Appendix F: FTIR Report

FTIR Air Emissions Test to Measure Spiked CH_4/C_2F_6 at a MWC (Municipal Waste Combustor)

Performed At The
Covanta Lake Waste-to-Energy Facility
Okahumpka, Florida

Test Date(s)
April 30-May3, 2024

Performed For
Jacobs (Contractor to the USEPA)

Report No.
TRC Environmental Corporation Report 590447

Report Submittal Date

9/30/24

TRC Environmental Corporation
1429 Rock Quarry Road, Suite 116
Raleigh, North Carolina 27610
USA

T (919) 828-3150
F (919) 838-9661

Report Certification

I certify that to the best of my knowledge:

- Testing data and all corresponding information have been checked for accuracy and completeness.
- Sampling and analysis have been conducted in accordance with the approved protocol and applicable reference methods (as applicable).
- All deviations, method modifications, or sampling and analytical anomalies are summarized in the appropriate report narrative(s).
- This report contains a total of XXX pages - including coversheet, table of contents and certification pages.

Thomas Dunder, Ph.D.
Technical Director

6/13/24
Date

TRC was operating in conformance with the requirements of ASTM D7036-04 during this test program.

Jon T. Howard
TRC Emission Testing Manager

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EMISSION DEMONSTRATION STUDY

1.0 INTRODUCTION

TRC Environmental Corporation (TRC) performed an emissions demonstration at the Covanta Lake Waste-to-Energy Facility of Jacobs in Okahumpka, Florida on April 30-May 2, 2024. The tests were authorized by and performed for Jacobs.

The purpose of the test was to use an FTIR analyzer to detect CF_4 and C_2F_6 that have been spiked into the municipal waste combustor (MWC) effluent upstream of combustion. In addition, extensive dynamic matrix spiking of CF_4 and C_2F_6 was conducted. The test served to determine if these indicator compounds, which are potential Products of Incomplete Combustion (PICs) from PFAS entering the MWC, can be detected using a high sensitivity FTIR analyzer in an MWC emissions matrix. If successful, the project will demonstrate that FTIR instrumentation can be used as an indication of complete destruction of PFAS in combustion or incineration.

1.1 Project Contact Information

Participants		
Test Facility	Covanta Lake Waste-to-Energy Facility Okahumpka, Florida 27711	
Test Coordinator	Jacobs Mail Code E305-04, 109 T.W. Alexander Drive Research Triangle Park, NC 27711	Matt Allan Senior Chemist 919.541.5329 (o) 919.349.4802 (m) Allen.Matt@epa.gov
EPA Observer	U.S. Environmental Protection Agency - Office of Research and Development Center for Environmental Measurement and Modeling 109 T.W. Alexander Drive (MS E343-04) Research Triangle Park, NC 27711	Jeff Ryan Senior Scientist (919) 541-1437 ryan.jeff@epa.gov
Air Emissions Testing Body (AETB)	TRC Environmental Corporation 1429 Rock Quarry Road, Suite 116 Raleigh, North Carolina 27610	Thomas Dunder, Ph.D. Technical Director (919) 593-6592 (phone) tdunder@trccompanies.com

The tests were conducted by Jim Barufaldi and Charles Vu of TRC. Documentation of the on-site ASTM D7036-04 Qualified Individual(s) (QI) is appended. Jeff Ryan of the EPA Office of Research and Development observed the program.

1.2 Facility and Process Description

The Covanta Lake Waste-to-Energy Facility operates the municipal waste combustor that was tested. The Lake facility generates electricity via the combustion of municipal waste. Since municipal waste includes consumer waste and other materials PFAS compounds can be present and have the potential to be emitted or destroyed in the combustion process. The testing included OTM-45 measurements by another contractor to determine if PFAS was in the air emissions. TRC conducted FTIR measurements to measure CF_4 and C_2F_6 as these compounds were spiked into the facility upstream of the combustion zone.

2.0 EXECUTIVE SUMMARY OF RESULTS

The results of this test program are summarized in the numerous tables in this report for each spiking condition. Continuous measurements were conducted as the facility operated. EPA injected CF_4 and C_2F_6 gases upstream of the combustor numerous times during the test. Dynamic matrix spiking was conducted using 4 different CF_4 and C_2F_6 gases during each day of testing. TRC has provided the detailed data to EPA in electronic form so that the injection data can be evaluated.

The table below summarizes the test methods used at the test location:

Unit ID/ Sample Location	Parameter Measured	Test Method	No. of Runs	Run Duration
Outlet Stack	Carbon Tetrafluoride (CF_4)	ASTM D6348	Continuous	All Test Day
	Hexafluoroethane (C_2F_6)	ASTM D6348	Continuous	All Test Day
	Moisture Content (*Bws*)	ASTM D6348	Continuous	All Test Day

3.0 DISCUSSION OF RESULTS

TRC operated 2 FTIR systems, an IMACC measuring a direct extractive, hot/wet sample. An MKS FTIR measured downstream of the sample conditioning system, so it measured a cool/dry sample. Both CF_4 and C_2F_6 are insoluble in water so they were not removed in the conditioning process. The original test plan only called for using the IMACC FTIR, but there was a second MKS FTIR already mounted in the mobile laboratory and a decision was made onsite to conduct complimentary measurements of conditioned gas with the MKS.

It was discovered onsite that the IMACC FTIR had erroneously been set to a lower resolution (1 cm^{-1} versus the required 0.5 cm^{-1}) by the instrument vendor. As a result, the data collected on 4/30/24 and 5/1/24 was not usable because reference standards were not available at the lower resolution. The resolution was set correctly on 5/2/24 and acceptable data was collected. Therefore, MKS data is presented for 3 days and IMACC data for one day. No other problems were encountered with the test equipment during the test program.

There are significant differences between the data collected by the MKS (conditioned sample) and the IMACC (direct extractive). The target analytes CF_4 (slightly water soluble, 20 mg/l) and C_2F_6 (negligibly soluble in water) can pass through the moisture conditioning system largely unaffected. Some negative bias in the CF_4 concentration may result because of the slight solubility. The moisture conditioning system removes any water-soluble compounds in the source gas, so besides moisture compounds such as HCl and HF, and to a lesser degree CO, SO_2, and NO/NO_2, are removed from the sample measured by the FTIR. Since water and, to a lesser extent SO_2, are spectral interferents for CF_4 and C_2F_6, their interference effects are minimized, and lower detection limits can be achieved. The approach of using sample conditioning to measure CF_4 and C_2F_6 by FTIR from high moisture sources such as combustion has potential utility to improve detection. Since CF_4 is slightly water soluble, the impact of conditioning in biasing the measurements low needs to be evaluated at each source via system calibrations and spike recoveries. It also must be stressed that other analytes of interest may be totally or partially removed from the measured gas stream. Other methods may be required to measure these analytes.

The IMACC FTIR was used for direct extractive measurements, and in contrast to the conditioned sample provided useful measurements of numerous other emission matrix components (H_2O, CO_2, CO, SO_2, NO, NO_2, HCl, HF, CH_2O, etc.). The moisture at this source exceeded 20% so there was considerable spectral interference. The CTS analysis was carefully programmed to minimize this interference. Since CF_4 spike recoveries at concentrations as low as 9 ppb were achieved with the IMACC system, it demonstrates that moisture interference did not significantly impact the measurements.

While initially unplanned, the use of two FTIR systems on separate gas streams (conditioned and direct extractive) demonstrated two viable approaches to measuring CF_4 and C_2F_6 in combustion sources. It should be noted that the MKS FTIR has inherently higher detection limits than the IMACC due to the different cell pathlengths (5.11 m MKS vs. 14.88 m IMACC) but was able to detect CF_4 spike recoveries at concentrations as low as 9 ppb because water interference was removed in the conditioned sample. Detection limits depend on pathlength, absorbance of IR light by each analyte, and the presence of spectral interferents. Increasing pathlength or removing spectral interference will result in lower detection limits.

Source operation appeared normal during the entire test program. No changes or problems were encountered except the IMACC resolution issue that required modification of any procedures presented in the test plan. No adverse test or environmental conditions were encountered during of this test program.

4.0 SAMPLING AND ANALYSIS PROCEDURES

All testing, sampling, analytical, and calibration procedures used for this test program were performed in accordance with the methods presented in the following sections. Where applicable, the Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods, USEPA 600/R-94/038c, September 1994 was used to supplement procedures.

4.1 Determination of Sample Point Locations

Sampling was conducted at the exhaust stack downstream of all pollution control equipment. The probe sampled at a single port in the small square duct that was as close to the center as practical. There were only two ports in one side of the duct and OTM-45 testing used the other port.

4.2 Moisture Determination by ASTM D6348-12.

Per Section 16.3 of Method 4, this method is an applicable alternative for the determination of the moisture content of stack gas. Please refer to Section 4.3 for additional detail.

4.3 Analyte Determination by ASTM D6348-12 FTIR Test Method

This method applies to the analysis of vapor phase organic or inorganic compounds which absorb energy in the mid-infrared spectral region, about 400 to 4000 cm^{-1} (25 to 2.5µm). This method is used to determine compound-specific concentrations in a multi-component vapor phase sample, which is contained in a closed-path gas cell. Spectra of samples are collected using double beam infrared absorption spectroscopy. The various components of the matrix are identified and quantified by absorbance of infrared radiation. A computer program is used to analyze spectra and report compound concentrations.

Two FTIR systems were used in the testing. An IMACC FTIR spectrometer was used for measurements of extracted, hot/wet, stack gas. This analyzer has a heated adjustable path gas cell that was set to ~14 meters. An MKS FTIR was used for measurements of conditioned gas, where moisture had been removed. The MKS has a fixed-length 5.11-meter heated gas cell. Both FTIR systems used liquid nitrogen cooled MCT (mercury cadmium telluride) traditional detectors. The spectral resolution of both analyzers was

0.5 cm^{-1} (wavenumbers). The instruments were calibrated using the MKS digital library of reference spectra, and all measurements and analytical results were recorded and stored digitally. The source emissions were extracted from the single sampling point in the gas stream and then transported to the FTIR analyzer via a heated, extractive sampling system.

FTIR system calibration was verified on site through direct and system calibration measurements using gas standards. These gases included the method-required CTS (calibration transfer standard, 10 ppm Ethylene) and a zero gas (nitrogen). Additional calibration measurements were conducted using. Dynamic matrix spiking was conducted using high (500 ppm) and low (1 ppm) concentration CF_4 and C_2F_6 gas standards. The matrix spiking dilution ratio was determined through separate spiking measurements using a sulfur hexafluoride (SF_6) tracer gas that was blended into the CF_4 and C_2F_6 gas standards.

FTIR Testing Details:

- The sampling system flow rate was 8 liters/minute.
- The sampling system included a heated probe maintained at 350 ^oF that utilized either a heated steel frit filter at the probe exit to remove particulate. The heated sampling umbilical was 100' in length.
- The sampling system components (heated sample line, heated head pump, heated manifold) and the FTIR gas cell were maintained at 350 ^oF.
- FTIR spectra were collected for one minute per sample and measured continuously during each test period.
- A system zero was measured at the start and end of each test day by flowing nitrogen through the sampling system to verify the absence of system bias.

The FTIR spectra were analyzed for the same gaseous components for both FTIR systems. These analytes included:

- Carbon Dioxide
- Carbon Monoxide
- Sulfur Dioxide
- Nitric Oxide
- Nitrous Oxide
- Nitrogen Dioxide
- Methane
- Ethylene
- Formaldehyde
- Water
- Hydrogen Chloride
- Hydrogen Fluoride

- Carbon Tetrafluoride
- Hexafluoroethane
- Sulfur Hexafluoride

Different software was used to operate the 2 FTIR systems and analyze the data from each. The MKS FTIR used the MG2000 software from MKS and the IMACC used the WaveRunIR™ software from Spectrum Environmental Solutions. The detailed analysis for each compound (regions used for analysis, identifying interferences, linearity calculation, etc.) was different for the 2 FTIR systems since each manufacturer's software was employed.

In addition, since both high (500 ppm) and very low (ppb-level) concentrations were measured for CF_4 and C_2F_6, separate analytical methods were developed for these compounds for the low and high levels. The high CF_4 and C_2F_6 calibrations were only used when measuring the direct and system calibration of the ~500 ppm standards for each gas. All lower concentrations were measured with the low concentration calibrations. The screen shots below show the low and high CF_4 calibrations for the MKS software.

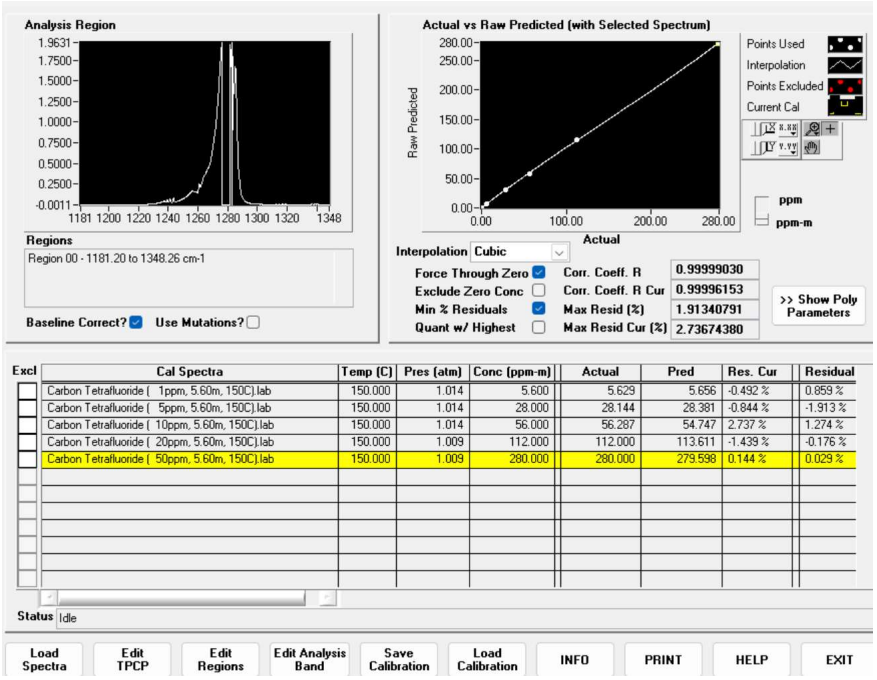


Figure 1: CF_4 Low Calibration (MKS Software)

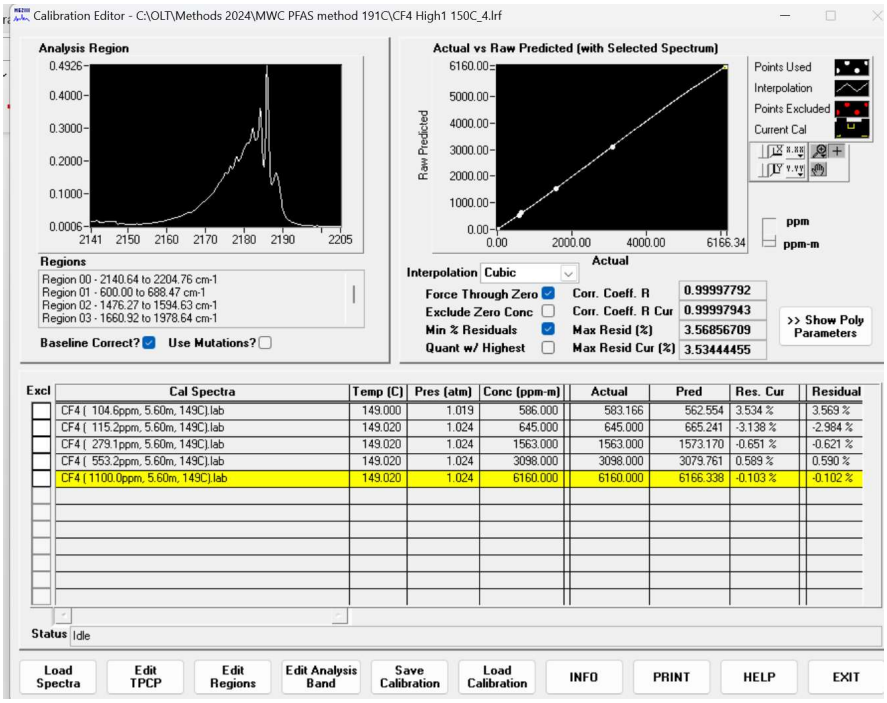


Figure 2: CF_4 High Calibration (MKS Software)

FTIR QA data can be found in **Appendix A.** The report appendix includes summaries of QA data collected during the test program. QA procedures included system checks, direct and system calibration and zero measurements, detector linearity checks, dynamic matrix spiking, and verification of analysis accuracy by manual subtraction. The analysis at each location was confirmed by manual subtraction of the measured compounds from a representative spectrum from each source. This confirmation served to validate the computerized FTIR analysis and demonstrate that additional compounds were not present at detectable concentrations.

Flue gas was transported to the analyzer via a heated, extractive sample system with temperature maintained greater than 250°F. After assembly and warm-up, the sample system was checked for leaks by capping the end of the sample probe and verifying that no sample flowed through the system via an in-line rotameter.

Instrument and sample system responses to calibration gas were verified on-site using:

1. A calibration transfer standard (CTS) gas (ppm-range Ethylene in nitrogen),
2. A Nitrogen zero gas,
3. CF_4 and C_2F_6 gas standards with a tracer component (ppm-range sulfur hexafluoride in nitrogen)
4. A CO_2 gas standard

Matrix spiking using the CF_4 and C_2F_6 gas standards was performed numerous times during the testing.

The FTIR Classical Least Squares (CLS) approach was used to calculate the concentrations of target compounds on a wet basis and the residual, which is the error associated with each reported concentration.

The analysis was confirmed by manual subtraction of the measured compounds from a representative spectrum. This confirmation served to validate the computerized FTIR analysis.

5.0 QUALITY ASSURANCE PROCEDURES

TRC integrates our Quality Management System (QMS) into every aspect of our testing service. We follow the procedures specified in current published versions of the test Method(s) referenced in this report. Any modifications or deviations are specifically identified in the body of the report. We routinely participate in independent, third party audits of our activities, and maintain:

- Accreditation from the Louisiana Environmental Laboratory Accreditation Program (LELAP);
- Accreditation from the Stack Testing Accreditation Council (STAC) and the American Association for Laboratory Accreditation (A2LA) that our operations conform with the requirements of ASTM D 7036 as an Air Emission Testing Body (AETB).

These accreditations demonstrate that our systems for training, equipment maintenance and calibration, document control and project management will fully ensure that project objectives are achieved in a timely and efficient manner with a strict commitment to quality.

All calibrations are performed in accordance with the test Method(s) identified in this report. If a Method allows for more than one calibration approach, or if approved alternatives are available, the calibration documentation in the appendices specifies which approach was used. All measurement devices are calibrated or verified at set intervals against standards traceable to the National Institute of Standards and Technology (NIST). NIST traceability information is available upon request.

ASTM D7036-04 specifies that: *"AETBs shall have and shall apply procedures for estimating the uncertainty of measurement. Conformance with this section may be demonstrated by the use of approved test protocols for all tests. When such protocols are used, reference shall be made to published literature, when available, where estimates of uncertainty for test methods may be found."* TRC conforms with this section by using approved test protocols for all tests.

6.0 TEST RESULTS

6.1 Analyte Spiking Data

Summaries of the matrix spiking results are shown in the tables below.

