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**ROCKY FLATS 1990-91
WINTER VALIDATION TRACER STUDY**

Report AQ 91-19

Volume I

Prepared for

EG&G - ROCKY FLATS PLANT

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MASTER

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ROCKY FLATS 1991 WINTER VALIDATION STUDY TRACER EXPERIMENTS

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1.0 INTRODUCTION

During the winter of 1990-91, North American Weather Consultants (NAWC) and its subcontractor, ABB Environmental Services (ABBES), conducted a Winter Validation Study (WVS) for EG&G Rocky Flats Involving 12 separate tracer experiments conducted between February 3 and February 19, 1991. Six experiments were conducted during nighttime hours and four experiments were conducted during daytime hours. In addition, there was one day/night and one night/day transitional experiment conducted.

1.1 Purpose

The primary purpose of the WVS was to gather data to further the approval process for the Terrain Responsive Atmospheric Code (TRAC). TRAC is an atmospheric dispersion model developed and operated at the Department of Energy's (DOE's) Rocky Flats Plant (RFP) north of Denver, Colorado. A secondary objective was to gather data that will serve to validate the TRAC model physics.

1.2 Other Studies

This WVS was a component of an ongoing program of development and validation of the TRAC model. During the summer of 1987, NAWC conducted a tracer study at the RFP using aircraft sampling and limited ground level samples.

During the WVS, there were numerous meteorological observations being made by other investigators, including EG&G's 61-m meteorological tower; National Oceanic and Atmospheric Administration's (NOAA) Program for Regional Observing and Forecasting Services (PROFS), the Wave Propagation Laboratory Doppler Lidar, Radio Acoustic Sounding System (RASS) and temperature profilers; Department of Energy's (DOE's) Atmospheric Studies in Complex Terrain (ASCOT) meteorological towers and profilers; NOAA's Air Resources Laboratory Tetroon Tracking; and the National Center for Atmospheric Research's (NCAR's) Portable Automated Mesomet (PAM) network of monitoring towers.

2.0 PROJECT DESIGN

2.1 Tracer Gas Release

The project design called for the release of sulfur hexafluoride (SF_6) gas at a site located at RFP. ABBES installed a mobile office trailer at the release site which was located on the east side of the complex at Universal Transverse Mercator (UTM) coordinates 482850 east and 4415050 north. The duration of tracer release for each test was 11 hours. Release was initiated two hours prior to the start of the fixed ground level sampling. Tracer gas release and the fixed ground level sampling were terminated at the same time.

A schematic diagram of the system used to release the tracer gas is provided in Figure 2.1. The system consisted of two identical flow channels. One channel was used for release rates below approximately 50 liters per minute (lpm) (0.302 kg/min). Both channels were used when higher release rates were required. The maximum release rate capacity of the system, using both channels, was approximately 100 lpm (0.604 kg/min).

The SF_6 was supplied from compressed gas cylinders, each containing approximately 52 kg SF_6 , connected to common manifolds. During the release periods, heat was applied to the compressed gas cylinders with heating tape to promote volatilization of the SF_6 . The manifolds were also wrapped with heating tape to raise the SF_6 temperature to approximately 21°C before release to the atmosphere.

Two-stage regulators on each manifold were used to reduce the cylinder gas pressure to between 30 and 40 pounds per square inch (psi) before entry of the tracer gas into the mass flow controllers. The release rate was controlled by the mass flow controllers. The output signal from the Tylan RO-28 MFC readout unit was recorded by an Odessa data logger.

After exiting the mass flow controllers, the tracer gas was conducted through 3/8 inch copper tubing to a release point 10 meters above ground level (AGL) and at an elevation of 1830 meters above mean sea level (MSL). The copper lines were supported by a temporary tower. Calibration data for the Tylan mass flow controller system are provided in Appendix A. A calibration of the mass flow controllers was provided by Tylan at the time of delivery.

A more thorough, 11 point calibration of the mass flow controllers was performed following the field study.

During the release periods operational logs were maintained to document the equipment used, release rate indicated by the mass flow controllers, and the primary and secondary gas pressures. All gas cylinders were weighed before and after the release period so that the release rate indicated by the mass flow meter could be checked against the release rate calculated from the cylinder weight loss. Copies of the data logs recorded during each of the release periods are provided in Appendix A.

A summary of the SF₆ release rates for the WVS experiments is given in Table 2-1. The table shows the release period, the release rate determined both from the mass flow controller and from cylinder weight loss data, and the difference between the Mass Flow Controller (MFC) and Weight (WT) release rates. The MFC release data were calculated using the results of the more rigorous flow rate calibration performed after completion of the field study.

Table 2-1
Summary Of SF₆ Release Rates For WVS Tests

Test No.	Start (a) Date/Time	End (a) Date/Time	Release, Kg/Hr		% Difference (d)
			MFC (b)	WT (c)	
1	910203 2000	910204 0700	13.71	13.24	-3.4
2	910204 2000	910205 0700	13.05	12.16	-6.8
3	910206 2000	910207 0700	13.71	13.33	-2.8
4	910207 2000	910208 0700	16.53	16.84	1.9
5	910209 1300	910209 2400	23.61	22.63	-4.2
6	910211 0700	910211 1800	23.61	22.94	-2.8
7	910212 0700	910212 1800	23.61	23.99	1.6
8	910214 0100	910214 1200	23.61	23.44	-0.7
9	910215 0700	910215 1800	23.61	23.29	-1.4
10	910216 2000	910217 0700	23.61	23.47	-0.6
11	910217 2000	910218 0700	23.61	23.04	-2.4
12	910219 0700	910219 1800	23.21	22.97	-1.0

- a. Dates given in yymmdd; time is Mountain Standard Time (MST).
- b. Release rate calculated from mass flow controllers. MFC calibrated at 760mm Hg, 21.11 °C.
- c. Release rate determined from cylinder weight loss.
- d. $(WT - MFC)100/MFC$.

2.2 Fixed Site Ground Sampling Network

Tracer gas sampling was performed at fixed ground level sites located on two concentric rings that circled the release site at the RFP. The radius of the circles were approximately 8 km and 16 km, respectively. Samplers were placed around both circles approximately each five degrees of arc (Figures 2.2-2.6). Due to inaccessibility, it was impossible to locate four samplers on the 8 km ring in the Eldorado Mountain area (Sites 2057-2060) and one sampler on the 16 km ring in the Boulder Mountain Park (Site 2137).

