINETIC HYDROGEN FLUORIDE

Run	Sampled Volume m³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Concentration in impinger mg	Limit of Detection % by mass	Leak %
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**<5%**	**≤ 5% of ELV**	**<=2%**
Run 1	0.0001	2.0	0.50	1.0	0.100	0.002	0.001	-
as a %	0.03	0.69	0.07	1.0	-	3.0	3.0	1.3
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**	**Yes**

Run	Volume (STP) m³	Mass of Hydrogen Fluoride mg	O2 Correction -	Leak mg/m³	Lab Uncertainty mg	Combined uncertainty
Run 1	1.5	0.02	-	0.001	-	-
MU as mg/m³	0.001	0.003	-	0.001	0.0056	**0.0067**
MU as %	1.2	3.0	-	0.75	5.0	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.01**	**mg/m³**	**12.02**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - NON-ISOKINETIC SULPHUR DIOXIDE

Run	Sampled Volume m³	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Concentration in impinger mg	Limit of Detection % by mass	Leak %
MU required	**<=2%**	**<2.5 k**	**<=1%**	**<=1%**	**<=5%**	**<5%**	**≤ 5% of ELV**	**<=2%**
Run 1	0.00004	2.000	0.500	1.000	0.100	0.169	0.040	-
as a %	0.028	0.687	0.066	1.000	-	3.000	3.031	1.450
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**	**Yes**	**Yes**

Run	Volume (STP) m³	Mass of Sulphur Dioxide mg	O2 Correction -	Leak mg/m³	Lab Uncertainty mg	Combined uncertainty
Run 1	1.0013	1.3056	-	0.0767	-	-
MU as mg/m³	0.1113	0.2775	-	0.0767	0.4578	**0.552**
MU as %	1.2152	3.0308	-	0.8372	5.0	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**1.10**	**mg/m³**	**12.06**	**%**

(k is a coverage factor which gives a 95% confidence in the quoted figures)
Developed for the STA by R Robinson, NPL

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - MOISTURE

Run	Sampled Volume m^3	Sampled Gas Temp K	Sampled Gas Pressure kPa	Sampled Gas Humidity % by volume	Oxygen Content % by volume	Leak %
MU required	**≤ 2%**	**≤ 2%**	**≤ 1%**	**≤ 1%**	**≤ 10%**	**≤ 2%**
Run 1	0.001	2.0	0.50	1.0	N/A	-
as a %	0.07	0.68	0.49	1.0	N/A	0.76
compliant?	**Yes**	**Yes**	**Yes**	**Yes**	**N/A**	**Yes**
Run	Volume (STP) m^3	Mass Gained mg	O_2 Correction -	Leak mg/m^3	Uncollected Mass mg	Combined uncertainty
Run 1	1.4	191900	1.0	557.5	57.7	-
MU as % v/v	0.21	0.01	-	0.07	0.005	**0.22**
MU as %	1.3	0.05	-	0.44	0.03	-

R1 - Uncertainty expressed at a 95% confidence level (where k = 2)	**0.44**	**% v/v**	**2.8**	**%**

APPENDIX 3 - Measurement Uncertainty Budget Calculations

MEASUREMENT UNCERTAINTY BUDGET - VELOCITY & VOLUMETRIC FLOW RATE

Measured Velocity at Actual Conditions	6.0	m/s
Measured Volumetric Flow rate at Actual Conditions	1055	m³/hr

Performance Characteristics & Source of Value	Units	Values	Requirement	Compliant
Uncertainty of Local Gas Velocity Determination				
Uncertainty of pitot tube coefficient	-	0.010		
Uncertainty of mean local dynamic pressures	-	0.34		
Factor loading, function of the number of measurements.	3 readings	0.591	minimum 3	Yes
Range of measurment device	pa	1000		
Resolution	pa	1.00		
Calibration uncertainty	pa	2.35	<1% of Value or 20 Pa whichever is greater	Yes
Drift	% range	0.10		
Linearity	% range	0.06	<2% of value	Yes
Uncertainty of gas density determination				
Uncertainty of molar mass determination	kg/mol	0.00003		
Uncertainty of temperature measurement	K	1.62	<1% of value	Yes
Uncertainty of absolute pressure in the duct	pa	521		
Uncertainty associated with the estimate of density	-	0.008		
Uncertainty associated with the measurement of local velocity	-	0.0001		
Uncertainty associated with the measurement of mean velocity	-	0.0002		

Measurement Uncertainty - Velocity	m/s
Combined uncertainty	0.08
Expanded uncertainty at a 95% Confidence Interval	0.16

Note - The expanded uncertainty uses a coverage factor of k = 2.

Expanded Measurement Uncertainty of Velocity at a 95% Confidence Interval	%
Expressed as a % of the Measured Concentration	1.4
Expanded uncertainty at a 95% Confidence Interval	2.7

Measurement Uncertainty Volumetric Flow Rate	m³/hr
Combined uncertainty	28
Expanded uncertainty at a 95% Confidence Interval	55

Note - The expanded uncertainty uses a coverage factor of k = 2.

Expanded Measurement Uncertainty of Volumetric Flow Rate at a 95% Confidence Interval	%
Expressed as a % of the Measured Concentration	2.7
Expanded uncertainty at a 95% Confidence Interval	5.2

END OF REPORT