Table 1: MKS Spiking Results

Date	Time	Spiked Compound	Meas. Spike Cylinder Conc.	Dilution Ratio	Expected Spike ppm	Measured Spike ppm	% Recovery	Comment
4/30/2024	9:27:53 AM	CF4	0.96	7.3	0.133	0.12	93.4%	12 ppb spike
4/30/2024	10:19:31 AM	CF4	0.96	29.8	0.032	0.030	91.2%	
4/30/2024	11:18:49 AM	CF4	0.96	78.6	0.012	0.012	96.3%	
4/30/2024	4:22:36 PM	C2F6	532.55	244.6	2.2	1.9	89.0%	Spike during Injection
5/1/2024	11:13:19 AM	C2F6	0.96	22.1	0.044	0.054	124.3%	
5/1/2024	11:34:11 AM	C2F6	0.96	97.1	0.010	0.010	99.4%	10 ppb spike
5/1/2024	12:00:33 PM	C2F6	0.96	131.9	0.0073	0.0090	123.2%	9 ppb spike
5/1/2024	2:13:26 PM	CF4	524.80	123.9	4.2	5.3	125.3%	Spike during Injection
5/1/2024	3:40:12 PM	C2F6	532.55	176.1	3.0	3.2	105.2%	Spike during Injection
5/1/2024	3:55:34 PM	C2F6	532.55	114.6	4.6	4.3	92.3%	Spike during Injection
5/2/2024	8:24:05 AM	C2F6	532.5	31.9	16.7	17.4	104.0%	
5/2/2024	8:46:03 AM	C2F6	532.5	28.2	18.9	19.6	104.0%	
5/2/2024	9:08:01 AM	C2F6	532.5	126.4	4.2	4.6	108.2%	
5/2/2024	9:16:48 AM	C2F6	532.5	246.7	2.2	2.0	91.4%	
5/2/2024	3:25:32 PM	C2F6	532.5	121.1	4.4	4.5	102.7%	
5/2/2024	4:14:57 PM	C2F6	532.5	112.4	4.7	5.6	117.7%	Spike during Injection
5/2/2024	10:34:45 AM	CF4	0.96	27.9	0.0	0.0	91.2%	
5/2/2024	1:29:22 PM	CF4	0.96	138.4	0.0	0.0	101.8%	7 ppb spike

Table 2: IMACC Spiking Results

Date	Time	Spiked Compound	Meas. Spike Cylinder Conc.	Dilution Ratio	Expected Spike ppm	Measured Spike ppm	% Recovery	Comment
5/2/2024	8:22:43 AM	C2F6	502.1	34.9	14.4	17.3	120.2%	
5/2/2024	8:43:44 AM	C2F6	502.1	33.1	15.2	17.9	117.9%	Replicate spike
5/2/2024	9:02:44 AM	C2F6	502.1	54.4	9.2	7.5	81.4%	
5/2/2024	8:56:44 AM	C2F6	502.1	313.7	1.6	1.7	107.0%	
5/2/2024	10:19:43 AM	CF4	1.2	33.1	0.036	0.042	118.1%	
5/2/2024	11:17:44 AM	CF4	1.2	38.3	0.031	0.026	84.6%	Replicate spike
5/2/2024	12:28:43 PM	CF4	1.2	123.7	0.010	0.009	96.3%	9 ppb spike
5/2/2024	3:33:44 PM	C2F6	502.1	128.4	3.9	4.1	104.9%	
5/2/2024	4:08:44 PM	C2F6	502.1	153.5	3.3	4.2	126.9%	

Spiking plots and emission tables are shown below. The spiking calculation tables are in the FTIR QA appendix. The emission tables include data for each spiking test and includes data before and after the spike was applied. The concentrations of several other compounds are included to demonstrate the source conditions during spiking.

6.2 MKS Analyte Spiking Data

EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348 CF4 Spiking						
Company:	**Covanta**		**Date:**	**4/30/2024**	**Page 1**	
Plant:	**Lake**		**TRC Project**	**590447**		
Unit:	**MWC**		**TRC ENVIRONMENTAL**			
	Date		04/30/24	04/30/24	04/30/24	
	Start Time		9:03	10:01	10:33	
	End Time		10:00	10:32	11:00	
	Spike		CF4	CF4	CF4	Average
Moisture	Moisture Method 320	Fraction	0.00049	0.00049	0.00050	0.00049
	Carbon Tetrafluoride CF4 Low	ppmvw	0.054	0.023	0.019	0.032
MW=	88.0043	ppmvd	0.054	0.023	0.019	0.032
	Sulfur Hexafluoride SF6	ppmvw	0.098	0.029	0.021	0.049
MW=	146.06	ppmvd	0.098	0.029	0.021	0.049
	Hexafluoroethane C2F6 Low	ppmvw	0.017	0.018	0.019	0.018
MW=	138.01	ppmvd	0.017	0.018	0.019	0.018
	Carbon Monoxide CO	ppmvw	8.1	10.1	10.7	9.6
MW=	28.01	ppmvd	8.1	10.1	10.7	9.6
	Sulfur Dioxide SO2	ppmvw	<0.037	<0.037	0.212	<0.096
MW=	64.065	ppmvd	<0.037	<0.037	0.212	<0.125
	Nitric Oxide NO	ppmvw	89.1	97.8	106.8	97.9
MW=	30.006	ppmvd	89.2	97.9	106.9	98.0
	Formaldehyde CH2O	ppmvw	<0.022	<0.021	<0.02	<0.021
MW=	30.026	ppmvd	<0.022	<0.021	<0.02	<0.021
	Hydrogen Chloride HCl	ppmvw	<0.049	<0.046	<0.043	<0.046
MW=	36.4606	ppmvd	<0.049	<0.046	<0.043	<0.046
EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348 CF4 Spiking						
Company:	**Covanta**		**Date:**	**4/30/2024**	**Page 2**	
Plant:	**Lake**		**TRC Project**	**590447**		
Unit:	**MWC**		**TRC ENVIRONMENTAL**			
	Test Run		1	2	3	Average
	Water H2O	%	0.049	0.049	0.050	0.049
M320	MW = 18.016	Fraction	0.00049	0.00049	0.00050	0.00049
	Carbon Dioxide CO2	%, Wet	7.9	8.1	8.4	8.1

Table 3: CF_4 Spike, MKS

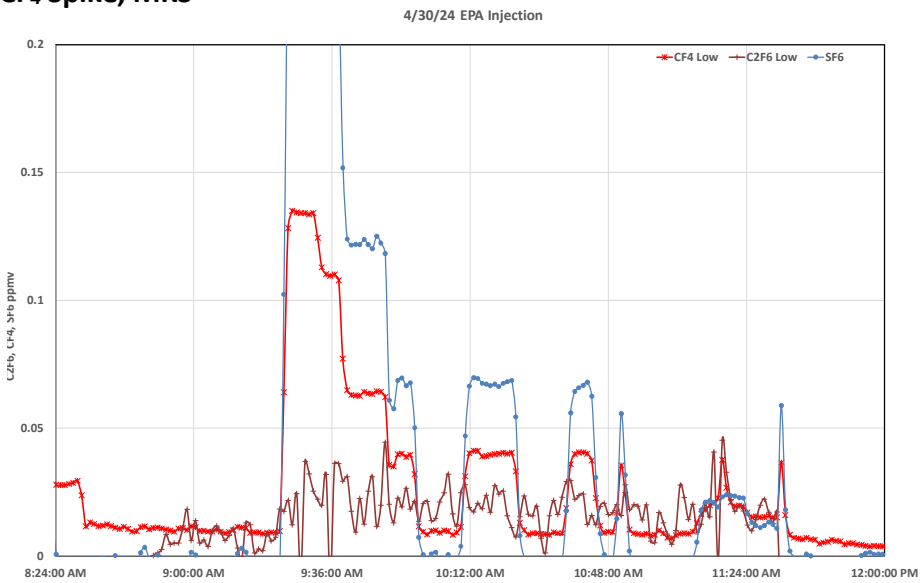


FIGURE 3: CF_4 SPIKING PLOT, MKS FTIR

EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348 C2F6 Spiking						
Company:	**Covanta**		**Date:**	**4/30/2024**	**Page 1**	
Plant:	**Lake**		**TRC Project**	**590447**		
Unit:	**MWC**		**TRC ENVIRONMENTAL**			
	Date		04/30/24	05/01/24	05/01/24	
	Start Time		15:40	15:05	15:39	
	End Time		16:35	15:38	16:01	
	Spike		C2F6	C2F6	C2F6	Average
Moisture	Moisture Method 320	Fraction	0.00051	0.00016	0.00013	0.00027
	Carbon Tetrafluoride CF4 Low	ppmvw	<0.01	0.59	0.033	<0.21
MW=	88.0043	ppmvd	<0.01	0.59	0.033	<0.21
	Sulfur Hexafluoride SF6	ppmvw	<0.0013	0.0063	0.013	<0.0068
MW=	146.06	ppmvd	<0.0013	0.0063	0.013	<0.0068
	Hexafluoroethane C2F6 Low	ppmvw	1.8	2.2	4.1	2.7
MW=	138.01	ppmvd	1.8	2.2	4.1	2.7
	Carbon Monoxide CO	ppmvw	9.1	7.4	6.9	7.8
MW=	28.01	ppmvd	9.1	7.4	6.9	7.8
	Sulfur Dioxide SO2	ppmvw	26.4	<0.071	<0.093	<8.856
MW=	64.065	ppmvd	26.4	<0.071	<0.093	<26.416
	Nitric Oxide NO	ppmvw	104.5	93.0	94.6	97.4
MW=	30.006	ppmvd	104.6	93.0	94.6	97.4
	Formaldehyde CH2O	ppmvw	<0.022	<0.019	<0.019	<0.02
MW=	30.026	ppmvd	<0.022	<0.019	<0.019	<0.019
	Hydrogen Chloride HCl	ppmvw	<0.043	<0.046	<0.045	<0.045
MW=	36.4606	ppmvd	<0.043	<0.046	<0.045	<0.046

EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348 C2F6 Spiking						
Company:	**Covanta**		**Date:**	**4/30/2024**	**Page 2**	
Plant:	**Lake**		**TRC Project**	**590447**		
Unit:	**MWC**		**TRC ENVIRONMENTAL**			
	Test Run		1	2	3	Average
	Water H2O	%	0.051	0.016	0.013	0.027
M320	MW = 18.016	Fraction	0.00051	0.00016	0.00013	0.00027
	Carbon Dioxide CO2	%, Wet	8.5	8.5	8.6	8.5

Table 4: C_2F_6 Spike, MKS

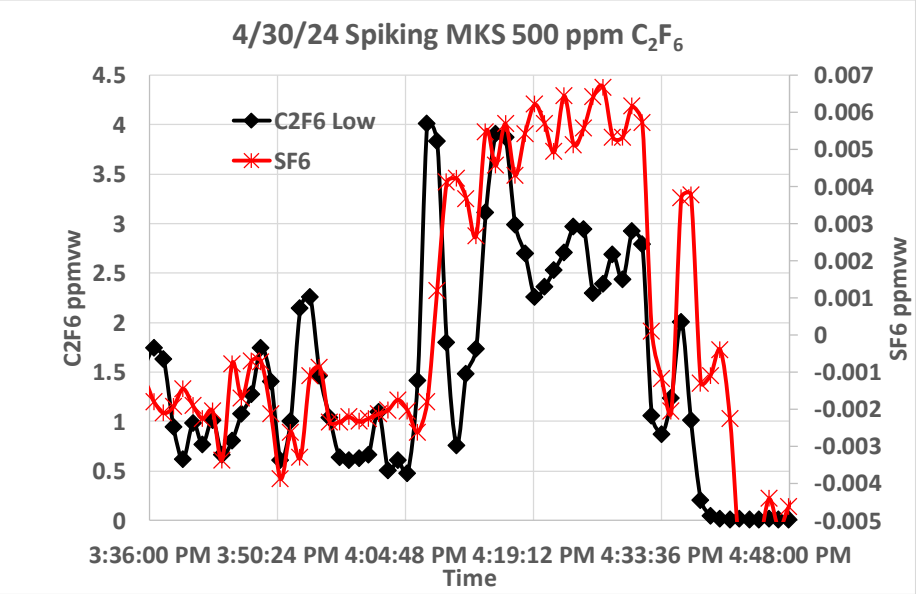


FIGURE 4: C_2F_6 SPIKING PLOT, MKS FTIR

EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348 C2F6 Spiking						
Company:	**Covanta**		**Date:**	**5/1/2024**	**Page 1**	
Plant:	**Lake**		**TRC Project**	**590447**		
Unit:	**MWC**		**TRC ENVIRONMENTAL**			
	Date		05/01/24	05/01/24	05/01/24	
	Start Time		11:00	11:32	11:51	
	End Time		11:30	11:50	12:20	
	Spike		C_2F_6	C_2F_6	C_2F_6	Average
Moisture	Moisture Method 320	Fraction	0.00012	0.00014	0.00017	0.00015
	Carbon Tetrafluoride CF4 Low	ppmvw	0.030	0.023	0.012	0.022
MW=	88.0043	ppmvd	0.030	0.023	0.012	0.022
	Sulfur Hexafluoride SF6	ppmvw	0.035	0.012	0.010	0.019
MW=	146.06	ppmvd	0.035	0.012	0.010	0.019
	Hexafluoroethane C2F6 Low	ppmvw	0.051	0.040	0.038	0.043
MW=	138.01	ppmvd	0.051	0.040	0.038	0.043
	Carbon Monoxide CO	ppmvw	5.6	6.1	8.2	6.6
MW=	28.01	ppmvd	5.6	6.1	8.2	6.6
	Sulfur Dioxide SO2	ppmvw	<0.04	<0.04	<0.039	<0.039
MW=	64.065	ppmvd	<0.04	<0.04	<0.039	<0.04
	Nitric Oxide NO	ppmvw	96.5	88.2	86.1	90.3
MW=	30.006	ppmvd	96.5	88.3	86.1	90.3
	Formaldehyde CH2O	ppmvw	<0.022	<0.023	<0.021	<0.022
MW=	30.026	ppmvd	<0.022	<0.023	<0.021	<0.023
	Hydrogen Chloride HCl	ppmvw	<0.049	<0.052	<0.048	<0.049
MW=	36.4606	ppmvd	<0.049	<0.052	<0.048	<0.052
EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348 C2F6 Spiking						
Company:	**Covanta**		**Date:**	**5/1/2024**	**Page 2**	
Plant:	**Lake**		**TRC Project**	**590447**		
Unit:	**MWC**		**TRC ENVIRONMENTAL**			
	Test Run		1	2	3	Average
	Water H2O	%	0.012	0.014	0.017	0.015
M320	MW = 18.016	Fraction	0.00012	0.00014	0.00017	0.00015
	Carbon Dioxide CO2	%, Wet	8.4	8.2	8.0	8.2

Table 5: C_2F_6 Spike, MKS

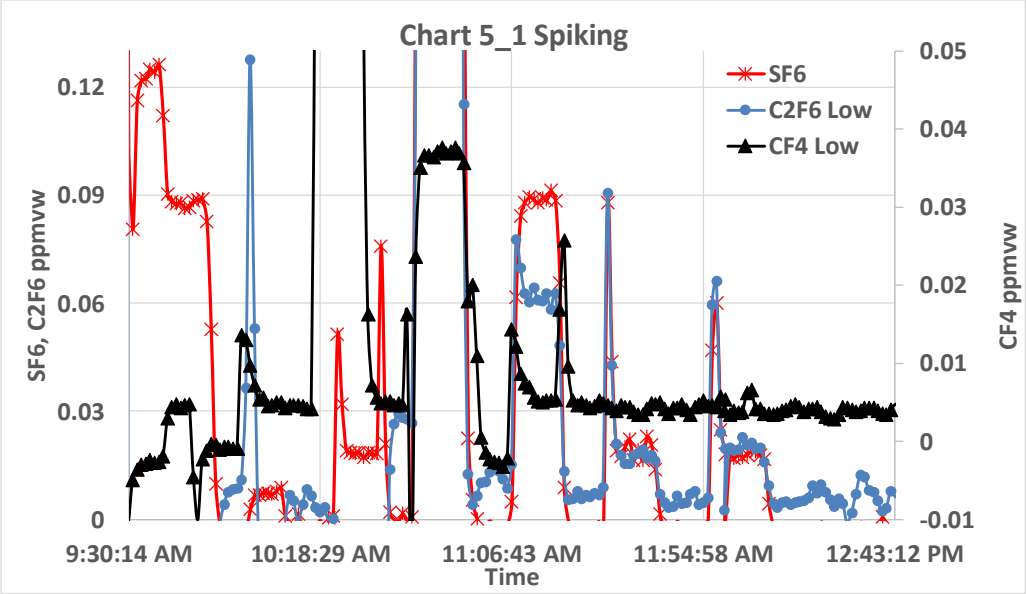


FIGURE 5: C_2F_6 SPIKING PLOT, MKS FTIR

EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348 C2F6 Spiking						
Company:	**Covanta**		**Date:**	**5/2/2024**	**Page 1**	
Plant:	**Lake**		**TRC Project**	**590447**		
Unit:	**MWC**		**TRC ENVIRONMENTAL**			
	Date		05/02/24	05/02/24	05/02/24	
	Start Time		8:15	8:33	9:01	
	End Time		8:32	9:00	9:31	
	Spike		C2F6	C2F6	C2F6	Average
Moisture	Moisture Method 320	Fraction	0.00020	0.00022	0.00027	0.00023
	Carbon Tetrafluoride CF4 Low	ppmvw	<0.029	<0.029	<0.014	<0.024
MW=	88.0043	ppmvd	<0.029	<0.029	<0.014	<0.029
	Sulfur Hexafluoride SF6	ppmvw	0.029	0.028	0.011	0.022
MW=	146.06	ppmvd	0.029	0.028	0.011	0.022
	Hexafluoroethane C2F6 Low	ppmvw	7.2	7.1	3.0	5.7
MW=	138.01	ppmvd	7.2	7.1	3.0	5.7
	Carbon Monoxide CO	ppmvw	11.0	9.7	7.9	9.6
MW=	28.01	ppmvd	11.0	9.7	7.9	9.6
	Sulfur Dioxide SO2	ppmvw	<0.14	<0.14	<0.07	<0.12
MW=	64.065	ppmvd	<0.14	<0.14	<0.07	<0.14
	Nitric Oxide NO	ppmvw	109.0	107.6	121.3	112.6
MW=	30.006	ppmvd	109.0	107.6	121.3	112.7
	Formaldehyde CH2O	ppmvw	<0.015	<0.016	<0.017	<0.016
MW=	30.026	ppmvd	<0.015	<0.016	<0.017	<0.016
	Hydrogen Chloride HCl	ppmvw	<0.035	<0.035	<0.037	<0.035
MW=	36.4606	ppmvd	<0.035	<0.035	<0.037	<0.035
EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348 C2F6 Spiking						
Company:	**Covanta**		**Date:**	**5/2/2024**	**Page 2**	
Plant:	**Lake**		**TRC Project**	**590447**		
Unit:	**MWC**		**TRC ENVIRONMENTAL**			
	Test Run		1	2	3	Average
	Water H2O	%	0.020	0.022	0.027	0.023
M320	MW = 18.016	Fraction	0.00020	0.00022	0.00027	0.00023
	Carbon Dioxide CO2	%, Wet	8.3	8.3	8.7	8.4