Clusters of five samplers each were placed in the following populated areas: Boulder (Sites 2145-2149), Interlocken Industrial Park in Broomfield (Sites 2150-2154), Standley Lake Subdivision in Arvada (Sites 2155-2159), and North Table Mountain near Golden (Sites 2160-2164). At the request of the EG&G Project Manager, three sampling sites (2161, 2162, and 2163) in the North Table Mountain cluster were relocated to the east side of the Mountain after Test 4. The designations of the relocated sites were 2114, 2122, and 2124.

Additional samplers were located at the Colorado Department of Health (CDH) facilities in Arvada (Site 2165), Camp (Site 2166), Platteville (Site 2168), Boulder (Site 2169), Carriage (Site 2170), Welby (Site 2171), and Englewood (Site 2172) (Figure 2.7).

In accordance with the design described above and considering the access limitations to some of the desired areas, a total of 164 sampling sites were identified. The identification numbers assigned to the sites, the UTM coordinates of the sites, and the site elevations are shown in Table 2-2. Sampling site coordinates were determined with the NAWC, van-mounted, global positioning system (GPS). The van was positioned within 10 meters of the sampling site for all coordinate measurements. Multiple GPS readings obtained at 10-second intervals were averaged to obtain the coordinate values. Corrections were not made for the difference in distance between the van and the sampling position since, in all cases, this difference was within the estimated accuracy of the GPS. The accuracy of the GPS coordinate measurements is estimated to be ± 25 meters. Sampling sites coordinates were then digitized and placed on several small scale topographical maps. Site ground-level elevations were then obtained to the nearest 10 meters.

Figure 2.2 Syringe Sampling Sites

2 - 6

2-7

Figure 1 is a map of the study area showing the distribution of 30 numbered sampling stations. The map includes UTM Easting coordinates (483300 to 503300) and Northing coordinates (4396000 to 4416000). A dashed line indicates the 4406000 Northing coordinate. The map shows a coastline with several islands and a large body of water. Sampling stations are marked with numbers and symbols (circles with crosses or triangles).

2 - 8

RFWVS SYRINGE SAMPLING SITE LOCATIONS - NE QUAD

Figure 2.6 Syringe Sampling Sites - Northeast Quadrant

RFWVS CDH SYRINGE SAMPLING SITE LOCATIONS

Figure 2.7 CDH Syringe Sampling Sites

Table 2-2

Rocky Flats - WVS 1991 - List of Sampling Sites

Site No.	UTM N/S Location meters	UTM E/W Location meters	Elevation meters
2001	4423425 N	0483768 E	1740
2002	4423467 N	0484561 E	1730
2003	4423382 N	0485549 E	1700
2004	4423586 N	0486182 E	1690
2005	4423074 N	0486325 E	1680
2006	4422186 N	0487433 E	1690
2007	4422883 N	0488472 E	1660
2008	4422276 N	0488961 E	1660
2009	4421279 N	0489090 E	1660
2010	4421172 N	0489859 E	1640
2011	4420299 N	0489832 E	1650
2012	4419916 N	0490077 E	1650
2013	4418845 N	0491236 E	1680
2014	4418629 N	0491629 N	1680
2015	4417459 N	0491632 E	1700
2016	4417235 N	0491835 E	1690
2017	4416216 N	0491789 E	1700
2018	4415633 N	0491872 E	1670
2019	4414993 N	0491785 E	1660
2020	4414540 N	0491761 E	1670
2021	4413735 N	0491798 E	1650
2022	4413068 N	0491660 E	1670
2023	4412543 N	0491003 E	1680
2024	4411606 N	0490767 E	1720
2025	4411057 N	0490262 E	1710
2026	4410273 N	0490265 E	1710
2027	4410028 N	0489610 E	1730
2028	4409390 N	0488972 E	1720
2029	4408962 N	0488686 E	1690
2030	4408339 N	0487919 E	1690
2031	4408398 N	0487192 E	1700
2032	4408055 N	0486672 E	1700
2033	4407786 N	0486104 E	1700
2034	4407543 N	0485473 E	1710
2035	4406771 N	0484864 E	1730
2036	4406726 N	0484031 E	1740
2037	4406774 N	0483284 E	1750
2038	4407190 N	0482639 E	1760
2039	4406369 E	0481792 E	1800
2040	4407691 N	0480993 E	1810
2041	4408591 N	0480543 E	1810
2042	4409243 N	0480351 E	1850
2043	4409799 N	0480071 E	1850

Table 2-2 Continued

Rocky Flats - WVS 1991 - List of Sampling Sites

Site No.	UTM N/S Location <u>meters</u>	UTM E/W Location <u>meters</u>	Elevation <u>meters</u>
2044	4410296 N	0478769 E	1890
2045	4410265 N	0478742 E	1900
2046	4410253 N	0478145 E	1990
2047	4410700 N	0478171 E	1970
2048	4416243 N	0476869 E	2010
2049	4411598 N	0476419 E	2170
2050	4412113 N	0476151 E	2170
2051	4413182 N	0476232 E	2140
2052	4413887 N	0476687 E	2000
2053	4414229 N	0475103 E	2090
2054	4414722 N	0474157 E	2140
2055	4415689 N	0476193 E	2140
2056	4415131 N	0477587 E	1970
2057*	0000000 N	0000000 E	0000
2058*	0000000 N	0000000 E	0000
2059*	0000000 N	0000000 E	0000
2061	4420151 N	0476588 E	1760
2062	4420456 N	0477186 E	1760
2063	4420186 N	0478053 E	1730
2064	4421229 N	0478286 E	1730
2065	4421646 N	0478989 E	1710
2066	4422092 N	0479380 E	1700
2067	4422185 N	0479934 E	1700
2068	4422854 N	0480419 E	1690
2069	4423189 N	0481063 E	1710
2070	4422952 N	0481902 E	1720
2071	4423206 N	0482482 E	1720
2072	4423359 N	0483344 E	1720
2073	4431215 N	0484422 E	1590
2074	4431602 N	0485739 E	1580
2075	4421999 N	0487385 E	1570
2076	4432012 N	0488798 E	1570
2077	4429589 N	0489452 E	1620
2078	4429569 N	0491123 E	1620
2079	4428757 N	0492437 E	1620
2080	4428462 N	0493641 E	1600
2081	4427597 N	0494828 E	1570
2082	4427624 N	0496866 E	1590
2083	4425330 N	0496997 E	1640
2084	4424068 N	0497051 E	1670
2085	4422856 N	0497845 E	1620
2086	4422053 N	0498670 E	1610
2087	4420586 N	0498664 E	1600

Table 2-2 Continued

Rocky Flats - WVS 1991 - List of Sampling Sites

Site No.	UTM N/S Location meters	UTM E/W Location meters	Elevation meters
2088	4418885 N	0499678 E	1620
2089	4417453 N	0499482 E	1660
2090	4416145 N	0499866 E	1670
2091	4414863 N	0499725 E	1690
2092	4413500 N	0499522 E	1670
2093	4411941 N	0499481 E	1660
2094	4410424 N	0499410 E	1660
2095	4409288 N	0498532 E	1640
2096	4408177 N	0497935 E	1620
2097	4407169 N	0497013 E	1640
2098	4405488 N	0497022 E	1610
2099	4404436 N	0495568 E	1630
2100	4403541 N	0494870 E	1650
2101	4402781 N	0493521 E	1660
2102	4401952 N	0492430 E	1700
2103	4401115 N	0491210 E	1710
2104	4400645 N	0489936 E	1700
2105	4400314 N	0488681 E	1720
2106	4399759 N	0487357 E	1730
2107	4399334 N	0486374 E	1760
2108	4399111 N	0482971 E	1810
2110	4399676 N	0481700 E	0760
2111	4399926 N	0480184 E	1770
2112	4400256 N	0479277 E	1800
2113	4402308 N	0478380 E	1950
2114	4404624 N	0483427 E	1810
2115	4402612 N	0475789 E	2110
2116	4403471 N	0474432 E	2190
2117	4403556 N	0472825 E	2320
2118	4403937 N	0471235 E	2390
2119	4404649 N	0469935 E	2420
2120	4405578 N	0468908 E	2470
2121	4406762 N	0467120 E	2580
2122	4404539 N	0483677 E	1780
2123	4409726 N	0465575 E	2550
2124	4404278 N	0483840 E	1750
2125	4413405 N	0465983 E	2800
2126	4414999 N	0467446 E	2700
2127	4415993 N	0469613 E	2480
2128	4416969 N	0468826 E	2540
2129	4418800 N	0467900 E	2580
2130	4419657 N	0469159 E	2220
2131	4420563 N	0470164 E	2150

Table 2-2 Continued

Rocky Flats - WVS 1991 - List of Sampling Sites

Site No.	UTM N/S Location <u>meters</u>	UTM E/W Location <u>meters</u>	Elevation <u>meters</u>
2132	4422770 N	0469360 E	2320
2133	4423444 N	0471089 E	2300
2134	4424965 N	0471408 E	2390
2135	4425679 N	0472271 E	2370
2136	4428389 N	0471815 E	1840
2137*	0000000 N	0000000 E	0000
2138	4429025 N	0475110 E	1670
2139	4430000 N	0476236 E	1660
2140	4430262 N	0477667 E	1630
2141	4430806 N	0478875 E	1620
2142	4430823 N	0480149 E	1610
2143	4431156 N	0481639 E	1600
2144	4431204 N	0482734 E	1590
2145	4423547 N	0478807 E	1740
2146	4424293 N	0478914 E	1720
2147	4424405 N	0479258 E	1710
2148	4424322 N	0479742 E	1680
2149	4424043 N	0479802 E	1680
2150	4419170 N	0490525 E	1660
2151	4418863 N	0490675 E	1670
2152	4418519 N	0490304 E	1690
2153	4418367 N	0490435 E	1700
2154	4418028 N	0490724 E	1720
2155	4411297 N	0488165 E	1750
2156	4410855 N	0488233 E	1730
2157	4410430 N	0487746 E	1740
2158	4410832 N	0487683 E	1750
2159	4411300 N	0487380 E	1730
2160	4401976 N	0480698 E	1820
2161**	4402079 N	0480550 E	1820
2162**	4402205 N	0480468 E	1820
2163**	4402196 N	0480276 E	1810
2164	4402587 N	0480036 E	1840
2165	4405385 N	0491510 E	1660
2166	4399924 N	0501095 E	1610
2167*	0000000 N	0000000 E	0000
2168	4451295 N	0515000 E	1480
2169	4429024 N	0477219 E	1640
2170	4399986 N	0497358 E	1640
2171	4409698 N	0504302 E	1570
2172	4389550 N	0500800 E	1640

* = site number never used

** = moved to 2114,2122,2124 after experiment number 4

Tracer gas sampling was performed with programmable, sequential syringe samplers. Most of the samplers used for the study were designed to hold nine 30cc syringes. These samplers were programmed to begin sample collection two hours after the start of the SF₆ release and to collect nine, consecutive, one-hour integrated, air samples. Samplers designed to accommodate twelve syringes were used at the CDH sites and were also programmed to collect one-hour, integrated air samples beginning two hours after the start of the SF₆ release. Since the CDH samplers contained twelve syringes, three samples were obtained after termination of the SF₆ release.

Twelve-place syringe samplers, programmed to begin sampling one hour before the start of the SF₆ release were deployed during some tests at sites shown in Table 2-3. SF₆ above the minimum detectable concentration of 33 ng/m³ was not observed in any syringe samples taken during the hour prior to initiation of the release. The samples were collected prior to release period to determine the presence of residual SF₆ from previous tests.

Table 2-3
Background Sampling Sites

TEST NUMBER											
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>	<u>12</u>
None	None	None	None	2004	2021	2021	2017	2017	2021	2021	2017
				2021			2021	2021			2021

During preparation for deployment, the samplers were loaded with syringes, programmed to start sampling at the specified time (Sampler Alarm), and the battery voltage was checked. The sampler preparation and deployment data were recorded on the form shown in Figure 2.8. At the time of sampler preparation, bar coded labels containing the syringe set number (xxxxx 00) and the sampler identification were affixed to the form. The syringes placed in the samplers contained previously applied bar coded labels with the corresponding syringe set number and the syringe position in the sampler (xxxxx 01.....xxxxx 09 or xxxxx 01xxxxx 12).