Table 6: C_2F_6 Spike, MKS

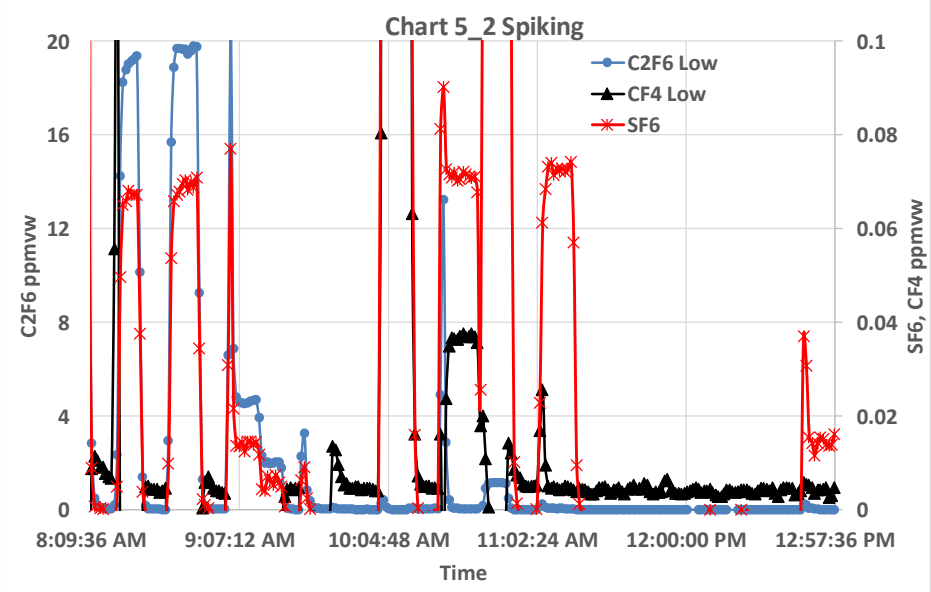


FIGURE 6: C_2F_6 SPIKING PLOT, MKS FTIR

EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348 C2F6 Spiking						
Company:	**Covanta**		**Date:**	**5/2/2024**	**Page 1**	
Plant:	**Lake**		**TRC Project**	**590447**		
Unit:	**MWC**		**TRC ENVIRONMENTAL**			
	Date		05/02/24	05/02/24	05/02/24	
	Start Time		9:01	15:00	15:57	
	End Time		9:31	15:56	16:25	
	Spike		C2F6	C2F6	C2F6	Average
Moisture	Moisture Method 320	Fraction	0.00027	0.00028	0.00021	0.00026
	Carbon Tetrafluoride CF4 Low	ppmvw	<0.014	0.50	<0.023	<0.178
MW=	88.0043	ppmvd	<0.014	0.50	<0.023	<0.257
	Sulfur Hexafluoride SF6	ppmvw	0.011	0.006	0.012	0.009
MW=	146.06	ppmvd	0.011	0.006	0.012	0.009
	Hexafluoroethane C2F6 Low	ppmvw	3.0	2.3	6.1	3.8
MW=	138.01	ppmvd	3.0	2.3	6.1	3.8
	Carbon Monoxide CO	ppmvw	7.9	7.3	7.2	7.5
MW=	28.01	ppmvd	7.9	7.3	7.2	7.5
	Sulfur Dioxide SO2	ppmvw	<0.074	<0.066	<0.134	<0.091
MW=	64.065	ppmvd	<0.074	<0.066	<0.134	<0.066
	Nitric Oxide NO	ppmvw	121.3	106.0	107.3	111.6
MW=	30.006	ppmvd	121.3	106.1	107.4	111.6
	Formaldehyde CH2O	ppmvw	<0.017	<0.017	<0.017	<0.017
MW=	30.026	ppmvd	<0.017	<0.017	<0.017	<0.017
	Hydrogen Chloride HCl	ppmvw	<0.037	<0.04	<0.04	<0.039
MW=	36.4606	ppmvd	<0.037	<0.04	<0.04	<0.04
EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348 C2F6 Spiking						
Company:	**Covanta**		**Date:**	**5/2/2024**	**Page 2**	
Plant:	**Lake**		**TRC Project**	**590447**		
Unit:	**MWC**		**TRC ENVIRONMENTAL**			
	Test Run		1	2	3	Average
	Water H2O	%	0.027	0.028	0.021	0.026
M320	MW = 18.016	Fraction	0.00027	0.00028	0.00021	0.00026
	Carbon Dioxide CO2	%, Wet	8.7	8.6	8.3	8.5

Table 5: C_2F_6 Spike, MKS

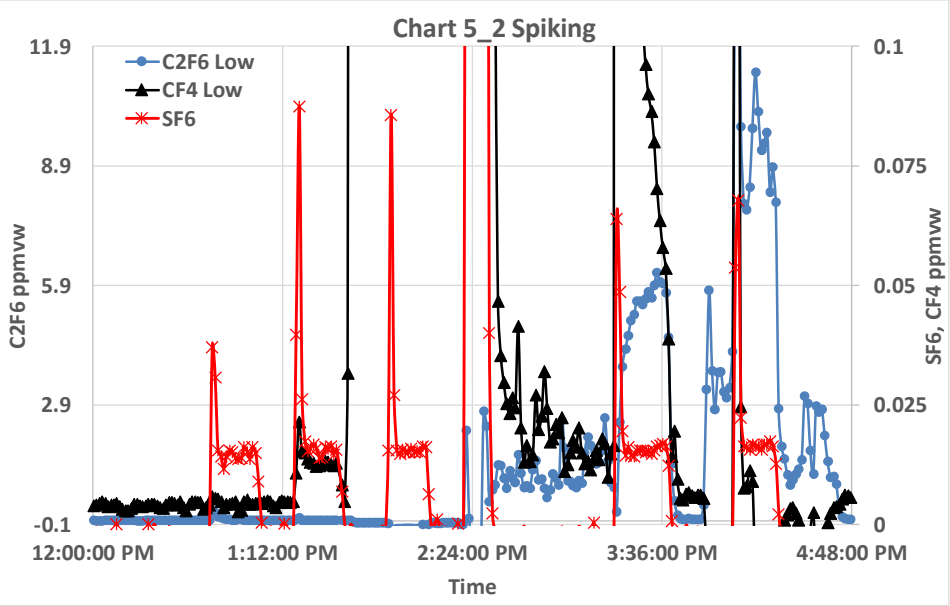


FIGURE 5: C_2F_6 SPIKING PLOT, MKS FTIR

EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348 CF4 Spiking						
Company:	**Covanta**		**Date:**	**5/2/2024**	**Page 1**	
Plant:	**Lake**		**TRC Project**	**590447**		
Unit:	**MWC**		**TRC ENVIRONMENTAL**			
	Date		05/02/24	05/02/24	05/02/24	
	Start Time		9:01	15:00	15:57	
	End Time		9:31	15:56	16:25	
	Spike		CF4	CF4	CF4	Average
Moisture	Moisture Method 320	Fraction	0.00027	0.00028	0.00021	0.00026
	Carbon Tetrafluoride CF4 Low	ppmvw	<0.014	0.50	<0.023	<0.178
MW=	88.0043	ppmvd	<0.014	0.50	<0.023	<0.257
	Sulfur Hexafluoride SF6	ppmvw	0.011	0.006	0.012	0.009
MW=	146.06	ppmvd	0.011	0.006	0.012	0.009
	Hexafluoroethane C2F6 Low	ppmvw	3.0	2.3	6.1	3.8
MW=	138.01	ppmvd	3.0	2.3	6.1	3.8
	Carbon Monoxide CO	ppmvw	7.9	7.3	7.2	7.5
MW=	28.01	ppmvd	7.9	7.3	7.2	7.5
	Sulfur Dioxide SO2	ppmvw	<0.074	<0.066	<0.134	<0.091
MW=	64.065	ppmvd	<0.074	<0.066	<0.134	<0.066
	Nitric Oxide NO	ppmvw	121.3	106.0	107.3	111.6
MW=	30.006	ppmvd	121.3	106.1	107.4	111.6
	Formaldehyde CH2O	ppmvw	<0.017	<0.017	<0.017	<0.017
MW=	30.026	ppmvd	<0.017	<0.017	<0.017	<0.017
	Hydrogen Chloride HCl	ppmvw	<0.037	<0.04	<0.04	<0.039
MW=	36.4606	ppmvd	<0.037	<0.04	<0.04	<0.04
EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348 CF4 Spiking						
Company:	**Covanta**		**Date:**	**5/2/2024**	**Page 2**	
Plant:	**Lake**		**TRC Project**	**590447**		
Unit:	**MWC**		**TRC ENVIRONMENTAL**			
	Test Run		1	2	3	Average
	Water H2O	%	0.027	0.028	0.021	0.026
M320	MW = 18.016	Fraction	0.00027	0.00028	0.00021	0.00026
	Carbon Dioxide CO2	%, Wet	8.7	8.6	8.3	8.5

Table 6: C_2F_6 Spike, MKS

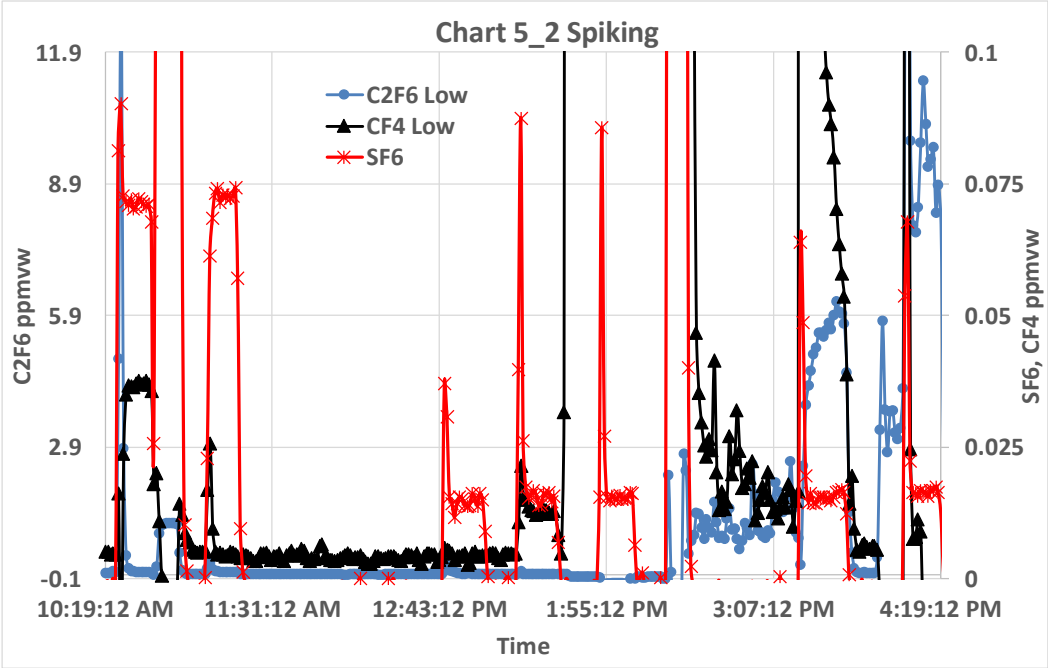


FIGURE 6: C_2F_6 SPIKING PLOT, MKS FTIR

6.3 IMACC Analyte Spiking Data

EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348						
Company:	Covanta		Date:	5/2/2024	Page 1	
Plant:	Lake		TRC Project	590447		
Unit:	MWC		TRC ENVIRONMENTAL			
	Date		05/02/24	05/02/24	05/02/24	
	Start Time		8:15	8:33	9:01	
	End Time		8:32	9:00	9:31	
	Spike		C2F6	C2F6	C2F6	Average
Moisture	Moisture Method 320	Fraction	0.22	0.23	0.23	0.23
	Carbon Tetrafluoride CF4 Low	ppmvw	<0.027	<0.028	<0.024	<0.026
MW=	88.0043	ppmvd	<0.027	<0.028	<0.024	<0.026
	Sulfur Hexafluoride SF6	ppmvw	0.092	0.094	0.084	0.090
MW=	146.06	ppmvd	0.12	0.12	0.11	0.12
	Hexafluoroethane C2F6 Low	ppmvw	7.7	7.3	2.8	5.9
MW=	138.01	ppmvd	9.9	9.5	3.7	7.7
	Carbon Monoxide CO	ppmvw	66.9	66.2	64.6	65.9
MW=	28.01	ppmvd	86.2	86.4	84.2	85.6
	Sulfur Dioxide SO2	ppmvw	74.0	79.5	79.1	77.5
MW=	64.065	ppmvd	95.4	103.7	103.2	100.7
	Nitric Oxide NO	ppmvw	123.1	124.0	137.2	128.1
MW=	30.006	ppmvd	158.6	161.9	178.9	166.5
	Hydrogen Chloride HCl	ppmvw	0.76	0.67	0.65	0.69
MW=	36.4606	ppmvd	0.97	0.87	0.85	0.90
	Formaldehyde CH2O	ppmvw	<0.017	<0.018	<0.018	<0.018
MW=	30.026	ppmvd	<0.022	<0.023	<0.024	<0.023
EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348						
Company:	Covanta		Date:	5/2/2024	Page 2	
Plant:	Lake		TRC Project	590447		
Unit:	MWC		TRC ENVIRONMENTAL			
	Test Run		1	2	3	Average
	Water H2O	%	22.4	23.4	23.3	23.0
M320	MW = 18.016	Fraction	0.22	0.23	0.23	0.23
	Carbon Dioxide CO2	%, Wet	10.0	10.2	10.6	10.3
M320	MW = 43.99	%, Dry Basis	12.9	13.3	13.9	13.3

Table 7: C_2F_6 Spike, IMACC FTIR

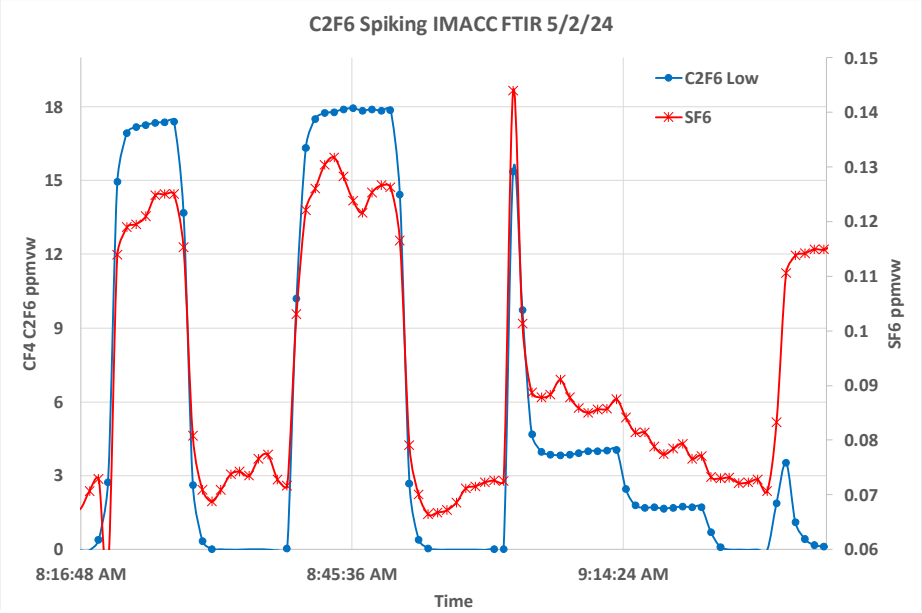


FIGURE 7: C_2F_6 SPIKING PLOT, IMACC FTIR

EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348						
Company:	Covanta		Date:	5/2/2024	Page 1	
Plant:	Lake		TRC Project	590447		
Unit:	MWC		TRC ENVIRONMENTAL			
	Date		05/02/24	05/02/24	05/02/24	
	Start Time		9:01	15:00	15:57	
	End Time		9:31	15:56	16:25	
	Spike		C2F6	C2F6	C2F6	Average
Moisture	Moisture Method 320	Fraction	0.23	0.21	0.21	0.22
	Carbon Tetrafluoride CF4 Low	ppmvw	<0.024	<0.026	<0.022	<0.024
MW=	88.0043	ppmvd	<0.024	<0.026	<0.022	<0.024
	Sulfur Hexafluoride SF6	ppmvw	0.084	0.083	0.087	0.085
MW=	146.06	ppmvd	0.11	0.11	0.11	0.11
	Hexafluoroethane C2F6 Low	ppmvw	2.8	2.3	5.9	3.7
MW=	138.01	ppmvd	3.7	2.9	7.4	4.7
	Carbon Monoxide CO	ppmvw	64.6	61.2	58.1	61.3
MW=	28.01	ppmvd	84.2	77.9	73.5	78.5
	Sulfur Dioxide SO2	ppmvw	79.1	77.7	68.6	75.1
MW=	64.065	ppmvd	103.2	99.0	86.7	96.3
	Nitric Oxide NO	ppmvw	137.2	122.1	124.5	127.9
MW=	30.006	ppmvd	178.9	155.4	157.3	163.9
	Hydrogen Chloride HCl	ppmvw	0.65	0.70	1.07	0.81
MW=	36.4606	ppmvd	0.85	0.89	1.35	1.03
	Formaldehyde CH2O	ppmvw	<0.018	0.0	0.0	<0.026
MW=	30.026	ppmvd	<0.024	0.0	0.0	<0.032

EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348						
Company:	Covanta		Date:	5/2/2024	Page 2	
Plant:	Lake		TRC Project	590447		
Unit:	MWC		TRC ENVIRONMENTAL			
	Test Run		1	2	3	Average
	Water H2O	%	23.3	21.5	20.9	21.9
M320	MW = 18.016	Fraction	0.23	0.21	0.21	0.22
	Carbon Dioxide CO2	%, Wet	10.6	10.0	9.9	10.2
M320	MW = 43.99	%, Dry Basis	13.9	12.8	12.5	13.1

Table 8: C_2F_6 Spike, IMACC FTIR

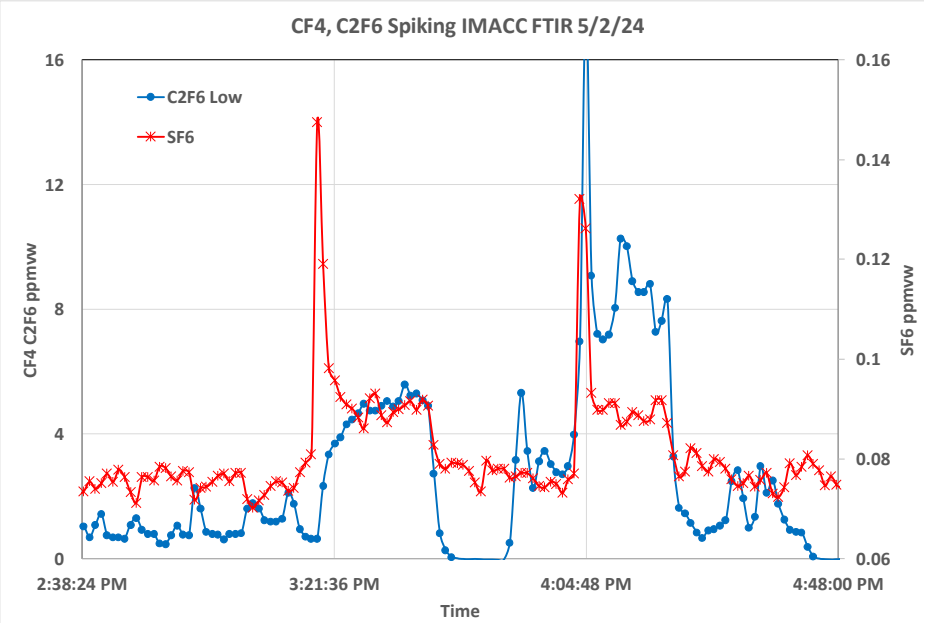


FIGURE 8: C_2F_6 SPIKING PLOT, IMACC FTIR

EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348						
Company:	Covanta		Date:	5/2/2024	Page 1	
Plant:	Lake		TRC Project	590447		
Unit:	MWC		TRC ENVIRONMENTAL			
	Date		05/02/24	05/02/24	05/02/24	
	Start Time		9:55	10:37	11:05	
	End Time		10:17	11:05	11:25	
	Spike		CF4	CF4	CF4	Average
Moisture	Moisture Method 320	Fraction	0.12	0.14	0.22	0.16
	Carbon Tetrafluoride CF4 Low	ppmvw	0.39	<0.014	<0.022	<0.143
MW=	88.0043	ppmvd	0.45	<0.014	<0.022	<0.16
	Sulfur Hexafluoride SF6	ppmvw	0.92	0.69	0.11	0.574
MW=	146.06	ppmvd	1.1	0.80	0.14	0.66
	Hexafluoroethane C2F6 Low	ppmvw	0.042	0.37	<0.016	<0.141
MW=	138.01	ppmvd	0.048	0.42	<0.02	<0.236
	Carbon Monoxide CO	ppmvw	33.3	41.2	62.5	45.7
MW=	28.01	ppmvd	37.9	47.8	80.0	55.2
	Sulfur Dioxide SO2	ppmvw	44.8	53.8	84.4	61.0
MW=	64.065	ppmvd	50.9	62.3	108.1	73.8
	Nitric Oxide NO	ppmvw	63.6	78.1	120.6	87.4
MW=	30.006	ppmvd	72.2	90.5	154.5	105.7
	Hydrogen Chloride HCl	ppmvw	0.33	0.39	0.62	0.45
MW=	36.4606	ppmvd	0.37	0.45	0.80	0.54
	Formaldehyde CH2O	ppmvw	<0.015	<0.015	<0.018	<0.016
MW=	30.026	ppmvd	<0.018	<0.018	<0.023	<0.018