ROCKY FLATS - WINTER VALIDATION STUDY
SYRINGE SAMPLER DEPLOYMENT FORM

SAMPLER PREPARATION DATA

TEST NO. SAMPLER NO.
SAMPLER CLOCK TIME SET TO MST ☒ AM ☒ PM
H H M M

SYRINGE SET IDENTIFICATION

TEST DATE YR MO DA

SAMPLER ALARM ☒ AM ☐ PM
H H M M

BATTERY CHARGE WITH LOAD volts

SAMPLER DEPLOYMENT CHECKS

SYRINGE SEQUENCE CHECK ☒ NEEDLE CHECK ☒ SEPTUM CHECK ☒ BATTERY CHECK ☒
CLOCK CHECK ☒ ALARM CHECK ☒ PROGRAM CHECK ☒ PROGRAM RESET ☒

DEPLOYMENT DATE YR MO DA

TIME DEPLOYED AT SITE (0000 - 2400 HR CLOCK) HRS

SITE NO.

SAMPLER DEPLOYED BY: J. Gluck

SAMPLER IDENTIFICATION

FIXED SITE IDENTIFICATION

COMMENTS: _____

Figure 2.8

The syringe samplers were deployed either on utility poles (P) or metal fence posts (S). The samplers on utility poles were located approximately 2.5 meters AGL and those on the fence posts were located approximately 1.5 meters AGL. Deployment was performed approximately one to four hours before the initiation of sampling.

Retrieval of the samplers began as soon as the sample collection period ended. The samplers were returned to the field sampling staging center for recovery of the syringes. The form shown in Figure 2.9 was used to record the retrieval data, sampler operating condition, and the validity of the syringe samples. The samples were sent to the field gas chromatograph (GC) laboratory for analysis within two hours after recovery from the samplers.

The staging area for sampler deployment and retrieval operations was located in rented space in the Standley Shores Shopping Plaza in Arvada at the intersection of Wadsworth Boulevard and 100th Avenue. Figure 2.10 presents the type of syringe sampler used on this study.

2.3 Mobile Sampling

Two mobile sampling platforms were provided for this project: a sampling van and a helicopter.

2.3.1 Van Sampling

NAWC's one ton Air Quality Sampling Van was used for mobile surface sampling (See Figure 2.11). A ScienTech LBF-3 real time SF₆ analyzer was rack mounted in the van, along with a NAWC computer based Data Acquisition System (DAS) and a Trimble GPS. A temperature sensor was mounted on the roof of the van, and a sample inlet probe on the side about 2.5 meters above ground level. A zero air system was installed in the van and programmed to inject ultra pure air into the SF₆ analyzer every two minutes, instead of the ambient air sample. This produced an accurate baseline to correct for any instrument drift.

A base map showing all roads in the area was entered into the DAS and displayed on a computer monitor. As the van drove around the study region its position, as determined from the GPS, was continually displayed as a green crosshair on the black and white base

ROCKY FLATS - WINTER VALIDATION STUDY SYRINGE SAMPLER RETRIEVAL FORM

SAMPLER RETRIEVAL DATA

RETRIEVED BY: J. Clock

TEST NO. 12 SAMPLER NO. 001 SITE NO. 006

DATE RETRIEVED YR 91 MO 02 DA 19 SYRINGE SET NO. 219800

TIME RETRIEVED (0000 - 2400 HR CLOCK) 2120 HRS

COMMENTS: _____

RETRIEVAL INSPECTION DATA

INSPECTED BY: L. Stephen

SAMPLER CLOCK CHECK ☒ ALARM CHECK ☒ PROGRAM CHECK ☒

BATTERY VOLTAGE: NO LOAD VOLTS WITH LOAD VOLTS

SYRINGE CHECK
CHECK IF SAMPLE APPEARS VALID.

INDICATE SAMPLING PROBLEMS BELOW BY CIRCLING AFFECTED SYRINGES.

<u>FLAGS</u>		<u>SYRINGES</u>
S	NEEDLE NOT SEALED/NO SEPTUM	1 2 3 4 5 6 7 8 9 10 11 12
N	NEEDLE MISSING	1 2 3 4 5 6 7 8 9 10 11 12
F	SYRINGE DID NOT RUN	1 2 3 4 5 6 7 8 9 10 11 12
P	SYRINGE DID NOT FULLY RUN	1 2 3 4 5 6 7 8 9 10 11 12
L	LATE SAMPLER DEPLOYMENT	☐ ALL
T	QUESTIONABLE DATA - CLOCK BAD AT FINAL CHECK-IN	☐ ALL
R	QUESTIONABLE DATA - EVIDENCE SAMPLER RAN TOO FAST OR TOO SLOW OR AT WRONG START TIME	☐ ALL
C	POSSIBLE SF6 CONTAMINATION	1 2 3 4 5 6 7 8 9 10 11 12
O	OTHER PROBLEM _____	1 2 3 4 5 6 7 8 9 10 11 12

COMMENTS: _____

Figure 2.9

Figure 2.10 Syringe Sampling Equipment

Figure 2.11 SF₆ Sampling Van

map. Whenever significant concentrations of SF_6 were encountered, the color of the track turned from green to red to highlight the presence of the SF_6 plume. Also displayed on the monitor was a graph of the instantaneous SF_6 concentrations observed for the previous four minutes.

The van was in constant radio communication with the NAWC Project Director located in the operations center at the Jefferson County Airport. Based on the meteorological observations available in the operations center, the van was directed to areas where the SF_6 plume was likely to be found. The van would follow roads that approximated the 8km and 16km circles around the Rocky Flats Tracer Gas Release Site. Upon finding the plume, the van would generally make multiple transects through the plume. The instrument operator in the van relayed his observations back to the operations center whenever SF_6 was being encountered. The operator also kept a record of all activities by using a tape recorder.

The data, including time, location, temperature and SF_6 concentrations were stored once per second on a hard disk in the DAS. At the end of each operation, the data were transferred to floppy disks for storage and future analysis.

2.3.2 Helicopter Sampling

A Bell Jetranger III was leased from HeliWest helicopters of Indian Hills, Colorado, together with pilots and ground support crews (See Figure 2.12). NAWC installed an instrument package in the helicopter that was identical to the van installation. This included the ScienTech LBF-3 SF_6 analyzer, the NAWC DAS, a GPS and a temperature probe. The temperature probe and sample inlet were mounted near the nose of the helicopter. Flight tests with tufts of yarn affixed to the sample inlet showed that the rotor downwash did not affect the inlet if a forward speed of at least 10 meters per second (mps) was maintained. Normal air speeds were in excess of 30 mps.

The flight technician was in constant radio communication with the NAWC Project Director. Normally, the helicopter would start sampling by making a complete circle around the 8km arc at as low an altitude as possible, usually 1700 meters msl. Plume intersects were immediately reported to the Project Director in order to assist in the direction of the sampling van. When the plume was found, the helicopter was instructed to do a vertical

Figure 2.12 SF₆ Sampling Helicopter

profile of the plume by making transects in altitude step increments of about 50 meters until the top of the plume was found.