EMISSIONS TEST RESULTS SUMMARY - ASTM Method D6348						
Company:	Covanta		Date:	5/2/2024	Page 2	
Plant:	Lake		TRC Project	590447		
Unit:	MWC		TRC ENVIRONMENTAL			
	Test Run		1	2	3	Average
	Water H2O	%	12.0	13.7	21.9	15.9
M320	MW = 18.016	Fraction	0.12	0.14	0.22	0.16
	Carbon Dioxide CO2	%, Wet	5.5	6.6	10.6	7.5
M320	MW = 43.99	%, Dry Basis	6.2	7.6	13.6	9.1

Table 9: CF_4 Spike, IMACC FTIR

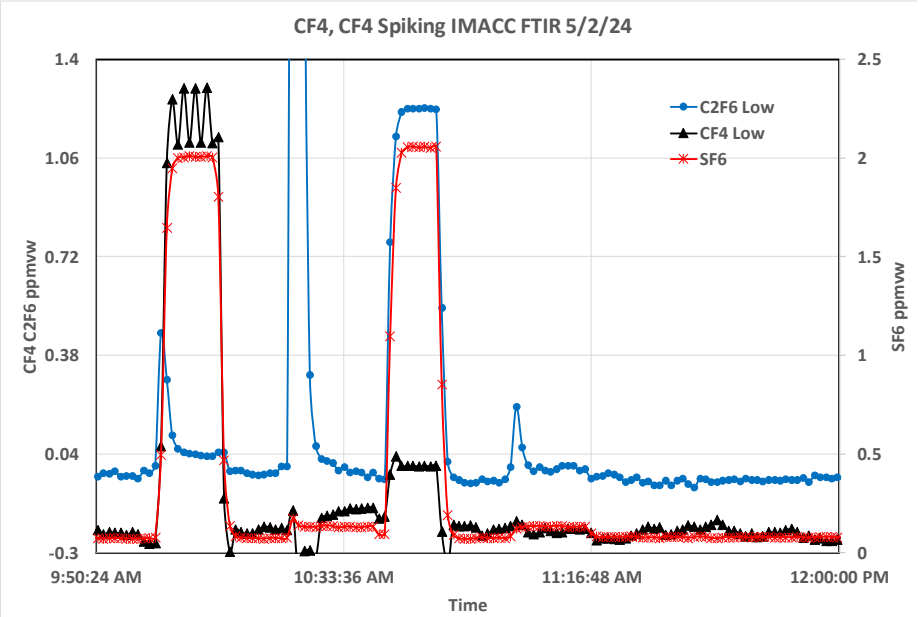


FIGURE 9: CF_4 SPIKING PLOT, IMACC FTIR

APPENDIX A: Qualified Individual Certificates

This is to Certify that:

Jim Barufaldi

Is a Qualified Individual as defined in Section 8.3 of ASTM D7036-04 for the following test methods:

EPA Methods 1, 1A, 2, 2A, 2C, 2D, 2F, 2G, 2H, 3, 3B, 4, 5, 5A, 5B, 5D, 5E, 5F, 5i, 17, 19, 201A, and 202.

The individual has met the minimum experience requirements defined in Section 8.3.4.2 of ASTM D7036-04 and has successfully passed a comprehensive examination for the test methods designated above.

This certification is effective until: 09-13-2024

Date of Issue: 09-18-2019

Certificate Number: 01516

Edward J MacKinnon
Air Measurements Practice Quality Manager

TRC

This certificate is the exclusive property of TRC and is non-transferable.

This is to Certify that:

Jim Barufaldi

Is a Qualified Individual as defined in Section 8.3 of ASTM D7036-04 for the following test methods:

EPA Methods 1, 2, 3, 4, 3B, 6, 6A, 6B, 7, 7C, 7D, 8, 11, 13A, 13B, 15A, 16A, 19, 26, 26A, and 202.

The individual has met the minimum experience requirements defined in Section 8.3.4.2 of ASTM D7036-04 and has successfully passed a comprehensive examination for the test methods designated above.

This certification is effective until: 09-16-2024

Date of Issue: 09-18-2019

Certificate Number: 01517

Edward J MacKinnon
Air Measurements Practice Quality Manager

TRC

This certificate is the exclusive property of TRC and is non-transferable.

This is to Certify that:

Jim Barufaldi

Is a Qualified Individual as defined in Section 8.3 of ASTM D7036-04 for the following test methods:

EPA Methods 1, 2, 3, 4, 12, 19, 29, 30B, 101, 101A, 102, and ASTM D6784-02.

The individual has met the minimum experience requirements defined in Section 8.3.4.2 of ASTM D7036-04 and has successfully passed a comprehensive examination for the test methods designated above.

This certification is effective until: 09-16-2024

Date of Issue: 09-18-2019

Certificate Number: 01519

Edward J MacKinnon
Air Measurements Practice Quality Manager

TRC

This certificate is the exclusive property of TRC and is non-transferable.

This is to Certify that:

James Barufaldi

Is a Qualified Individual as defined in Section 8.3 of ASTM D7036-04 for the following test methods:

EPA Test Methods 320 and 321

The individual has met the minimum experience requirements defined in Section 8.3.4.2 of ASTM D7036-04 and has successfully passed an internal comprehensive examination for the test methods designated above.

This certification is effective until: 01-06-2027

Date of Issue: 01-10-2022

Certificate Number: 01768

Edward MacKinnon
Air Measurements Practice Quality Manager

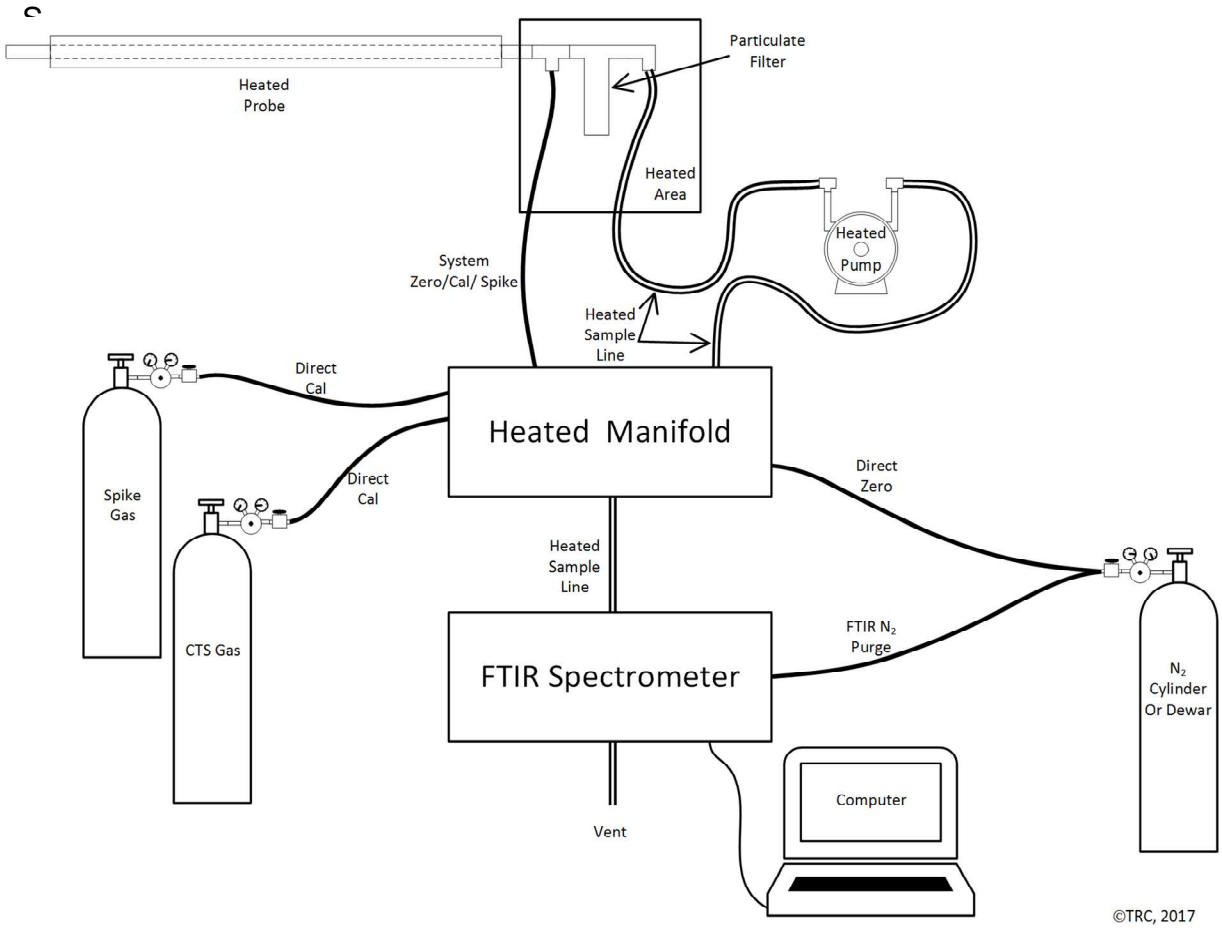
TRC

This certificate is the exclusive property of TRC and is non-transferable.

APPENDIX B: Sample Train Diagram

Measurement of Vapor Phase Organic and Inorganic Emissions by Extractive FTIR

ASTM Method D6348-12



APPENDIX C: ASTM Method D6348 QA Data

Quality control measures for the FTIR measurements included calibrations, bias checks, and system and instrument leak checks as well as verification and documentation of instrument performance. Testing was conducted at 1 source using one MKS FTIR analyzer, one IMACC FTIR analyzer, and a heated, extractive sampling system. The IMACC measured on a direct extractive, hot/wet basis. The MKS measured a conditioned sample after moisture removal.

As discussed in the main report, the IMACC FTIR had an issue during testing on 4/30/24 and 5/1/24 that made the data unusable without significant modification of the analytical program. The instrument had been set to measure at 1 cm^{-1} resolution instead of the required 0.5 cm^{-1} value. As a result, only data from 5/2/24 is presented. Some QA data, including calibration measurements and time response, were only performed on the earlier days and are not reported.

The FTIR system was challenged with direct and system calibration checks for several components. A CTS (calibration transfer standard) containing ethylene (C_2H_4, nominally 10 ppm) was used for local and system calibration checks and to verify the system pathlength. Nitrogen gas from a nitrogen cylinder was used for local and system zero checks. Four cylinders were used for direct and dynamic matrix spiking calibrations in addition to the ethylene CTS and a CO_2 standard used for direct and system calibrations:

Table 1: Calibration Gases

Cylinder ID	Expiration	Compound	ppm	Compound	ppm
CC124037	3/29/2032	CF4	511.7	SF6	2.101
ALM038592	4/4/2032	C2F6	502.9	SF6	2.103
CC178185	3/29/2032	CF4	1.020	SF6	2.059
CC440016	4/2/2032	C2F6	1.059	SF6	2.060
CC462799	9/15/2031	Ethylene	99.94		
EB0004004		O2	9.99 (%)	CO2	9.9 (%)

Measurement Equipment Leak Check, Detector Linearity Check

The sampling system was checked for leaks after assembly on-site and allowing all heated equipment to stabilize. The leak-check was performed by capping the end of the sample probe and observing the sampling system flow rate as measured by an inline rotameter. The rotameter indicated zero flow, showing the sampling system was leak free. A detector linearity check was performed by verifying that response in a region with no detector sensitivity (200-500 cm^{-1}) had no detectable signal (Figure 1).

Table 2: Sampling System Leak Check and Detector Linearity

Sampling System Leak Check	
Date Conducted	4/29/2024
Length of Sample Line (feet)	100
System Flow Rate (lpm)	8
Leak Check Flow Rate (lpm)	0
Allowable Leak Check Flow Rate (lpm)	0.2
Pass/Fail	**PASS**

MKS MCT Detector Saturation Check	
Date Conducted	4/30/2024
Maximum Signal 200-500 cm^{-1}	0.002
Maximum Single Beam Signal	1.22
Allowable Signal 200-500 cm^{-1} (1% of Max)	0.0122
Pass/Fail	**PASS**

1% of Max Single Beam Signal Acceptance Criteria
(Not specified in method)

IMACC MCT Detector Saturation Check	
Date Conducted	5/2/2024
Maximum Signal 200-500 cm^{-1}	0.1
Maximum Single Beam Signal	70.22
Allowable Signal 200-500 cm^{-1} (1% of Max)	0.7022
Pass/Fail	**PASS**

1% of Max Single Beam Signal Acceptance Criteria
(Not specified in method)

Figure 1: MKS Single Beam Spectrum, 200-500 cm^{-1} and Full Scale

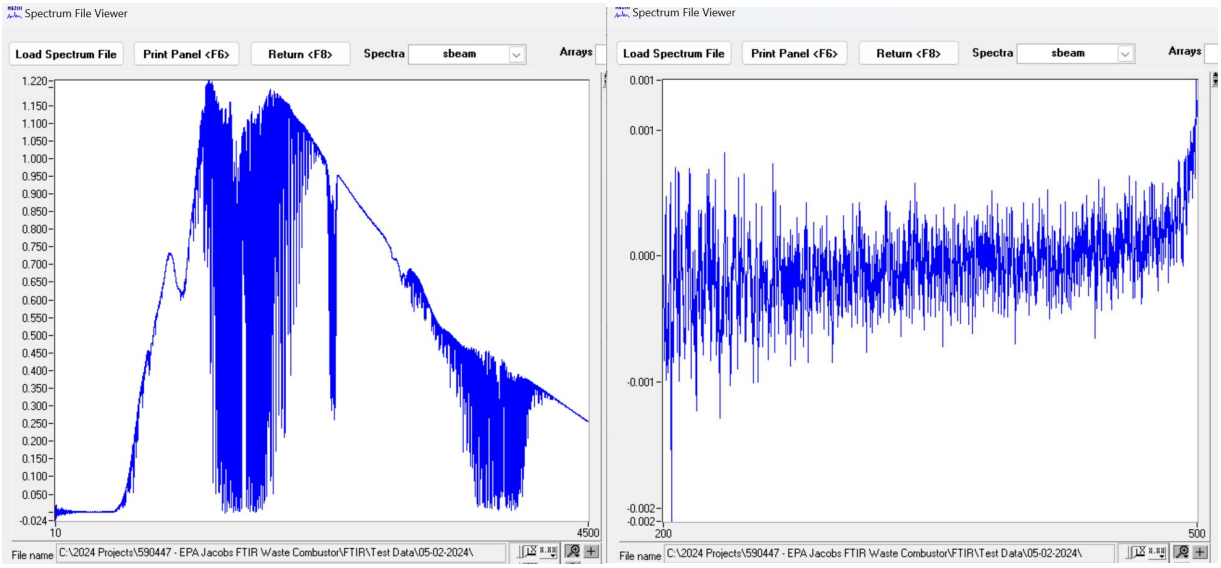
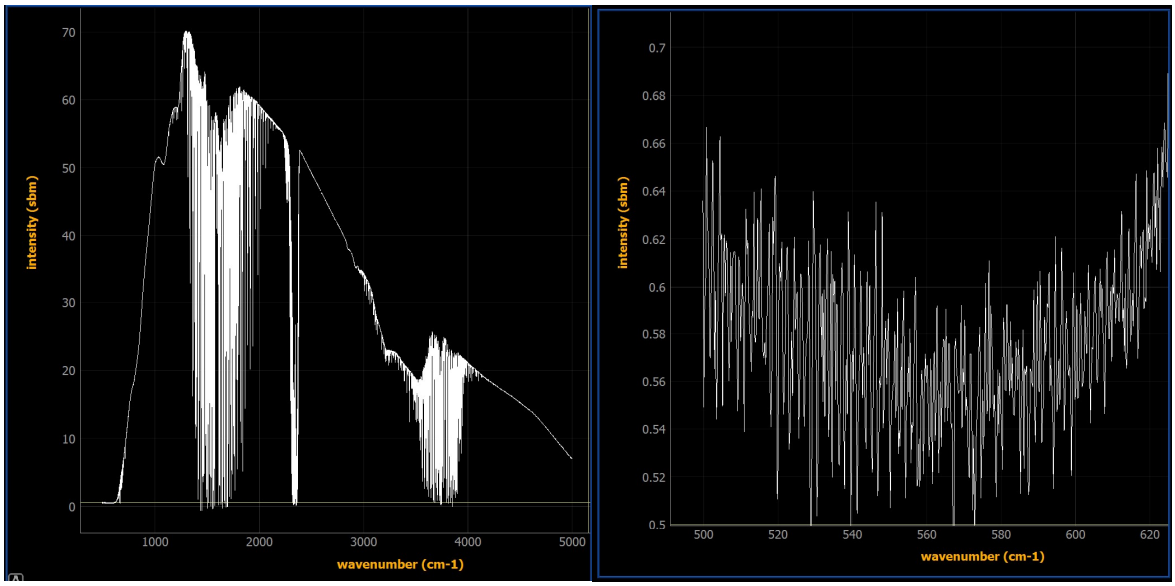


Figure 2: IMACC Single Beam Spectrum, 500-600 cm^{-1} and Full Scale



CTS Calibration Check

Direct and system CTS calibration measurements were made each day prior to the test runs and upon completion of testing. The 99.94 ppm ethylene gas standard (cylinder CC462799) was used to demonstrate instrument performance. The repeatability (% RPD) of each measurement is reported that is a calculation comparing two successive measurements of the CTS gas and indicates the calibration gas had stabilized. The pre- and post-test measurements must agree within 5%. The CTS gas calibrations met method requirements.

Table 3: FTIR CTS Measurement Summary

Calibration Test	Date/Time	Measured (ppm)	% Error	% RPD	% Difference (Pre/Post)
Pre-Test Direct MKS	4/30/24 07:36	99.6	-0.35%	0.33%	
Post-Test Direct MKS	4/30/24 16:48	99.5	-0.48%	0.041%	0.13%
Pre-Test Direct MKS	5/01/24 07:47	99.6	-0.35%	0.019%	
Post-Test Direct MKS	5/01/24 16:32	99.2	-0.76%	0.37%	0.41%
Pre-Test Direct MKS	5/02/24 07:37	99.5	-0.44%	0.0027%	
Post-Test Direct MKS	5/02/24 17:14	99.2	-0.76%	0.0045%	0.32%
Pre-Test Direct IMACC	5/02/24 07:43	100.1	0.12%	0.0050%	
Post-Test Direct IMACC	5/02/24 17:00	100.3	0.32%	0.52%	0.20%
Pre-Test System MKS	4/30/24 08:28	99.5	-0.44%	0.042%	
Post-Test System MKS	4/30/24 11:46	99.4	-0.59%	0.0048%	0.15%
Pre-Test System MKS	5/01/24 08:05	99.6	-0.33%	0.013%	
Pre-Test System MKS	5/02/24 07:47	99.5	-0.43%	0.00039%	
Post-Test System MKS	5/02/24 17:04	99.5	-0.47%	0.0053%	0.037%
Post-Test System IMACC	5/02/24 17:14	100.3	0.39%	2.11%	

FTIR CTS Response Summary

The sampling system response time was determined using the System CTS calibration. The CTS was measured in a system calibration immediately after a system zero calibration. A response time of 3 minutes was measured based on measuring 95% of the CTS cylinder concentration as measured in a direct calibration. As discussed above, no CTS time response is reported for the IMACC FTIR due to the resolution issue that was encountered when the time response was determined.

Table 4: MKS CTS System Calibration Time Response

Date/Time	C_2H_4 ppmvw	% of Cylinder Concentration	Elapsed Time (min)	Response
4/30/24 08:21	0.42	0.4%	0	
4/30/24 08:23	52.2	52.2%	1	
4/30/24 08:24	93.4	93.4%	2	
4/30/24 08:25	98.4	98.4%	3	>0.95
4/30/24 08:26	99.0	99.1%	4	

Direct and System Zero Calibration Check

The FTIR systems were challenged with nitrogen gas flowed directly to the analyzer and through the sampling system at the start and end of each test day. There is no method requirement for the zero calibration check, but TRC has established a quality assurance standard requiring an acceptable zero calibration be demonstrated by detection of analytes (except H_2O and CO_2) below 1 ppm. The tables below show the zero measurement for selected analytes; acceptable zero calibration values were obtained for all measured compounds. The background concentrations were well below stack levels.