2.4 Operating Procedures

The project design called for conducting the tracer experiments under an unbiased variety of meteorological conditions. Therefore, a preset schedule was established by TRC, Inc., the Project Coordinator. This schedule was adhered to throughout the project and is shown in Table 2-4.

Prior to the first several experiments, the van made a sweep of the area around the 8km arc in order to check for any background or residual concentrations of SF_6 . Since no residual amounts were encountered, background sweeps were eliminated after experiment six (in the interest of reducing a heavy workload). It was assumed that the fixed location samplers, which began sampling before the SF_6 was released, would provide adequate evidence of contamination.

The tracer release began two hours prior to the start of sampling. A release rate was determined based on the meteorological conditions anticipated during the experiment. The release rate was approximately 13 kg/hr for the first three experiments, 17 kg/hr for the fourth and 23 kg/hr for the last eight experiments. The tracer gas was released continuously for 11 consecutive hours.

The fixed location samplers on the 8km and 16km rings took hourly syringe samples for nine hours, starting two hours after the beginning of the tracer release and ending at the same time as the release ended. During this same time interval the mobile van and helicopter made continuous measurements, except for periods of rest or refueling. The sequential samplers located in the clusters and at the CDH sites operated for 12 hours, sampling for three hours beyond the termination of the other samplers. Some samplers in the clusters were programmed to begin sampling one hour before the beginning of the tracer emission to check for background concentrations.

Table 2-4

Field Operation Summary Sheet

Test/Date/Time (Type, #) (Feb) (LST)	SF ₆ Emission Rate and Time KG/HR	No. Of Samplers Deployed Sampling Period		Mobile Time/Opr.	Helicopter Time/Opr.
		8 km Arc	16 km Arc		
Night 1, 2/3-4 20:00-07:00	13.24 20:00-07:00	64 of 66 22:00-07:00	68 of 68 22:00-07:00	22:00-07:00	2200-07:00
Night 2, 2/4-5 20:00-07:00	12.16 20:00-07:00	58 of 66 22:00-07:00	59 of 68 22:00-07:00	22:00-07:00	22:00-07:00
Night 3, 2/6-7 20:00-07:00	13.33 20:00-07:00	62 of 66 22:00-07:00	68 of 68 22:00-07:00	22:00-07:00	22:00-07:00
Night 4, 2/7-8 20:00-07:00	16.84 20:00-07:00	65 of 66 22:00-07:00	64 of 68 22:00-07:00	22:00-07:00	Not operating
Trans 5, 2/9 13:00-24:00	22.63 13:00-24:00	61 of 66 15:00-24:00	67 of 68 15:00-24:00	15:00-24:00	16:00-24:00
Day 6, 2/11 07:00-18:00	22.94 07:00-18:00	64 of 66 09:00-18:00	67 of 68 09:00-18:00	09:00-18:00	09:00-18:00
Day 7, 2/12 07:00-18:00	23.99 07:00-18:00	66 of 66 09:00-18:00	67 of 68 09:00-18:00	08:45-18:00	08:07-18:00
Trans 8, 2/14 01:00-12:00	23.44 00:00-12:00	66 of 66 03:00-12:00	66 of 68 03:00-12:00	03:00-12:00	02:10-12:00
Day 9, 2/15 07:00-18:00	23.29 07:00-18:00	66 of 66 09:00-18:00	68 of 68 09:00-18:00	09:00-18:00	08:20-18:00
Night 10, 2/16-17 20:00-07:00	23.47 20:00-07:00	66 of 66 22:00-07:00	68 of 68 22:00-07:00	22:00-07:00	22:00-07:00
Night 11, 2/17-18 20:00-07:00	23.04 20:00-07:00	66 of 66 22:00-07:00	68 of 68 22:00-07:00	22:00-07:00	22:00-07:00
Day 12, 2/19 07:00-18:00	22.97 07:00-18:00	66 of 66 09:00-18:00	68 of 68 09:00-18:00	09:00-18:00	09:00-18:00

3.0 QUALITY CONTROL

Quality Control (QC) procedures were applied at several points during the course of the study. These included equipment and procedure checks during the field program, and QC during the data analysis phase of the program.

3.1 Quality Control of Fixed Site Field Sampling

3.1.1 Syringe Sampler Checks and Inspections

Before deployment, a final QC inspection of all syringe samplers was performed to determine that they were fully operational, properly loaded with syringes, and programmed for the desired sampling time and duration. The inspection was made at the field staging center just prior to deployment to the field sites. The presampling QC inspection included:

- a. verification that the number of the syringe set in the sampler corresponded to the syringe set number on the bar coded label affixed to the Deployment Form for the sampler,
- b. verification that the syringes were loaded into the sampler in the proper sequence i.e., syringe position in the sampler corresponded to the proper syringe number on the bar coded label,
- c. verification that a needle was securely placed on the syringes and that a septum was inserted in the sampler base plate,
- d. verification that the sampler clock was set to the proper time, the alarm was set to the proper sampling start time, and the DIP switches were set for the proper sampling program, and,
- e. the battery voltage was sufficient for proper operation of the sampler, i.e., $\geq$ 9.0 volts with load resistance.

The final step in the presampling inspection was to depress the "Program Reset" button to ensure that the preset sampling program was initiated. A presampling checklist on the Syringe Sampler Deployment Form was completed for all samplers before deployment. (See Figure 2.8 for a copy of the Syringe Sampler Deployment Form.)

Immediately after the samplers were retrieved and returned to the field staging center, a QC Inspection was performed. The postsampling inspection included the following checks of the samplers and syringe samples:

- a. verification that the sampler clock was set to the proper time, the alarm was set to the proper sampling start time, and the DIP switches were set for the proper sampling program,
- b. measurement of the battery voltage with and without load resistance, and
- c. assessment of the validity of the syringe samples.

Results of the postsampling QC Inspection were recorded on the Syringe Sampler Retrieval Form (See Figure 2.9). Any abnormalities that would affect the validity of the syringe samples were also entered on the form.

3.1.2 Internal Quality Assurance Audits

During the tests, the ABBES QA Officer, Joseph Delwiche, performed onsite audits of the operation of the samplers. Following the tests, Mr. Delwiche also performed spot audits on the accuracy and completeness of the data entered on Syringe Sampler Deployment and Retrieval Forms. Copies of the reports containing results of these audits are provided in Appendix B. The information provided in the Audit Reports was one of the resources used in the data validation process.