Table 5: MKS Zero Calibration Measurement Summary

Calibration Test	Date/Time	Carbon Tetrafluoride		Hexafluoroethane		Water	
		ppm	Residual	ppm	Residual	%	Residual
Pre-Test Direct	4/30/24 07:27	0.0071	0.064	0.0016	0.0036	-0.019	0.0023
Pre-Test System	4/30/24 08:11	0.11	0.070	0.026	0.040	-0.009	0.0214
Post-Test Direct	4/30/24 16:39	0.12	0.082	0.057	0.0094	0.045	0.0019
Pre-Test Direct	5/01/24 07:33	0.10	0.059	0.0015	0.0017	-0.002	0.0014
Pre-Test System	5/01/24 07:49	0.25	0.098	0.0033	0.0040	-0.010	0.0034
Post-Test Direct	5/01/24 16:38	0.076	0.086	0.0094	0.0075	0.007	0.0020
Pre-Test Direct	5/02/24 07:30	0.087	0.058	-0.0051	0.0030	-0.004	0.0018
Post-Test Direct	5/02/24 16:55	0.041	0.065	0.024	0.0063	0.023	0.002

Table 6: IMACC Zero Calibration Measurement Summary

Calibration Test	Date/Time	Carbon Tetrafluoride		Hexafluoroethane		Water	
		ppm	Residual	ppm	Residual	%	Residual
Pre-Test Direct	5/02/24 07:30	0.00015	0.00018	-0.0014	0.00037	-27.1	11.4
Post-Test Direct	5/02/24 17:47	-0.00083	0.00018	0.00017	0.00024	-45.2	5.6

Direct and System Calibration Check

Direct and system calibration measurements were performed with the gases listed earlier. The sampling system response time for each of the calibration gases was **2 minutes**.

Table 7: MKS FTIR Calibration Measurement Summary

Compound	Expected (ppm)	Cal Type	Date Time	Measured (ppm)	% Error	% RPD
CF4	511.7	Direct	4/29/24 12:32	524.8	2.6%	0.0092%
SF6	2.1	Direct	4/29/24 12:32	2.03	-3.5%	0.020%
C2F6	502.9	Direct	4/29/24 17:34	532.5	5.9%	0.089%
SF6	2.103	Direct	4/29/24 17:34	2.03	-3.5%	0.042%
CF4	1.02	Direct	4/30/24 07:58	0.96	-5.5%	0.075%
SF6	2.059	Direct	4/30/24 07:58	2.00	-2.7%	0.0052%
C2F6	1.059	Direct	4/30/24 08:05	1.0	-3.0%	0.46%
SF6	2.06	Direct	4/30/24 08:05	2.04	-0.86%	0.028%
CO2	9.9	Direct	5/02/24 09:40	9.9	-0.35%	0.052%
CF4	511.7	System	5/01/24 09:23	524.0	2.4%	0.010%
SF6	2.101	System	5/01/24 09:23	2.04	-3.1%	0.0025%
C2F6	1.059	System	5/01/24 10:49	0.98	-3.8%	0.18%
SF6	2.06	System	5/01/24 10:49	2.04	-1.1%	0.026%

Table 8: IMACC FTIR Calibration Measurement Summary

Compound	Expected (ppm)	Cal Type	Date Time	Measured (ppm)	% Error	% RPD
C2F6	511.7	Direct	5/02/24 07:53	502.1	-1.9%	0.028%
SF6	2.1	Direct	5/02/24 07:53	2.0	-2.6%	0.13%
CO2	99000	Direct	5/02/24 09:38	95585.7	-3.4%	3.2%
CF4	1.0	Direct	5/02/24 10:03	1.2	16.0%	13.3%
SF6	2.1	Direct	5/02/24 10:03	2.0	-4.1%	2.7%
C2F6	1.1	Direct	5/02/24 10:46	1.2	16.2%	0.14%
SF6	2.1	Direct	5/02/24 10:46	2.1	-2.2%	0.15%
CF4	511.7	Direct	5/02/24 14:25	490.4	-4.2%	0.07%
SF6	2.1	Direct	5/02/24 14:25	2.1	-1.6%	0.02%

System Calibration Time Response

Table 9: MKS CF_4 System Calibration Time Response

Date/Time	CF_4 ppmvw	% of Direct Calibration	Elapsed Time (min)	Response
5/01/24 09:15	0.0085	0.0%	0	
5/01/24 09:16	5.8	1.1%	1	
5/01/24 09:18	394.6	75.2%	2	
5/01/24 09:19	511.7	97.5%	3	>0.95
5/01/24 09:20	521.4	99.4%	4	

Table10: MKS Sulfur Hexafluoride System Calibration Time Response

Date/Time	SF_6 ppmvw	% of Direct Calibration	Elapsed Time (min)	Response
5/01/24 09:15	0.00	-0.1%	0	
5/01/24 09:16	0.29	14.1%	1	
5/01/24 09:18	1.60	78.8%	2	
5/01/24 09:19	1.98	97.9%	3	>0.95
5/01/24 09:20	2.03	99.9%	4	

Table 11: MKS C_2F_6 System Calibration Time Response

Date/Time	C_2F_6 ppmvw	% of Direct Calibration	Elapsed Time (min)	Response
5/01/24 10:41	-0.01	-0.7%	0	
5/01/24 10:42	0.10	9.8%	1	
5/01/24 10:43	0.75	76.7%	2	
5/01/24 10:44	0.95	97.1%	3	>0.95
5/01/24 10:45	0.98	99.8%	4	

Analysis Confirmation by Manual Subtraction

In order to confirm the accuracy of the computer analysis, a separate manual analysis was conducted by subtracting the scaled reference spectra of the analyzed compounds from one representative spectrum during the test program. The results from this scaled subtraction are compared with the computer analysis to verify accuracy. The spectra used, their measurement time/location, and results of the manual subtraction are in the tables below.

The reference spectra for the compounds identified in these spectra were sequentially subtracted, and the subtraction factor (the ratio between the spectrum measured at the source and reference spectrum) was used to calculate the measured concentration. The table below compares the calculated and manually subtracted concentrations. In some cases the percent difference between the two analyses is relatively large, but the absolute concentration difference is small. "ND" indicates the compound was not detected in the computerized analysis, and this was confirmed by manual subtraction. This comparison confirms the spectral analysis accuracy and verifies that additional compounds are not present in the matrix that could be interferents from the analytes of interest.

Table 12: FTIR Analysis Confirmation by Manual Subtraction- MKS

Confirmation of CLS Analysis by Manual Subtraction			
Client	Covanta		
Source	Lake		
Location	MWC		
City, State	Florida		
TRC Project Number	590447		
Spectrum File Name	REWORLD_002038.LAB		
Spectrum Date	5/2/2024		
Spectrum Time	11:59:19 AM		
Analysis Method	MWC PFAS method 191C		
Compund	Measured Concentration	Subtraction Concentration	% Difference
Carbon Dioxide CO2	9.0	8.9	1.4%
Water H2O	0.030	0.032	6.2%
Carbon Monoxide CO	5.3	5.6	5.4%
Nitric Oxide NO	113.4	112.7	0.59%
Nitrous Oxide N2O	1.5	1.6	4.2%
Methane CH4	0.48	0.47	2.4%

Table 13: FTIR Analysis Confirmation by Manual Subtraction- IMACC

Confirmation of CLS Analysis by Manual Subtraction			
Client	Covanta		
Source	Lake		
Location	MWC		
City, State	Florida		
TRC Project Number	590447		
Spectrum File Name	5/2/2024 12:00		
Spectrum Date	5/2/2024		
Spectrum Time	12:00:44 PM		
Analysis Method	EPA MWC Method_7 Mod CF 150C Refs		
Compund	Measured Concentration	Subtraction Concentration	% Difference
Carbon Dioxide CO2	110479.0	113300.0	2.6%
Water H2O	225030.0	222300.0	1.2%
Carbon Monoxide CO	62.9	62.8	0.20%
Nitric Oxide NO	128.2	126.4	1.4%
Nitrous Oxide N2O	3.0	3.0	0.68%
Methane CH4	-2.1	ND	ND

Dynamic Matrix Spiking Calibration

Dynamic matrix spiking calibration was conducted at all test locations using the carbon tetrafluoride/SF_6 and hexafluoroethane/SF6 standards identified in the Calibration section above. A mass flow meter and needle valve were used to spike the stack gas with the fluorocarbons along with the SF_6 tracer. Some spiking was conducted while EPA was injecting CF_4 or C_2F_6 into the facility. The acceptable limits for spike recovery in the EPA Method 320 are 70-130% recovery. With two exceptions of insufficient dilution, the spiking met all method requirements. An example calculation is presented below for one of the spiking events.

Table 15: MKS Spiking Results Summary

Date	Time	Spiked Compound	Meas. Spike Cylinder Conc.	Dilution Ratio	Expected Spike ppm	Measured Spike ppm	% Recovery	Comment
4/30/2024	9:27:53 AM	CF4	0.96	7.3	0.133	0.12	93.4%	12 ppb spike
4/30/2024	9:27:53 AM	CF4	0.96	9.5	0.102	0.094	92.7%	
4/30/2024	10:19:31 AM	CF4	0.96	29.8	0.032	0.030	91.2%	
4/30/2024	11:18:49 AM	CF4	0.96	78.6	0.012	0.012	96.3%	
4/30/2024	4:22:36 PM	C2F6	532.55	244.6	2.2	1.9	89.0%	Spike during Injection
5/1/2024	11:13:19 AM	C2F6	0.96	22.1	0.044	0.054	124.3%	
5/1/2024	11:34:11 AM	C2F6	0.96	97.1	0.010	0.010	99.4%	10 ppb spike
5/1/2024	12:00:33 PM	C2F6	0.96	131.9	0.0073	0.0090	123.2%	9 ppb spike
5/1/2024	2:13:26 PM	CF4	524.80	123.9	4.2	5.3	125.3%	Spike during Injection
5/1/2024	3:40:12 PM	C2F6	532.55	176.1	3.0	3.2	105.2%	Spike during Injection
5/1/2024	3:55:34 PM	C2F6	532.55	114.6	4.6	4.3	92.3%	Spike during Injection
5/2/2024	8:24:05 AM	C2F6	532.5	31.9	16.7	17.4	104.0%	
5/2/2024	8:46:03 AM	C2F6	532.5	28.2	18.9	19.6	104.0%	
5/2/2024	9:08:01 AM	C2F6	532.5	126.4	4.2	4.6	108.2%	
5/2/2024	9:16:48 AM	C2F6	532.5	246.7	2.2	2.0	91.4%	
5/2/2024	3:25:32 PM	C2F6	532.5	121.1	4.4	4.5	102.7%	
5/2/2024	4:14:57 PM	C2F6	532.5	112.4	4.7	5.6	117.7%	Spike during Injection
5/2/2024	10:34:45 AM	CF4	0.96	27.9	0.0	0.0	91.2%	
5/2/2024	1:29:22 PM	CF4	0.96	138.4	0.0	0.0	101.8%	7 ppb spike
5/2/2024	1:55:29 PM	CF4	524.8	123.5	4.25	4.51	106.0%	Spike during Injection

Table 16: IMACC Spiking Results Summary

Date	Time	Spiked Compound	Meas. Spike Cylinder Conc.	Dilution Ratio	Expected Spike ppm	Measured Spike ppm	% Recovery	Comment
5/2/2024	8:22:43 AM	C2F6	502.1	34.9	14.4	17.3	120.2%	
5/2/2024	8:43:44 AM	C2F6	502.1	33.1	15.2	17.9	117.9%	Replicate spike
5/2/2024	9:02:44 AM	C2F6	502.1	54.4	9.2	7.5	81.4%	
5/2/2024	8:56:44 AM	C2F6	502.1	313.7	1.6	1.7	107.0%	
5/2/2024	10:19:43 AM	CF4	1.2	33.1	0.036	0.042	118.1%	
5/2/2024	11:17:44 AM	CF4	1.2	38.3	0.031	0.026	84.6%	Replicate spike
5/2/2024	12:28:43 PM	CF4	1.2	123.7	0.010	0.009	96.3%	9 ppb spike
5/2/2024	3:33:44 PM	C2F6	502.1	128.4	3.9	4.1	104.9%	
5/2/2024	4:08:44 PM	C2F6	502.1	153.5	3.3	4.2	126.9%	

The detailed spiking tables are below.

Table 17: MKS CF_4 Spiking Table (1 ppm Spike Gas)

Dynamic Matrix Spiking Table			CF4	1.0 Measured Concentration	
Date Conducted	4/30/2024		SF6	2.00 Measured Concentration	
	Time Start	Time End	CF4 ppmvw	SF_6 ppmvw	
Tracer Off	9:03	9:08		-0.002	
Tracer On	9:27	9:32		0.27	
Spike Off	9:03	9:08	0.010		
Spike On	9:27	9:32	0.13		
	Expected Spike		0.13		
	Spike Off		0.010	-0.002	
	Diluted Spike Off		0.008		Corrected: Dilution by Spike
	Spike On		0.13	0.273	
	Dilution Factor			0.138	**7.3** Dilution Ratio
	Measured Spike		0.12	0.276	
	Spike Recovery		**93.4%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	7.27	FAIL
Spike Recovery	70-130%	93.4%	PASS

Table 18: MKS CF_4 Spiking Table (1 ppm Spike Gas)

Dynamic Matrix Spiking Table			CF4	1.0 Measured Concentration	
Date Conducted	4/30/2024		SF6	2.00 Measured Concentration	
	Time Start	Time End	CF4 ppmvw	SF_6 ppmvw	
Tracer Off	9:03	9:08		-0.002	
Tracer On	10:19	10:23		0.07	
Spike Off	9:03	9:08	0.010		
Spike On	10:19	10:23	0.04		
	Expected Spike		0.032		
	Spike Off		0.010	-0.002	
	Diluted Spike Off		0.009		Corrected: Dilution by Spike
	Spike On		0.039	0.065	
	Dilution Factor			0.034	**29.8** Dilution Ratio
	Measured Spike		0.030	0.067	
	Spike Recovery		**91.2%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	29.79	PASS
Spike Recovery	70-130%	91.2%	PASS

Table 19: MKS CF_4 Spiking Table (1 ppm Spike Gas)

Dynamic Matrix Spiking Table			CF4	1.0	Measured Concentration
Date Conducted	4/30/2024		SF6	2.00	Measured Concentration

	Time Start	Time End	CF4 ppmvw	SF_6 ppmvw	
Tracer Off	9:03	9:08		-0.002	
Tracer On	11:18	11:23		0.02	
Spike Off	9:03	9:08	0.010		
Spike On	11:18	11:23	0.02		
	Expected Spike		0.012		
	Spike Off		0.010	-0.002	
	Diluted Spike Off		0.009		Corrected: Dilution by Spike
	Spike On		0.021	0.023	
	Dilution Factor			0.013	**78.6** Dilution Ratio
	Measured Spike		0.012	0.025	
	Spike Recovery		**96.3%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	78.57	PASS
Spike Recovery	70-130%	96.3%	PASS

Table 20: MKS C_2F_6 Spiking Table (500 ppm Spike Gas During EPA C_2F_6 Injection)

Dynamic Matrix Spiking Table			C2F6	532.5	Measured Concentration
Date Conducted	4/30/2024		SF6	2.03	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	15:57	16:01		-0.0023	
Tracer On	16:22	16:26		0.0060	
Spike Off	15:57	16:01	0.73		
Spike On	16:22	16:26	2.66		
	Expected Spike		2.18		
	Spike Off		0.73	-0.0023	
	Diluted Spike Off		0.73		Corrected: Dilution by Spike
	Spike On		2.66	0.0060	
	Dilution Factor			0.0041	**244.6** Dilution Ratio
	Measured Spike		1.94	0.0083	
	Spike Recovery		**89.0%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	244.56	PASS
Spike Recovery	70-130%	89.0%	PASS

Table 21: MKS C_2F_6 Spiking Table (1 ppm Spike Gas)

Dynamic Matrix Spiking Table			C2F6	1.0	Measured Concentration
Date Conducted	5/1/2024		SF6	2.00	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	11:25	11:29		-0.0015	
Tracer On	11:13	11:17		0.089	
Spike Off	11:25	11:29	0.0071		
Spike On	11:13	11:17	0.061		
	Expected Spike		0.044		
	Spike Off		0.0071	-0.0015	
	Diluted Spike Off		0.0068		Corrected: Dilution by Spike
	Spike On		0.061	0.089	
	Dilution Factor			0.045	**22.1** Dilution Ratio
	Measured Spike		0.054	0.091	
	Spike Recovery		**124.3%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	22.12	PASS
Spike Recovery	70-130%	124.3%	PASS

Table 22: MKS C_2F_6 Spiking Table (1 ppm Spike Gas)

Dynamic Matrix Spiking Table			C2F6	1.0	Measured Concentration
Date Conducted	5/1/2024		SF6	2.00	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	11:25	11:29		-0.0015	
Tracer On	11:34	11:38		0.019	
Spike Off	11:25	11:29	0.0071		
Spike On	11:34	11:38	0.017		
	Expected Spike		0.010		
	Spike Off		0.0071	-0.0015	
	Diluted Spike Off		0.0071		Corrected: Dilution by Spike
	Spike On		0.017	0.019	
	Dilution Factor			0.010	**97.1** Dilution Ratio
	Measured Spike		0.010	0.021	
	Spike Recovery		**99.4%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	97.10	PASS
Spike Recovery	70-130%	99.4%	PASS

Table 23: MKS C_2F_6 Spiking Table (1 ppm Spike Gas)

Dynamic Matrix Spiking Table			C2F6	1.0	Measured Concentration
Date Conducted	5/1/2024		SF6	2.00	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	11:25	11:29		-0.0015	
Tracer On	12:00	12:03		0.014	
Spike Off	11:25	11:29	0.0071		
Spike On	12:00	12:03	0.016		
	Expected Spike		0.007		
	Spike Off		0.0071	-0.0015	
	Diluted Spike Off		0.0071		Corrected: Dilution by Spike
	Spike On		0.016	0.014	
	Dilution Factor			0.008	**131.9** Dilution Ratio
	Measured Spike		0.009	0.015	
	Spike Recovery		**123.2%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	131.87	PASS
Spike Recovery	70-130%	123.2%	PASS

Table 24: MKS C_2F_6 Spiking Table (500 ppm Spike Gas)

Dynamic Matrix Spiking Table			C2F6	532.5	Measured Concentration
Date Conducted	5/1/2024		SF6	2.03	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	15:00	15:05		-0.0013	
Tracer On	15:40	15:44		0.010	
Spike Off	15:00	15:05	0.30		
Spike On	15:40	15:44	3.48		
	Expected Spike		3.02		
	Spike Off		0.30	-0.0013	
	Diluted Spike Off		0.30		Corrected: Dilution by Spike
	Spike On		3.48	0.010	
	Dilution Factor			0.006	**176.1** Dilution Ratio
	Measured Spike		3.18	0.012	
	Spike Recovery		**105.2%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	176.13	PASS
Spike Recovery	70-130%	105.2%	PASS

Table 25: MKS C_2F_6 Spiking Table (500 ppm Spike Gas)

Dynamic Matrix Spiking Table			C2F6	532.5 Measured Concentration	
Date Conducted	5/1/2024		SF6	2.03 Measured Concentration	
	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	15:00	15:05		-0.0013	
Tracer On	15:55	15:59		0.016	
Spike Off	15:00	15:05	0.30		
Spike On	15:55	15:59	4.58		
	Expected Spike		4.65		
	Spike Off		0.30	-0.0013	
	Diluted Spike Off		0.30		Corrected: Dilution by Spike
	Spike On		4.58	0.016	
	Dilution Factor			0.009	**114.6** Dilution Ratio
	Measured Spike		4.29	0.018	
	Spike Recovery		**92.3%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	114.61	PASS
Spike Recovery	70-130%	92.3%	PASS

Table 26: MKS CF_4 Spiking Table (500 ppm Spike Gas During EPA CF_4 Injection)

Dynamic Matrix Spiking Table			CF4	524.8 Measured Concentration	
Date Conducted	5/1/2024		SF6	2.03 Measured Concentration	
	Time Start	Time End	CF4 ppmvw	SF_6 ppmvw	
Tracer Off	13:44	13:49		-0.0015	
Tracer On	14:13	14:17		0.015	
Spike Off	13:44	13:49	2.63		
Spike On	14:13	14:17	7.91		
	Expected Spike		4.24		
	Spike Off		2.63	-0.0015	
	Diluted Spike Off		2.60		Corrected: Dilution by Spike
	Spike On		7.91	0.015	
	Dilution Factor			0.0081	**123.9** Dilution Ratio
	Measured Spike		5.31	0.016	
	Spike Recovery		**125.3%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	123.87	PASS
Spike Recovery	70-130%	125.3%	PASS

Table 27: MKS CF_4 Spiking Table (500 ppm Spike Gas)

Dynamic Matrix Spiking Table			C2F6	532.5	Measured Concentration
Date Conducted	5/1/2024		SF6	2.03	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	15:00	15:05		-0.0013	
Tracer On	15:55	15:59		0.016	
Spike Off	15:00	15:05	0.30		
Spike On	15:55	15:59	4.58		
	Expected Spike		4.65		
	Spike Off		0.30	-0.0013	
	Diluted Spike Off		0.30		Corrected: Dilution by Spike
	Spike On		4.58	0.016	
	Dilution Factor			0.009	**114.6** Dilution Ratio
	Measured Spike		4.29	0.018	
	Spike Recovery		**92.3%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	114.61	PASS
Spike Recovery	70-130%	92.3%	PASS

Table 28: MKS C_2F_6 Spiking Table (500 ppm Spike Gas)

Dynamic Matrix Spiking Table			C2F6	532.5	Measured Concentration
Date Conducted	5/2/2024		SF6	2.03	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	8:31	8:36		-0.0021	
Tracer On	8:24	8:28		0.062	
Spike Off	8:31	8:36	0.048		
Spike On	8:24	8:28	17.40		
	Expected Spike		16.7		
	Spike Off		0.048	-0.0021	
	Diluted Spike Off		0.047		Corrected: Dilution by Spike
	Spike On		17.4	0.062	
	Dilution Factor			0.031	**31.9** Dilution Ratio
	Measured Spike		17.4	0.064	
	Spike Recovery		**104.0%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	31.90	PASS
Spike Recovery	70-130%	104.0%	PASS

Table 29: MKS C_2F_6 Spiking Table (500 ppm Spike Gas)

Dynamic Matrix Spiking Table			C2F6	532.5	Measured Concentration
Date Conducted	5/2/2024		SF6	2.03	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	8:31	8:36		-0.0021	
Tracer On	8:46	8:50		0.070	
Spike Off	8:31	8:36	0.048		
Spike On	8:46	8:50	19.66		
	Expected Spike		18.9		
	Spike Off		0.048	-0.0021	
	Diluted Spike Off		0.046		Corrected: Dilution by Spike
	Spike On		19.7	0.070	
	Dilution Factor			0.035	**28.2** Dilution Ratio
	Measured Spike		19.6	0.072	
	Spike Recovery		**104.0%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	28.25	PASS
Spike Recovery	70-130%	104.0%	PASS

Table 30: MKS C_2F_6 Spiking Table (500 ppm Spike Gas)

Dynamic Matrix Spiking Table			C2F6	532.5	Measured Concentration
Date Conducted	5/2/2024		SF6	2.03	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	8:31	8:36		-0.0021	
Tracer On	9:08	9:12		0.014	
Spike Off	8:31	8:36	0.048		
Spike On	9:08	9:12	4.61		
	Expected Spike		4.2		
	Spike Off		0.048	-0.0021	
	Diluted Spike Off		0.048		Corrected: Dilution by Spike
	Spike On		4.6	0.014	
	Dilution Factor			0.008	**126.4** Dilution Ratio
	Measured Spike		4.6	0.016	
	Spike Recovery		**108.2%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	126.37	PASS
Spike Recovery	70-130%	108.2%	PASS

Table 31: MKS C_2F_6 Spiking Table (500 ppm Spike Gas)

Dynamic Matrix Spiking Table			C2F6	532.5	Measured Concentration
Date Conducted	5/2/2024		SF6	2.03	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	8:31	8:36		-0.0021	
Tracer On	9:16	9:21		0.0061	
Spike Off	8:31	8:36	0.048		
Spike On	9:16	9:21	2.02		
	Expected Spike		2.16		
	Spike Off		0.048	-0.0021	
	Diluted Spike Off		0.048		Corrected: Dilution by Spike
	Spike On		2.02	0.0061	
	Dilution Factor			0.0041	**246.7** Dilution Ratio
	Measured Spike		1.97	0.0082	
	Spike Recovery		**91.4%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	246.74	PASS
Spike Recovery	70-130%	91.4%	PASS

Table 32: MKS C_2F_6 Spiking Table (500 ppm Spike Gas During EPA C_2F_6 Injection)

Dynamic Matrix Spiking Table			C2F6	532.5	Measured Concentration
Date Conducted	5/2/2024		SF6	2.03	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	15:01	15:05		-0.0016	
Tracer On	15:25	15:29		0.015	
Spike Off	15:01	15:05	0.924		
Spike On	15:25	15:29	5.43		
	Expected Spike		4.4		
	Spike Off		0.924	-0.0016	
	Diluted Spike Off		0.916		Corrected: Dilution by Spike
	Spike On		5.4	0.015	
	Dilution Factor			0.008	**121.1** Dilution Ratio
	Measured Spike		4.5	0.017	
	Spike Recovery		**102.7%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	121.11	PASS
Spike Recovery	70-130%	102.7%	PASS

Table 34: MKS C_2F_6 Spiking Table (500 ppm Spike Gas During EPA C_2F_6 Injection)

Dynamic Matrix Spiking Table			C2F6	532.5	Measured Concentration
Date Conducted	5/2/2024		SF6	2.03	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	15:56	16:00		-0.0021	
Tracer On	16:14	16:19		0.016	
Spike Off	15:56	16:00	3.31		
Spike On	16:14	16:19	8.86		
	Expected Spike		4.7		
	Spike Off		3.31	-0.0021	
	Diluted Spike Off		3.28		Corrected: Dilution by Spike
	Spike On		8.9	0.016	
	Dilution Factor			0.009	**112.4** Dilution Ratio
	Measured Spike		5.6	0.018	
	Spike Recovery		**117.7%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	112.38	PASS
Spike Recovery	70-130%	117.7%	PASS

Table 35: MKS CF_4 Spiking Table (1 ppm Spike Gas)

Dynamic Matrix Spiking Table			CF4	0.96	Measured Concentration
Date Conducted	5/2/2024		SF6	2.00	Measured Concentration

	Time Start	Time End	CF4 ppmvw	SF_6 ppmvw	
Tracer Off	10:16	10:20		-0.0012	
Tracer On	10:34	10:39		0.070	
Spike Off	10:16	10:20	0.0055		
Spike On	10:34	10:39	0.037		
	Expected Spike		0.035		
	Spike Off		0.0055	-0.0012	
	Diluted Spike Off		0.0053		Corrected: Dilution by Spike
	Spike On		0.037	0.070	
	Dilution Factor			0.036	**27.9** Dilution Ratio
	Measured Spike		0.031	0.072	
	Spike Recovery		**91.2%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	27.94	PASS
Spike Recovery	70-130%	91.2%	PASS

Table 36: MKS CF_4 Spiking Table (1 ppm Spike Gas)

Dynamic Matrix Spiking Table			CF4	0.96	Measured Concentration
Date Conducted	5/2/2024		SF6	2.00	Measured Concentration

	Time Start	Time End	CF4 ppmvw	SF_6 ppmvw	
Tracer Off	13:10	13:15		-0.0006	
Tracer On	13:29	13:34		0.014	
Spike Off	13:10	13:15	0.0047		
Spike On	13:29	13:34	0.0118		
	Expected Spike		0.0070		
	Spike Off		0.0047	-0.00059	
	Diluted Spike Off		0.0047		Corrected: Dilution by Spike
	Spike On		0.0118	0.014	
	Dilution Factor			0.0072	**138.4** Dilution Ratio
	Measured Spike		0.0071	0.014	
	Spike Recovery		**101.8%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	138.41	PASS
Spike Recovery	70-130%	101.8%	PASS

Table 37: MKS CF_4 Spiking Table (500 ppm Spike Gas During EPA CF_4 Injection)

Dynamic Matrix Spiking Table			CF4	524.8	Measured Concentration
Date Conducted	5/2/2024		SF6	2.03	Measured Concentration

	Time Start	Time End	CF46 ppmvw	SF_6 ppmvw	
Tracer Off	13:37	13:42		-0.0012	
Tracer On	13:55	13:59		0.015	
Spike Off	13:37	13:42	1.6		
Spike On	13:55	13:59	6.1		
	Expected Spike		4.3		
	Spike Off		1.6	-0.0012	
	Diluted Spike Off		1.6		Corrected: Dilution by Spike
	Spike On		6.1	0.015	
	Dilution Factor			0.0081	**123.5** Dilution Ratio
	Measured Spike		4.5	0.016	
	Spike Recovery		**106.0%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	123.48	PASS
Spike Recovery	70-130%	106.0%	PASS

Table 38: IMACC C_2F_6 Spiking Table (500 ppm Spike Gas)

Dynamic Matrix Spiking Table			C2F6	502.07	Measured Concentration
Date Conducted	5/2/2024		SF6	2.05	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	8:10	8:14		0.064	
Tracer On	8:22	8:26		0.12	
Spike Off	8:10	8:14	-0.0014		
Spike On	8:22	8:26	17.3		
	Expected Spike		14.4		
	Spike Off		-0.0014	0.064	
	Diluted Spike Off		-0.0014		Corrected: Dilution by Spike
	Spike On		17.3	0.123	
	Dilution Factor			0.029	**34.9** Dilution Ratio
	Measured Spike		17.3	0.059	
	Spike Recovery		**120.2%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	34.88	PASS

Table 39: MKS C_2F_6 Spiking Table (500 ppm Spike Gas)

Dynamic Matrix Spiking Table			C2F6	502.07	Measured Concentration
Date Conducted	5/2/2024		SF6	2.05	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	8:10	8:14		0.064	
Tracer On	8:43	8:47		0.13	
Spike Off	8:10	8:14	-0.0014		
Spike On	8:43	8:47	17.9		
	Expected Spike		15.2		
	Spike Off		-0.0014	0.064	
	Diluted Spike Off		-0.0014		Corrected: Dilution by Spike
	Spike On		17.9	0.126	
	Dilution Factor			0.030	**33.1** Dilution Ratio
	Measured Spike		17.9	0.062	
	Spike Recovery		**117.9%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	33.13	PASS
Spike Recovery	70-130%	117.9%	PASS

Table 40: IMACC C_2F_6 Spiking Table (500 ppm Spike Gas)

Dynamic Matrix Spiking Table			C2F6	502.07	Measured Concentration
Date Conducted	5/2/2024		SF6	2.05	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	8:10	8:14		0.064	
Tracer On	9:02	9:06		0.10	
Spike Off	8:10	8:14	-0.0014		
Spike On	9:02	9:06	7.5		
	Expected Spike		9.2		
	Spike Off		-0.0014	0.064	
	Diluted Spike Off		-0.0014		Corrected: Dilution by Spike
	Spike On		7.5	0.102	
	Dilution Factor			0.018	**54.4** Dilution Ratio
	Measured Spike		7.5	0.038	
	Spike Recovery		**81.4%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	54.37	PASS
Spike Recovery	70-130%	81.4%	PASS

Table 41: IMACC C_2F_6 Spiking Table (500 ppm Spike Gas)

Dynamic Matrix Spiking Table			C2F6	502.07	Measured Concentration
Date Conducted	5/2/2024		SF6	2.05	Measured Concentration

	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	8:56	9:00		0.071	
Tracer On	9:18	9:22		0.078	
Spike Off	8:56	9:00	-0.015		
Spike On	9:18	9:22	1.7		
	Expected Spike		1.6		
	Spike Off		-0.015	0.071	
	Diluted Spike Off		-0.015		Corrected: Dilution by Spike
	Spike On		1.7	0.078	
	Dilution Factor			0.0032	**313.7** Dilution Ratio
	Measured Spike		1.7	0.007	
	Spike Recovery		**107.0%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	313.71	PASS
Spike Recovery	70-130%	107.0%	PASS

Table 42: IMACC $CF4_6$ Spiking Table (1 ppm Spike Gas)

Dynamic Matrix Spiking Table			CF4	1.18	Measured Concentration
Date Conducted	5/2/2024		SF6	1.97	Measured Concentration

	Time Start	Time End	CF6 ppmvw	SF_6 ppmvw	
Tracer Off	10:19	10:23		0.073	
Tracer On	10:29	10:33		0.13	
Spike Off	10:19	10:23	-0.22		
Spike On	10:29	10:33	-0.17		
	Expected Spike		0.036		
	Spike Off		-0.22	0.073	
	Diluted Spike Off		-0.21		Corrected: Dilution by Spike
	Spike On		-0.17	0.132	
	Dilution Factor			0.0302	**33.1** Dilution Ratio
	Measured Spike		0.042	0.060	
	Spike Recovery		**118.1%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	33.14	PASS

Table 43: IMACC $CF4_6$ Spiking Table (1 ppm Spike Gas)

Dynamic Matrix Spiking Table			CF4	1.18	Measured Concentration
Date Conducted	5/2/2024		SF6	1.97	Measured Concentration

	Time Start	Time End	CF6 ppmvw	SF_6 ppmvw	
Tracer Off	11:17	11:21		0.080	
Tracer On	11:11	11:15		0.13	
Spike Off	11:17	11:21	-0.25		
Spike On	11:11	11:15	-0.22		
	Expected Spike		0.031		
	Spike Off		-0.25	0.080	
	Diluted Spike Off		-0.25		Corrected: Dilution by Spike
	Spike On		-0.22	0.131	
	Dilution Factor			0.0261	**38.3** Dilution Ratio
	Measured Spike		0.026	0.052	
	Spike Recovery		**84.6%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	38.25	PASS
Spike Recovery	70-130%	84.6%	PASS

Table 44: IMACC $CF4_6$ Spiking Table (1 ppm Spike Gas)

Dynamic Matrix Spiking Table			CF4	1.18	Measured Concentration
Date Conducted	5/2/2024		SF6	1.97	Measured Concentration

	Time Start	Time End	CF6 ppmvw	SF_6 ppmvw	
Tracer Off	12:28	12:32		0.075	
Tracer On	12:56	13:00		0.091	
Spike Off	12:28	12:32	-0.22		
Spike On	12:56	13:00	-0.21		
	Expected Spike		0.0096		
	Spike Off		-0.22	0.075	
	Diluted Spike Off		-0.22		Corrected: Dilution by Spike
	Spike On		-0.21	0.091	
	Dilution Factor			0.0081	**123.7** Dilution Ratio
	Measured Spike		0.0092	0.016	
	Spike Recovery		**96.3%**		

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Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	123.67	PASS
Spike Recovery	70-130%	96.3%	PASS

Table 45: IMACC $CF4_6$ Spiking Table (500 ppm Spike Gas During EPA CF_4 Injection)

Dynamic Matrix Spiking Table			CF4	490.40	Measured Concentration
Date Conducted	5/2/2024		SF6	2.07	Measured Concentration

	Time Start	Time End	CF6 ppmvw	SF_6 ppmvw	
Tracer Off	14:09	14:13		0.071	
Tracer On	14:01	14:05		0.090	
Spike Off	14:09	14:13	1.9		
Spike On	14:01	14:05	7.7		
	Expected Spike		4.6		
	Spike Off		1.9	0.071	
	Diluted Spike Off		1.9		Corrected: Dilution by Spike
	Spike On		7.7	0.090	
	Dilution Factor			0.0095	**105.6** Dilution Ratio
	Measured Spike		5.8	0.020	
	Spike Recovery		**125.3%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	105.61	PASS
Spike Recovery	70-130%	125.3%	PASS

Table 46: IMACC $CF4_6$ Spiking Table (500 ppm Spike Gas During EPA CF_4 Injection)

Dynamic Matrix Spiking Table			C2F6	502.07	Measured Concentration
Date Conducted	5/2/2024		SF6	2.05	Measured Concentration
	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	14:38	14:42		0.075	
Tracer On	15:33	15:37		0.091	
Spike Off	14:38	14:42	9.0		
Spike On	15:33	15:37	13.1		
	Expected Spike		3.9		
	Spike Off		9.0	0.075	
	Diluted Spike Off		9.0		Corrected: Dilution by Spike
	Spike On		13.1	0.091	
	Dilution Factor			0.0078	**128.4** Dilution Ratio
	Measured Spike		4.1	0.016	
	Spike Recovery		**104.9%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	128.43	PASS
Spike Recovery	70-130%	104.9%	PASS

Table 47: IMACC $CF4_6$ Spiking Table (500 ppm Spike Gas During EPA CF_4 Injection)

Dynamic Matrix Spiking Table			C2F6	502.07	Measured Concentration
Date Conducted	5/2/2024		SF6	2.05	Measured Concentration
	Time Start	Time End	C2F6 ppmvw	SF_6 ppmvw	
Tracer Off	15:53	15:57		0.076	
Tracer On	16:08	16:12		0.089	
Spike Off	15:53	15:57	12.4		
Spike On	16:08	16:12	16.5		
	Expected Spike		3.3		
	Spike Off		12.4	0.076	
	Diluted Spike Off		12.3		Corrected: Dilution by Spike
	Spike On		16.5	0.089	
	Dilution Factor			0.0065	**153.5** Dilution Ratio
	Measured Spike		4.2	0.013	
	Spike Recovery		**126.9%**		

Criteria	Acceptable Limit	Measured Value	Pass/Fail
Dilution Ratio	>10	153.46	PASS
Spike Recovery	70-130%	126.9%	PASS

The example calculation for Table 47 is provided below.

Example Calculations

Calculations are performed using the equations in EPA Method 321, Section 9.3 where EPA clarified equations in Method 320 and provided the missing calculation of % Recovery.

Dilution Factor DF

DILUTION FACTOR = TRACER GAS (SPIKED) - TRACER GAS (UNSPIKED)
TRACER GAS CYLINDER CONCENTRATION

Tracer Spiked =	0.089	ppmvw
Tracer Unspiked Spiked =	0.076	ppmvw
Tracer Cylinder Concentration Cs(tracer	2.0	ppmvw
Dilution Factor =	**153.5**	**or 0.0065 : 1 Dilution Ratio**

Unspiked Concentration (Dilution Correction)

CORRECTED UNSPIKED CONCENTRATION = UNSPIKED CONCENTRATION X (1- DILUTION FACTOR

Su Unspiked Concentration =	12.40	ppmvw
Dilution Factor DF =	153.5	
Corrected Unspiked Concentration =	**12.3**	**ppmvw**

Expected Spike Concentration

Ce EXPECTED SPIKE = (Cs X DF) + CORRECTED UNSPIKED

Spike Cylinder Concentration Cs =	502.1	ppmvw
DF =	153.5	
Corrected Unspiked Concentration =	12.3	ppmvw
Ce =	**3.3**	**ppmvw**

Measured Spike Concentration

Measured Spike Concentration Sm=	4.15	ppmvw

Percent Spike Recovery

% R = 100 - Sm - Su(1-DF)
DF X Cs

Percent Spike Recovery = 126.9%

The figures below show examples of spiking.