3.1.3 Collocated Measurements

Collocated samplers were operated at selected sites during Tests 3 through 12 to assess the reproducibility of the tracer concentration measurements. The results of the measurements made with collocated samplers are provided in Appendix C.

3.2 Quality Control of Mobile SF₆ Analyzers

3.2.1 Lag and Response Checks

Lag and response times were checked for both mobile SF₆ samplers at the end of the field experiments. Response times were checked by changing the data acquisition system to sample at ten times per second and injecting syringes of different SF₆ calibration gases. Response times were then noted to the nearest 100 milliseconds (See Figure 3.1). Lag times through the manifold and external pump were measured to be approximately one second in both sampling platforms.

Mobile sampling systems were leak checked at the beginning and end of the field season. This included the sampling manifold, external pump, external tubing and connectors, and regulators.

3.2.2 Multipoint Calibrations

Calibrations incorporated multiple injections of a particular concentration of calibration gas from a common syringe to test for repeatability. Calibrations were compared from day to day to check for repeatability and to aid in diagnosing problems.

The SF₆ analyzer was calibrated prior to and after each experiment. A copy of the logsheet used to record calibrations is included in Table 3-1. A multipoint calibration was performed with no less than five SF₆ concentrations over the range of 55 to 7300 parts-per-trillion (ppt) (10⁻¹²). Thirty cm³ syringes, thoroughly flushed and filled with standard gases, were slowly injected directly into the sample inlet port on the front panel. The continuous analyzer was allowed at least one hour to reach equilibrium after start up. Calibration gases were procured from Scott-Marrin, Inc. Riverside, California. These gases were also used on the gas chromatographs used in the syringe sample analyses.

3.2.3 External Field Audits

TRC audit samples consisting of SF₆ in 30 cc plastic syringes were analyzed with the continuous analyzers. These samples were given to NAWC personnel prior to the first experiment. Samples were injected after each post flight/drive calibration. After the initial

Van SF6 Analyzer Response Check
February 20, 1991

Helicopter SF6 Analyzer Response Check
February 20, 1991

Figure 3.1

Table 3.1

CONTINUOUS SF6 ANALYZER DATA FORM NORTH AMERICAN WEATHER CONSULTANTS SALT LAKE CITY, UTAH 84106															
PROJECT: RFWVS FEBRUARY, 1991															
DATE _____				OPERATOR _____											
NITROGEN CYLINDER _____				PSI _____											
INTERNAL BATTERY VOLTAGE _____				VOLTS DC _____											
AUXILIARY POWER SOURCE _____				_____											
SAMPLE VALVE SETTING _____				_____											
HYDROGEN VALVE SETTING _____				_____											
DRYER N2 FLOW RATE _____				PSI _____		CC/MIN _____									
DETECTOR N2 FLOW RATE _____				PSI _____		CC/MIN _____									
HYDROGEN FLOW RATE _____				PSI _____		CC/MIN _____									
PERIOD _____		GAIN _____		_____											
DRYER TEMPERATURE CONTROLLER (TIME ON) _____				_____											
DRYER SET TEMPERATURE _____				°C _____											
FINAL DRYER TEMPERATURE _____				°C _____											
REACTOR TEMPERATURE CONTROLLER (TIME ON) _____				_____											
HYDROGEN CYLINDER _____				PSI _____											
REACTOR SET TEMPERATURE _____				°C _____											
FINAL REACTOR TEMPERATURE _____				°C _____											
PRESSURIZED OR UNPRESSURIZED ENVIRONMENT _____															
NITROGEN ZERO KNOB SETTING _____				BASELINE VOLTAGE _____											
SAMPLE ZERO KNOB SETTING _____				BASELINE VOLTAGE _____											
CALIBRATION #1 TIME _____ RESPONSE IN VOLTS: <div style="display: flex; justify-content: space-around; margin-top: 5px;"> 101005002000500010000 </div> <table border="1" style="width: 100%; height: 20px; margin-top: 5px;"> <tr> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> </tr> </table>															
CALIBRATION #2 TIME _____ RESPONSE IN VOLTS: <div style="display: flex; justify-content: space-around; margin-top: 5px;"> 101005002000500010000 </div> <table border="1" style="width: 100%; height: 20px; margin-top: 5px;"> <tr> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> </tr> </table>															
CALIBRATION #3 TIME _____ RESPONSE IN VOLTS: <div style="display: flex; justify-content: space-around; margin-top: 5px;"> 101005002000500010000 </div> <table border="1" style="width: 100%; height: 20px; margin-top: 5px;"> <tr> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> </tr> </table>															
CALIBRATION #4 TIME _____ RESPONSE IN VOLTS: <div style="display: flex; justify-content: space-around; margin-top: 5px;"> 101005002000500010000 </div> <table border="1" style="width: 100%; height: 20px; margin-top: 5px;"> <tr> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> <td style="width: 16.6%;"></td> </tr> </table>															
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 25%;">DETECTOR CLEANED</td> <td style="width: 10%;"></td> <td style="width: 10%;">TIME 1</td> <td style="width: 10%;"></td> <td style="width: 10%;">TIME 2</td> <td style="width: 10%;"></td> <td style="width: 10%;">TIME 3</td> <td style="width: 10%;"></td> </tr> </table>								DETECTOR CLEANED		TIME 1		TIME 2		TIME 3	
DETECTOR CLEANED		TIME 1		TIME 2		TIME 3									

injections, NAWC personnel advised TRC personnel that they suspected that the syringes contained a contaminant. NAWC was advised by TRC to continue injections.

These audits did not provide useful information on the health of the instruments, as the majority of the syringes were contaminated and caused erroneous responses. A plastic compound was used to cap the syringes, which caused a very strong response when injected into the analyzers, much higher than would be expected for the concentration of calibration gas enclosed in the syringe. More evidence of this adverse reaction occurred after the last experiment when several syringes treated with the plastic compound were injected into the analyzers. Both instruments "pegged" and remained this way for several minutes. Normally, purge time is a matter of seconds. This test demonstrated that the compound caused a significant, lasting interference after injection. These syringes may have contributed to the significant baseline drift and associated sensitivity loss noted during the first four experiments of the field campaign.

The tritium foil in the electron capture detector was physically removed from the instrument and hand cleaned starting on the fifth experiment. This procedure was performed numerous times. Each time the foil was cleaned a marked increase in performance was noted. This process could help explain the increased sensitivity and decreased baseline drift after the fourth experiment.