Figure 3: MKS Dynamic Matrix Spiking, 500 ppm C_2F_6

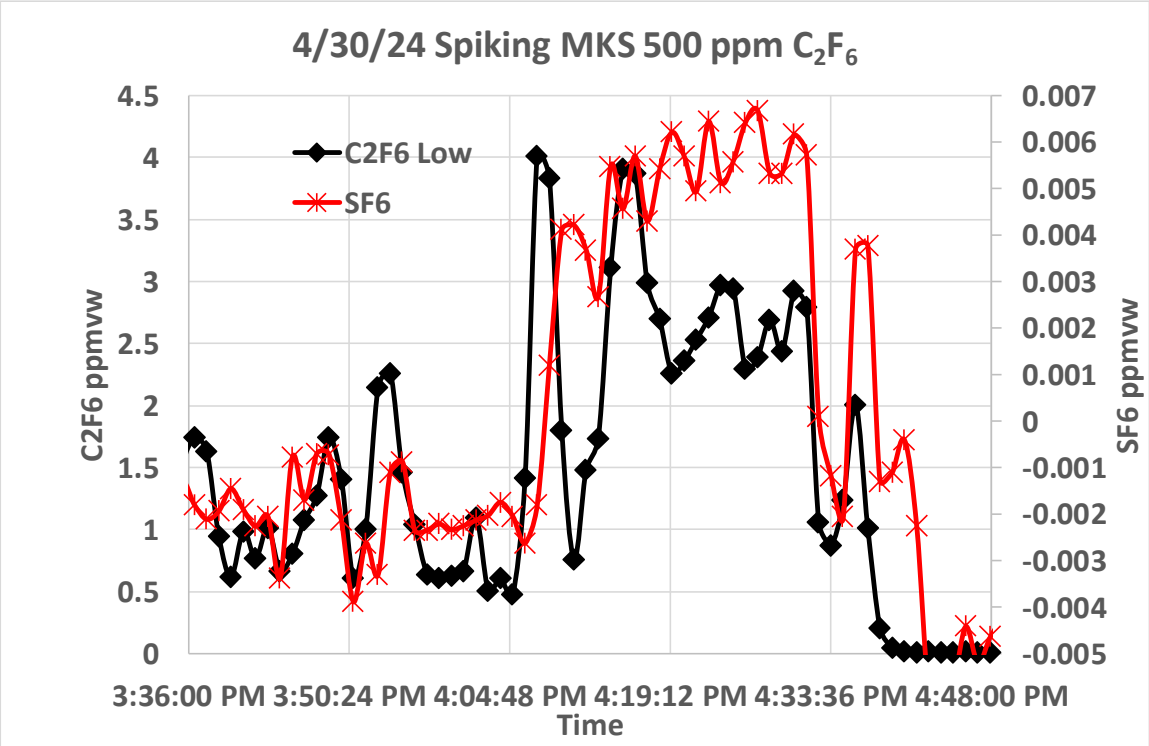


Figure 4: MKS Dynamic Matrix Spiking, 1 ppm CF_4 and C_2F_6

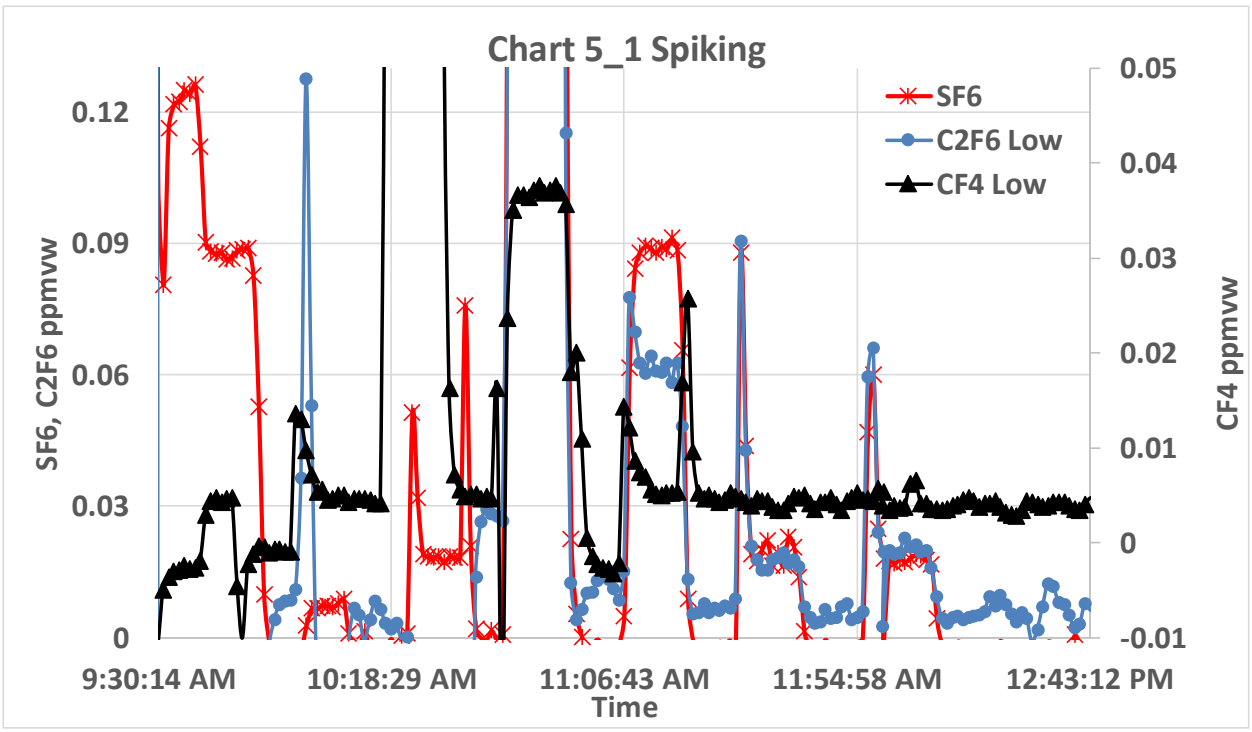


Figure 5: IMACC Dynamic Matrix Spiking, 500 ppm C_2F_6

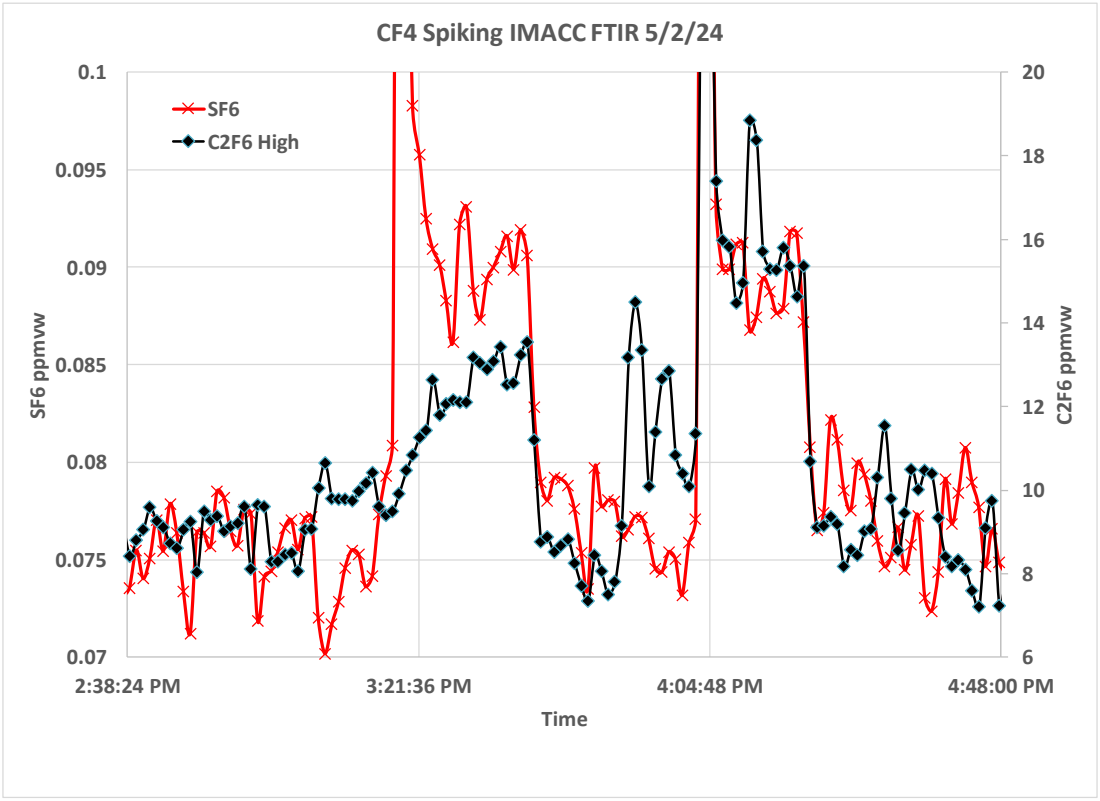
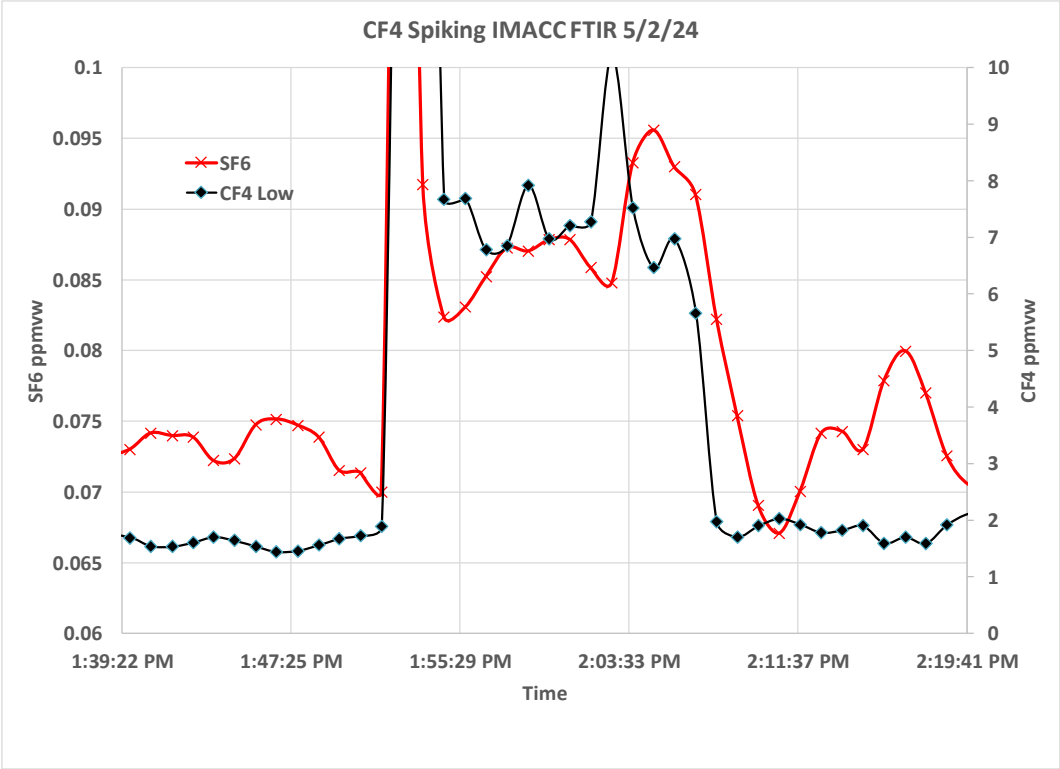


Figure 6: IMACC Dynamic Matrix Spiking, 500 ppm CF_4 During EPA CF_4 Injection



FTIR Peak Width and Wavelength Accuracy

The screenshot below shows the wavelength and peak width accuracy in comparison with a water peak from a reference standard demonstrating proper FTIR performance.

Figure 7: MKS Peak Width Screenshot 5/2/24

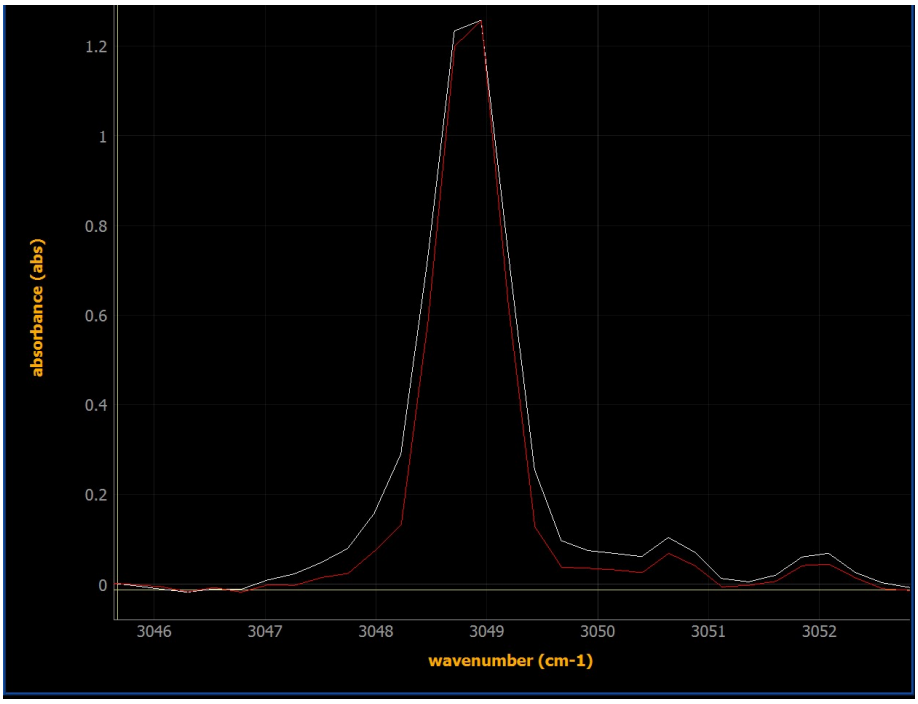
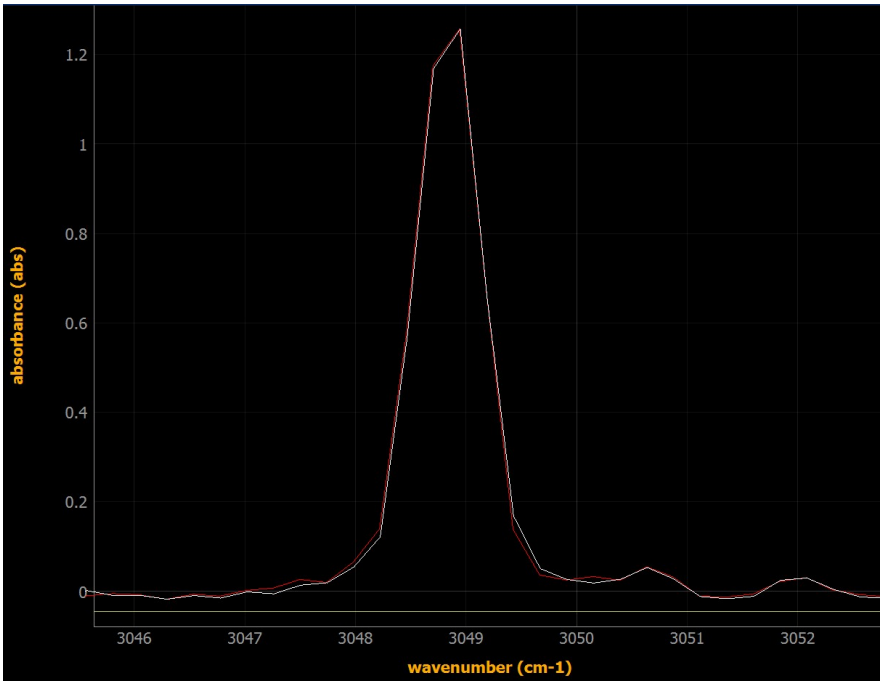


Figure 8: IMACC Peak Width Screenshot 5/2/24



EPA Protocol Calculations

The EPA FTIR protocol defines two measures of FTIR data quality, the Minimum Analytical Uncertainty (MAU) and the Fractional Model Uncertainty (FMU). These are analogous to the Instrumental Detection Limit and Percent Measurement Uncertainty used in other analytical

measurements. The MAU is a measure of the noise limited detection limit and does not take into account the interferences encountered in measuring a complex gas matrix. The FMU is a more true detection limit taking into account the interferences in the gas matrix.

The noise-limited detection is defined in EPA Reference Method 320 as Minimum Analytical Uncertainty defined as:

$$\mathbf{MAU} = \frac{RMS_{noise} * [\nu_u - \nu_l]}{\frac{\mathbf{A}_i}{\mathbf{C}_i * \mathbf{L}_i}}$$

In this equation RMS_{noise} is the RMS (root mean square) noise in the analysis region between ν_u and ν_l, A_i the area of the i^{th} reference spectrum in this analysis region, while C_i, L_i are the concentration and path length of the reference spectrum. MAU has the units of ppm*m and represents the lowest detection possible with the system as limited by system noise. If the system has a path length of L the ppm limit is (1/L) time this value.

The true detection of an FTIR system is usually limited not by noise but by interference from other compounds. The FMU attempts to model this by looking at the spectral residual resulting after analysis (what is left over that the analysis routines have not accounted for) and comparing this to the reference spectra. FMU is defined as:

$$\mathbf{FMU} = \frac{RMS_{resid} * (\nu_u - \nu_l)}{\frac{\mathbf{A}_i}{(\mathbf{C}_i * \mathbf{L}_i)} * C_i^{cls}}$$

Here RMS_{resid} is the RMS of the spectral residual in the analysis region from ν_u to ν_l, A_i is (as above) the area of the i^{th} reference spectrum normalized to its concentration (C_i) and path length (L_i), and C_i^{cls} is the (ppm*m) concentration provided by the CLS-routine (classical least squares) for the i^{th} analyte. The FMU is a percentage representing the percent-uncertainty of the analysis system near detection limit. The CLS error bar provided by most CLS routines is very similar to this value as it is derived from the spectral residual and the references as well.

An equivalent extractive FTIR test method has been published by ASTM (ASTM D6348 12, Standard Test Method for Determination of Gaseous Compounds by Extractive Direct Interface Fourier Transform Infrared (FTIR) Spectroscopy). This test method includes additional equations to calculate the MDC (minimum detectable concentration). For example, the MDC #1 and MDC#3 are defined as:

$$\boldsymbol{MDC\#1} = \frac{RMS_{noise}}{RMS_{ref}} \times \frac{C_i \times L_i}{L_{cell}}$$

$$\boldsymbol{MDC\#3} = \frac{RMS_{resid}}{RMS_{ref}} \times \frac{C_i \times L_i}{L_{cell}}$$

These equations are shown in a different format than the ASTM method so that the factors defined above can be expressed in the same fashion. The RMS_{ref} is the RMS of the reference spectrum in

the analysis region from v_u to v_l and L_{cell} is the pathlength of the gas cell used in the test program. The ASTM Method also states that the spectral residual returned by the CLS analysis program of the FTIR analyzer can be used as MDC#3.

The table below summarizes the FTIR Protocol and ASTM calculations for this test program. For the MKS software, a single spectrum from the 5/2/24 testing was selected as representative of the test runs and was used for the calculations (same spectra identified in Manual Subtraction section). The MKS Analysis Validation Utility (AVU) was used for the calculations. The table lists the measured concentration and residual from the CLS analysis and the calculated MAU and FMU for carbon tetrafluoride and hexafluoroethane. The different calculations yield a wide range of concentrations. The spectral residuals indicate that the measurements were performed with sufficient accuracy to quantify the concentrations. The Spectrum WaveRunIR™ software uses sets of spectra (noise-limited, source, interferent only) for the calculations.

Additional detection limits were calculated using 3 times the standard deviation of 8 consecutive measurements. An instrument DL used zero spectra and a source DL used measured spectra from the facility.

All of the data in the tables below are in ppmvw units.

Table 48: MKS FTIR Protocol Calculation Summary

Analyte	Measured Conc. (ppm)	Measured CLS Residual	ASTM D6348 MDC#3	ASTM D6348 MDC#1	FTIR Protocol MAU (ppm)	FTIR Protocol FMU (%)	Instrument Detection Limit (3*(Standard Deviation of 8 zero spectra)	Source Detection Limit (3*(Standard Deviation of 8 sample spectra)
CF4 Low	0.0039	0.0061	0.050	0.010	0.030	0.15	0.00064	0.00088
C2F6 Low	0.015	0.0082	0.10	0.030	0.050	0.15	0.0035	0.017

Date 5/2/2024
Time 12:00:25 PM
Spectrum REWORLD_002039.LAB
The MKS software uses a set of spectra containing 10% water and 10% CO2 for MDC1 and MAU, a single direct zero spectrum for MDC2 (measured 7:37 on 5/2/24) and a single source spectrum for MDC3 and FMU as shown above.

Table 49: IMACC FTIR Protocol Calculation Summary

Analyte	Measured Conc. (ppm)	Measured CLS Residual	ASTM D6348 MDC#3 (ppm)	ASTM D6348 MDC#2 (ppm)	ASTM D6348 MDC#1 (ppm)	FTIR Protocol MAU (ppm)	FTIR Protocol FMU (%)	Instrument Detection Limit (3*(Standard Deviation of 8 zero spectra)	Source Detection Limit (3*(Standard Deviation of 8 sample spectra)
CF_4	-0.24	0.018	39.7	0.37	0.015	0.015	5740.0	0.0020	0.031
C_2F_6	-0.048	0.016	7.4	0.055	0.069	0.069	-1380.0	0.0067	0.019

The Spectrum NuWave software uses different spectra for the various calculations. A set of 8 direct zero spectra are used to calculate MDC1 and MAU. The spectra used were measured from 17:35 to 17:48 on the IMACC FTIR on 5/2/24 when nitrogen flowed through the cell. MDC2 uses as set of 8 interferent-only spectra. Spectra measured by TRC of 12% moisture in nitrogen were used for the interferent spectra. MDC3 and FMU are measured from a set of 8 source spectra, and these were measured on 5/2/24 from 8:09-8:16.

APPENDIX D: Calibration Gas Certificates

Airgas
an Air Liquide company

Airgas Specialty Gases
Airgas USA LLC
616 Miller Cut Off Road
La Porte, TX 77571
Airgas.com

CERTIFICATE OF ANALYSIS

Grade of Product: CERTIFIED STANDARD-SPEC

Customer:	TRC ENVIRONMENTAL CORP - C328 BUDA, TX		
Part Number:	X02NI99C15A1268	Reference Number:	126-402844727-1
Cylinder Number:	CC462799	Cylinder Volume:	144.0 CF
Laboratory:	124 - La Porte Mix - TX	Cylinder Pressure:	2015 PSIG
Analysis Date:	Sep 15, 2023	Valve Outlet:	350
Lot Number:	126-402844727-1		

Expiration Date: Sep 15, 2031

Product composition verified by direct comparison to calibration standards traceable to N.I.S.T. weights and/or N.I.S.T. Gas Mixture reference materials.

ANALYTICAL RESULTS

Component	Req Conc	Actual Concentration (Volume %)	Actual Concentration (Weight %)	Analytical Uncertainty
ETHYLENE	100.0 PPM	99.94 PPM	100.1 PPM	± 2%
NITROGEN	Balance	Balance		

Notes:.
PO NUMBER: 206220

Signature on file
Approved for Release

RED BALL
TECHNICAL GAS SERVICES

ilac-MRA

PJLA
Accreditation #82764

Red Ball Technical Gas Service
555 Craig Kennedy Way
Shreveport, LA 71107
800-551-8150
PGVP Vendor ID # G12023

EPA PROTOCOL GAS CERTIFICATE OF ANALYSIS

Cylinder Number:	EB0004004	**Certification Date:**	06/07/2023
Product ID Number:	124300	**Expiration Date:**	06/05/2031
Cylinder Pressure:	1900 PSIG	**MFG Facility:**	- Shreveport - LA
COA #	EB0004004.20230530-0	**Lot Number:**	EB0004004.20230530
Customer PO. NO.:		**Tracking Number:**	6041595
Customer:		**Previous Certification Dates:**	

This calibration standard has been certified per the May 2012 EPA Traceability Protocol, Document EPA-600/R-12/531, using procedure G1.

Do Not Use This Cylinder Below 100 psig (0.7 Megapascal).

Certified Concentration(s)

Component	Concentration	Uncertainty	Analytical Principle	Assayed On
Carbon Dioxide	**9.90 %**	±0.09 %	NDIR	06/07/2023
Oxygen	**9.99 %**	±0.03 %	MPA	06/06/2023
Nitrogen	Balance			

Analytical Measurement Data Available Online.

Reference Standard(s)

Serial Number	Lot	Expiration	Type	Balance	Component	Concentration	Uncertainty(%)	NIST Reference
CC737073	CC737073.20211012	09/01/2030	GMIS	N2	O2	19.99 %	0.128	SRM 2658a
EB0004315	EB0004315.20201022	04/05/2030	GMIS	N2	CO2	24.75 %	0.237	C2190301.03
EB0041460	EB0041460.20150401	10/03/2030	GMIS	N2	CO2	9.52 %	0.191	C2190301.03

Analytical Instrumentation

Component	Principle	Make	Model	Serial	MPC Date
O2	MPA	Thermo	410i	1162980025	05/09/2023
CO2	NDIR	Thermo	410i	1162980025	05/23/2023

SMART-CERT

This is to certify the gases referenced have been calibrated/tested, and verified to meet the defined specifications. This calibration/test was performed using Gases or Scales that are traceable through National Institute of Standards and Technology (NIST) to the International System of Units (SI). The basis of compliance stated is a comparison of the measurement parameters to the specified or required calibration/testing process. The expanded uncertainties use a coverage factor of k=2 to approximate the 95% confidence level of the measurement, unless otherwise noted. This calibration certificate applies only to the item described and shall not be reproduced other than in full, without written approval from Red Ball Technical Gas Services. If not included, the uncertainty of calibrations are available upon request and were taken into account when determining pass or fail.

Gabriel Ouma
Analytical Chemist
Assay Laboratory: Red Ball TGS
Version 02-J, Revised on 2018-09-17

Airgas
an Air Liquide company

Airgas Specialty Gases
Airgas USA LLC
6141 Easton Road
Plumsteadville, PA 18949
Airgas.com

CERTIFICATE OF ANALYSIS

Grade of Product: CERTIFIED STANDARD-SPEC

Customer:	JACOBS TECHNOLOGY INC		
Part Number:	X03NI99C15A04D9	Reference Number:	160-403004518-1
Cylinder Number:	ALM038592	Cylinder Volume:	144.4 CF
Laboratory:	124 - Plumsteadville - PA	Cylinder Pressure:	2015 PSIG
Analysis Date:	Apr 04, 2024	Valve Outlet:	580
Lot Number:	160-403004518-1		

Expiration Date: Apr 04, 2032

Product composition verified by direct comparison to calibration standards traceable to N.I.S.T. weights and/or N.I.S.T. Gas Mixture reference materials.

ANALYTICAL RESULTS

Component	Req Conc	Actual Concentration (Mole %)	Analytical Uncertainty
SULFUR HEXAFLUORIDE	2.000 PPM	2.103 PPM	+/- 5%
R116 HEXAFLUOROETHANE	500.0 PPM	502.9 PPM	+/- 2%
NITROGEN	Balance		

Notes:PO number: EPATP-0000006002

Signature on file
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Airgas
an Air Liquide company

Airgas Specialty Gases
Airgas USA LLC
6141 Easton Road
Plumsteadville, PA 18949
Airgas.com

CERTIFICATE OF ANALYSIS

Grade of Product: CERTIFIED STANDARD-SPEC

Part Number:	X03NI99C15A04E5	Reference Number:	160-403004517-1
Cylinder Number:	CC178185	Cylinder Volume:	144.3 CF
Laboratory:	124 - Plumsteadville - PA	Cylinder Pressure:	2015 PSIG
Analysis Date:	Mar 29, 2024	Valve Outlet:	580
Lot Number:	160-403004517-1		

Expiration Date: Mar 29, 2032

Product composition verified by direct comparison to calibration standards traceable to N.I.S.T. weights and/or N.I.S.T. Gas Mixture reference materials.

ANALYTICAL RESULTS

Component	Req Conc	Actual Concentration (Mole %)	Analytical Uncertainty
R14 TETRAFLUOROMETHANE	1.000 PPM	1.020 PPM	+/- 5%
SULFUR HEXAFLUORIDE	2.000 PPM	2.059 PPM	+/- 5%
NITROGEN	Balance		

Signature on file
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Airgas
an Air Liquide company

Airgas Specialty Gases
Airgas USA LLC
6141 Easton Road
Plumsteadville, PA 18949
Airgas.com

CERTIFICATE OF ANALYSIS

Grade of Product: CERTIFIED STANDARD-SPEC

Part Number:	X03NI99C15A04E7	Reference Number:	160-403004516-1
Cylinder Number:	CC124037	Cylinder Volume:	144.4 CF
Laboratory:	124 - Plumsteadville - PA	Cylinder Pressure:	2015 PSIG
Analysis Date:	Mar 29, 2024	Valve Outlet:	580
Lot Number:	160-403004516-1		

Expiration Date: Mar 29, 2032

Product composition verified by direct comparison to calibration standards traceable to N.I.S.T. weights and/or N.I.S.T. Gas Mixture reference materials.

ANALYTICAL RESULTS

Component	Req Conc	Actual Concentration (Mole %)	Analytical Uncertainty
SULFUR HEXAFLUORIDE	2.000 PPM	2.101 PPM	+/- 5%
R14 TETRAFLUOROMETHANE	500.0 PPM	511.7 PPM	+/- 2%
NITROGEN	Balance		

Signature on file
Approved for Release

Airgas
an Air Liquide company

Airgas Specialty Gases
Airgas USA LLC
6141 Easton Road
Plumsteadville, PA 18949
Airgas.com

CERTIFICATE OF ANALYSIS

Grade of Product: CERTIFIED STANDARD-SPEC

Customer:	JACOBS TECHNOLOGY INC		
Part Number:	X03NI99C15A04E1	Reference Number:	160-403004519-1
Cylinder Number:	CC440016	Cylinder Volume:	144.3 CF
Laboratory:	124 - Plumsteadville - PA	Cylinder Pressure:	2015 PSIG
Analysis Date:	Apr 02, 2024	Valve Outlet:	580
Lot Number:	160-403004519-1		

Expiration Date: Apr 02, 2032

Product composition verified by direct comparison to calibration standards traceable to N.I.S.T. weights and/or N.I.S.T. Gas Mixture reference materials.

ANALYTICAL RESULTS

Component	Req Conc	Actual Concentration (Mole %)	Analytical Uncertainty
R116 HEXAFLUOROETHANE	1.000 PPM	1.056 PPM	+/- 5%
SULFUR HEXAFLUORIDE	2.000 PPM	2.060 PPM	+/- 5%
NITROGEN	Balance		

Notes:PO number: EPATP-0000006002

Signature on file
Approved for Release

APPENDIX E: Raw Field Data Sheets

Reworld Lake 4/30/2024

Time	Activity	Notes
6:50	Arrive at plant	LiN2 and verify all heaters
7:10	Install new method	14.88 Pathlength 1min scan 2min background
7:20	Background	IMACC on wet sample and MKS on dry sample
7:25	Direct Zero	
7:29	Direct CTS	7:33 to 7:36 Average IMACC = 99 MKS = 99.4
7:37	DIrect Cal	500 CF4, 2 SF6 Average IMACC = 514, 0.346 MKS = 586, 2.05
7:45	Direct Cal	500 C2F6, 2 SF6 Average IMACC = 508, 2.33 MKS = 619, 2.05
7:53	Direct Cal	1 CF4, 2 SF6 Average IMACC = 1.1, 2.3 MKS = 1.3, 2.02
8:01	Direct Cal	1 C2F6, 2 SF6 Average IMACC = 1.25, 2.35 MKS = 1.12, 2.06
8:07	System Zero	
8:20	System CTS	IMACC = 97.5 MKS = 99.5
8:29	Sample	
9:21	Spiking	1 CF4, 2 SF6 Start at 0.75L/m, 0.6L/m, 0.3L/m, and 0.15L/m using ASC-10 Good response on MKS and IMACC
10:20	Sample	Native from 10:20 to 10:35
10:36	Spiking	0.15 L/m approx 85:1
10:53	Spiking	0.02 L/m with Omega MFC 160:1
11:35	System Zero	
11:40	System CTS	IMACC = 98.53, MKS = 99.4
11:50	Direct Zero	Change to 2min sample and 5min Background
11:55	Background	
12:05	Sample	IMACC moisture is incorrect around 50% of actual. Switch MKS to wet and moisture is confirmed to be 15% to 18%
13:20	Sample	Switch back to MKS dry
13:40	Sample	Injecting CF4 into Dryer. Start at 20L/min. Reduce to 10L/m and then to 8L/m. MKS is accurate. IMACC is way toc 20L/m IMACC reading unstable 200-600ppm, MKS steady at 24ppm 10L/m IMACC reading stable on CF4 high at 80ppm, MKS stable at 12ppm 8L/m IMACC readting stable on CF4 high at 90ppm, MKS stable at 10ppm
14:05	Sample	Stop CF4 injection
14:34	Sample	Injecting CF4 into underfire air. 8L/m MKS = 3.2 ppm CF4, IMACC 1.4 ppm CF4
14:48	Sample	Stop CF4 injection
14:55	Sample	Injection C2F6 into underfire air. 50L/m
15:15	Sample	Start SUMMA can collection
16:00	Sample	End SUMMA can collection
16:08	Spike	Spike C2F6 500 gas
16:30	End Spike	10 ml/min. Natve average from 15:15 to 16:00. Spike average from 16:06 to 16:30. MKS Data.
16:35	Direct Zero	
16:40	Direct CTS	IMACC = 98.69, MKS = 99.44
16:58	Background	

Reworld Lake 5/1/2024

Time	Activity	Notes
7:00	Arrive at plant	LiN2 and verify all heaters
7:10	Install new method	13.69 Pathlength 2min scan 5min background
7:30	Background	IMACC on wet sample and MKS on dry sample
7:35	Direct Zero	
7:40	Direct CTS	Average IMACC = 96.12 MKS = 99.5
7:50	System Zero	
7:58	System CTS	Average IMACC = 95.4 MKS = 99.6
8:09	Direct Zero	
8:15	Direct Zero	New pathlegth 13.15
8:18	Background	
8:25	Direct CTS	Average IMACC = 100 MKS = 99.6
8:36	Direct Cal	500 C2F6, 2 SF6 Average IMACC = 523, 2.71 MKS = 616.6, 2.06
8:46	Direct Cal	500 CF4, 2 SF6 Average IMACC = 533, 1.18 MKS = 583.4, 2.05
8:56	Sample	IMACC Moisture looks correct now. CO2 is still way off
9:16	System Cal	500 CF4, 2 SF6 Average IMACC = 518 1.186MKS = 583.5, 2.06
9:43	Spike	0.2 L/m ASC-10, 500 CF4, 2 SF6, 22.9:1, 107.5% recovery on MKS
	Spike	0.01 L/m using MFC a littl elow to get good readings
	Spike	0.020 L/m using MFC, 200:1, 112% recovery on MKS. SF6 not stable at this level due to native moving around
10:07	Sample	New Native
10:27	Spike	0.040 L/m using MFC, 100:1, 106.5% recovery on MKS.
10:34	System Zero	
10:42	System Cal	1 C2F6, 2 SF6 Average IMACC = 1.28, 2.7 MKS = 1.08, 2.07
10:52	Sample	
11:05	Spike	0.20 L/m using ASC-10, 25:1, 123% recovery on MKS, 78% on IMACC
11:17	Sample	
11:30	Spike	0.040 L/m using MFC, 100:1, 175% recovery on MKS. 28% on IMACC. SF6 hard to see
11:42	Sample	
11:56	Spike	0.040 L/m using MFC, 100:1, 160% recovery on MKS. 104% on IMACC
12:10	Sample	
13:40	Sample	CF4 injection 16L/m into under fire air
13:58	Sample	Start Average for Native
14:12	Spike	Start Average for spike 500 CF4, 2 SF6 EPA Injection masks spiking
14:30	Sample	C2F6 injection 50L/m into under fire air
14:40	Sample	Start SUMMA can collection
15:25	Sample	End SUMMA can collection
15:32	Spike	0.02 L/m Average from 15:32 to 15:47
15:54	Spike	0.035 L/m
16:16	Direct Zero	
16:28	Direct CTS	Average IMACC = 100 MKS = 99.6
16:39	Background	

Reworld Lake 5/2/2024

Time	Activity	Notes
7:00	Arrive at plant	LiN2 and verify all heaters
7:10	Direct Zero	13.69 Pathlength 2min scan 5min background
7:30	Background	IMACC on wet sample and MKS on dry sample
7:32	Direct CTS	IMACC = 108 MKS = 99.5
		Change pathlength to 14.21
7:50	Direct CTS	IMACC - 100 MKS = 99.5
8:00	Direct Cal	500 C2F6, 2 SF6 IMACC = 484, 2.51 MKS = 618, 2.05
8:15	Sample	Native C2F6, SF6 IMACC 0.152, 0.0737 MKS 0.071, -0.002
8:17	Spike	500 C2F6 @ 0.15 L/min
8:30	Sample	Native C2F6, SF6 IMACC 0.175, 0.0847 MKS 0.053, -0.003
8:40	Spike	500 C2F6 @ 0.15 L/min
8:50	Sample	Native C2F6, SF6 IMACC 0.163, 0.0782 MKS 0.05056, -0.004
9:01	Spike	500 C2F6 @ 0.035 L/min
9:14	Spike	500 C2F6 @ 0.010 L/min
9:22	Sample	
9:30	Direct Cal	O2/CO2 9.99%, 9.90% CO2 IMACC = 9.4 MKS = 9.88
9:42	Sample	
10:00	Direct Cal	1CF4, 2 SF6 IMACC = 1.37, 2.47 MKS 1.244, 2.001
10:15	Sample	Native CF4, SF6 IMACC -0.148, 0.0832 MKS 0.111, -0.002
10:24	Spike	1 CF4, 2 SF6 @ 0.15 L/m
10:42	Direct	C2F6 = 1, SF6 = 2
11:00	Sample	Native C2F6, SF6 IMACC 0.14, 0.0836 MKS 0.013, -0.002
11:02	Spike	1 CF4, 2 SF6 @ 0.15 L/m
11:15	Sample	Native C2F6, SF6 IMACC 0.142, 0.0872 MKS 0.013, -0.002
12:45	Spike	1 CF4, 2 SF6 @ 0.035 L/m
13:05	Sample	Native
13:15	Spike	1 CF4, 2 SF6 @ 0.035 L/m
13:33	Sample	
13:35	Sample	CF4 Inject
13:55	Spike	1 CF4, 2 SF6 @ 0.035 L/m
14:08	Sample	
14:18	Direct Cal	500 CF4, 2 SF6 IMACC = 492.6, 1.283 MKS 584.6, 2.049
14:30	Sample	Inject C2F6 50L/min
15:18	Spike	500 C2F6 @ 0.035 L/min
15:38	Sample	Inject C2F6 200L/m
16:03	Spike	500 C2F6 @ 0.035 L/min
16:19	Sample	
16:49	Direct Zero	
16:57	Direct CTS	IMACC 100, MKS 99.4
17:05	System CTS	IMACC 99.5, MKS 99.2
17:16	System Zero	
17:22	Direct Zero	
17:29	Direct Zero	10 minute Zero for MDL
17:40	Background	

Injection times

14:30	Sample	Inject C2F6 50L/min
15:38	Sample	Inject C2F6 200L/m

1429 Rock Quarry Road, Suite 116
Raleigh, North Carolina 27610
T (919) 828-3150
F (919) 838-9661
TRCcompanies.com

Mr. Matt Allan
Senior Chemist
Jacobs
Mail Code E305-04, 109 T.W. Alexander Drive
Research Triangle Park, North Carolina 27711

Dear Mr. Allan:

I have sent an electronic copy of the report for the YYYY NESHAP Emission Compliance Study performed by TRC Environmental Corporation (TRC) for Jacobs at the Covanta Lake Waste-to-Energy Facility in Okahumpka, Florida on April 30-May 2, 2024.

If you have any questions regarding this report, please let us know. We appreciate the opportunity to provide you with our services.

Sincerely,

TRC Environmental Corporation

Thomas Dunder, Ph.D.
Technical Director