In addition, NAWC personnel noted the hanger at JEFFCO airport smelled of solvents and paint fumes, both of which can cause analyzer contamination. Both the helicopter and sampling van were housed in this hanger. After the 3rd experiment NAWC personnel modified the analyzers to sample clean outside air when located in the hanger.

3.2.4 Analyzer Maintenance

To assure that the SF₆ analyzer had a stable baseline and response, 30 cm³ of high purity methanol were flushed through the detector prior to each experiment. The methanol was injected through the detector nitrogen port and immediately dried with ultra pure nitrogen. This procedure was performed at least one hour prior to calibration.

Prior to the field project the temperature control, detector and battery charging electronics were verified as operational. A visual inspection of the analyzer's internal batteries and a battery capacity test were also performed.

Log sheets, which require the analyzer operator to record all pertinent parameters about the SF₆ analyzer, were filled out for each day the analyzer was operated. This permanent log provided a convenient way to track any problems with the analyzer and allowed preventive maintenance to be performed. Copies of these log sheets for both the helicopter and mobile van are found in Appendix M. The analyzer operator was provided thorough checklists to use before, during and after each experiment to avoid any inadvertent omissions in procedures. Standard operating procedures for the mobile SF₆ analyzers are found in Appendix L.

3.3 Quality Control For Fixed Site Sample Analysis

The following activities were conducted to maintain and assess the quality of the field GC analysis of the syringe samples collected at the fixed sampling sites:

- o Periodic calibration of the gas chromatography systems.
- o Analysis of quality control check samples with the field samples.
- o Analysis of zero air blank samples with the field samples.
- o Duplicate analysis of field samples.
- o Analysis of SF₆ audit samples provided by TRC.

Descriptions of these activities are presented in the following sections.

3.3.1 GC Calibrations

Calibration of each GC system was performed before and after analysis of the syringe samples from each test. The calibration data acquired by the GC system data acquisition system was downloaded and stored on 5-1/4 inch floppy diskettes. Calibration records for each system were maintained on separate diskettes.

The six SF₆ standards used to calibrate the GC system were purchased from Scott-Marrin, Riverside, CA. The concentrations of the calibration standards were 55.6, 251, 998,

2470, 5300, and 7300 ppt SF₆ in pure air. Ultra-pure zero air, also purchased from Scott-Marrin, was used in the calibrations to establish zero response of the GC systems. Scott-Marrin states that SF₆ concentrations in the standards are accurate to within ± 5 percent.

3.3.2 Quality Control Check Sample Analysis

A Quality Control Check Sample (QCCS) was analyzed after analysis of each group of 30 field samples. The material used for the QCCS was the Scott-Marrin standard gas mixture containing 998 ppt SF₆ in pure air. The results of all QCCS measurements performed during the analysis of the field samples are presented in Appendix D. The Appendix contains a tabular listing and control chart plots of the QCCS data. All QCCS measurements performed during the program were within the 998 ppt $\pm 15\%$ control limit.

3.3.3 Blank Sample Analysis

Blank (zero air) samples were analyzed after analysis of each group of 100 field samples. The results of all blank determinations performed during the analysis of the field samples are presented in Appendix E. Analysis of every blank sample showed no SF₆ concentration.

3.3.4 Duplicate Analysis of Samples

Duplicate analyses were performed on approximately 3 percent of the syringe samples from each test. The results of these analyses are presented in Appendix F. The data in this appendix presents the results of the duplicate sample (DUP) analysis that was performed as a routine QC measure. The second analysis of duplicate samples was performed within four hours of the original analysis. Appendix F also include results of samples (RNA) that were reanalyzed to confirm concentration patterns observed in the data. Reanalysis of samples may have occurred from approximately 4 to 18 days after the original analysis.

3.3.5 Audit Sample Analysis

TRC audit samples, consisting of SF₆ in 30cc plastic syringes, were analyzed with the GC systems during analysis of the field samples. The audit sample analyses were performed in several batches during analysis of samples from different tests. Several different GC systems were used for the analysis. Table 3-2 gives the results of the analysis of the TRC audit samples.

Table 3-2
Audit Sample Analysis Results

TRC Sample Number	SF ₆ Concentration ABBES Value (ppt)	TRC Value (ppt)	Difference, (a)
30	221	0	-- (b)
37	22	0	22. ppt
41	0	0	0. ppt
87	5	0	5. ppt(c)
108	12	0	12. ppt
110	0	0	0. ppt
Average			8. ppt
24	10	9.8±30%	2.0%
46	15	9.8	53.1%
81	11	9.8	22.4%
90	9	9.8	-8.2%
07	12	9.8	32.7%
Average			20.4%
4	52	49± 30%	6.1%
27	53	49	8.2%
38	56	49	14.3%
39	54	49	10.2%
48	56	49	14.3%
50	55	49	12.2%
82	54	49	10.2%
85	55	49	12.2%
109	46	49	-6.1%
Average			9.1%

Table 3-2 Continued
Audit Sample Analysis Results

TRC Sample Number	SF ₆ Concentration ABBES Value (ppt)	TRC Value (ppt)	Difference, (a)
5	103	98 ± 20%	5.1%
22	109	98	11.2%
26	111	98	13.3%
28	111	98	13.3%
36	105	98	7.1%
40	110	98	12.2%
45	114	98	16.3%
49	103	98	5.1%
89	103	98	5.1%
106	88	98	-10.2%
Average			7.8%
1	468	460 ± 20%	1.7%
3	503	460	9.3%
23	505	460	9.8%
29	508	460	10.4%
42	512	460	11.3%
44	513	460	11.5%
84	504	460	9.6%
Average			9.1%
2	1017	930 ± 20%	9.5%
21	1049	930	12.8%
25	1059	930	13.9%
43	1030	930	10.8%
47	1072	930	15.3%
83	1046	930	12.5%
86	832	930	-10.5%
Average			9.2%

- a) Percent Difference = 100 (ABBES Value - TRC Value)/TRC Value.
b) Possible contamination of sample?
c) Syringe was cracked.

3.4 Quality Control For Continuous Mobile Samplers Analysis

Calibrations for both sampling platforms were scrutinized for repeatability. The majority of calibrations performed in the field were dual injections; that is, two injections of a known concentration of SF_6 calibration gas were performed back to back to measure repeatability. These dual injections were used during analysis to aid in evaluating analyzer performance. Calibrations were also compared during any one experiment and differences in response were noted. If large differences were found to exist (greater than 25% change in response), then multiple calibration correction equations were derived. If all calibrations were similar, then one correction equation was applied to the entire data set. SF_6 analyzer data were then shifted by two seconds during analysis to account for external lag and response times.

The baseline for both SF_6 analyzer's noise level was determined by selecting sections of baseline readings (out of the SF_6 plume), measuring the peak to peak voltage magnitude during this time period, applying the correction equation to this voltage to convert to SF_6 concentration, and then doubling this concentration. Because of the unpressurized environment the baseline noise level in the helicopter was set to be 1000 ng/m^3 while in the van it was set to 100 ng/m^3 . These noise levels were used for all experiments.

During data analysis it became evident that the positioning system in the helicopter lost lock on many instances. The sampling van, which used an identical positioning system, did not exhibit this problem. The problem appeared to be the location on the helicopter to which the external antenna was mounted. The antenna was mounted on the forward nose and was occasionally shadowed by the body of the helicopter. During these periods the positioning system outputs the last valid location until a lock is reestablished (GPS dropouts are presented in Appendix H). There is no way to recover the position data. Plumes encountered while the positioning system was not updating have been so designated in the plume dimension tables. Dimensions for these plumes have been calculated by assuming a set air speed and constant direction. The majority of the cross sectional plots contained doubtful location information and were therefore discarded. This problem, coupled with the high baseline noise level, requires that the continuous SF_6 data measured in the helicopter be used as a diagnostic tool to accompany the ground syringe and mobile ground sampling data. The user should exercise caution in interpreting these data.

4.0 DATA ANALYSIS

Data analyses were performed on the ground based fixed site sampling network and the mobile data collected in the van and helicopter.

4.1 Fixed Site Data Processing and Validation

The fixed site measurement data were managed in the field using a personal computer (PC) equipped with Oracle database software. Identification information on the site location (site number), the sampler placed at the site, and the syringe set in the sampler were entered into the PC system by bar code reader from the labels attached to the Syringe Sampler Deployment Forms (SSDF). The syringe analysis data, as DIF files, were transferred to the Oracle database from diskettes created by the PC based DAS used with the gas chromatographs. The information for each sample was associated through the syringe set number entered from the SSDF and the syringe set number recorded during analysis by the DAS. The Oracle database was used to merge the data and provide diagnostic and preliminary results reports. Table 4-1 is a summary of the data recovery by experiment. Table 4-2 is a summary of SF₆ "hits" at all fixed site ground-level sites. Table 4-3 is a listing of missing sites by experiment number.

Validation of the data was performed following the field study. Validity of each sample was determined by examining the sampler deployment and retrieval records, analysis records, QC data, and audit reports. In the final data report, each value was assigned a validity flag, and additional informational flags were applied to indicate events or conditions that may affect the quality of the result. The following flagging protocol was employed:

4.1.1 Data Validation Flags

- V: Valid result; no known conditions that adversely affect data quality.
- I: Invalid result; known analytical or sampling error that renders the result invalid.

Table 4-1
Data Recovery Summary (a)

TEST NO.	SAMPLERS DEPLOYED	SYRINGES DEPLOYED	VALID RESULTS	% DATA RECOVERY
1	154	1407	1234	87.7
2	139	1272	1143	89.9
3	158	1443	1174	81.4
4	156	1422	1246	87.6
5	162	1479	1351	91.3
6	168	1533	1404	91.6
7	167	1524	1475	96.8
8	168	1533	1505	98.2
9	168	1533	1455	94.9
10	167	1524	1477	96.9
11	166	1515	1452	95.8
12	169	1542	1529	99.2
TOTALS AVERAGE	1942	17727	16445	92.8

a) Results Include collocated samplers deployed during tests.

Table 4-2
Summary of Hits at Fixed Ground-Level Sampling Sites

<u>Test No.</u>	<u>Hits At 8 Km</u>	<u>Hits At 16 Km</u>	<u>Hits At Clusters</u>	<u>Hits At CDH</u>	<u>Total^(a)</u>
1	242	251	74	11	578
2	226	235	49	23	533
3	246	251	85	19	601
4	316	463	110	64	953
5	430	453	107	30	1020
6	173	175	68	11	427
7	121	102	30	13	266
8	166	173	55	17	411
9	278	231	82	32	623
10	398	252	85	27	762
11	271	243	65	7	586
12	106	116	8	9	239

a) Hits shown are the number of syringe samples that contained SF6 at a concentration greater than the MDC of 33 nanograms per cubic meter. Hits are shown at sites in 8 and 16 km rings around the RFP, at the cluster sites, and at the Colorado Department of Health sites.

Table 4-3
Missing Sites Summary

	EXPERIMENT NUMBER											
	1	2	3	4	5	6	7	8	9	10	11	12
Site No.	2044	2014	2044	2022	2044	2057	2057	2057	2057	2057	2057	2057
	2045	2015	2045	2024	2045	2058	2058	2058	2058	2058	2058	2058
	2048	2017	2048	2027	2051	2059	2059	2059	2059	2059	2059	2059
	2057	2019	2055	2044	2053	2060	2060	2060	2060	2060	2060	2060
	2058	2043	2057	2045	2057	2130	2130	2130	2137	2137	2137	2137
	2059	2044	2058	2048	2058	2137	2137	2137	2161	2151	2161	2161
	2060	2045	2059	2057	2059	2161	2161	2161	2162	2152	2162	2162
	2099	2046	2060	2058	2060	2162	2162	2162	2163	2161	2163	2163
	2100	2047	2069	2059	2063	2163	2163	2163	2167	2162	2167	2167
	2114	2048	2114	2060	2130	2167	2167	2167		2163		
	2122	2057	2122	2122	2161					2167		
	2124	2058	2124	2137	2162							
	2137	2059	2137	2160	2163							
	2138	2060	2148	2162	2167							
	2145	2069	2149	2167								
	2148	2076	2167	2172								
	2154	2079										
	2167	2085										
		2088										
		2096										
		2114										
		2122										
		2124										
		2130										
		2137										
		2139										
		2146										
		2149										
		2150										
		2151										
		2153										
		2154										
		2167										

Minus 9999 (-9999) was substituted as the result for samples that were determined to be Invalid due to sampling or analytical problems. Flags are provided to indicate the reason for invalidation.

4.1.2 Data Quality/Information Flags

A valid (V) or Invalid (I) label was applied to each result as described in Section 4.1.1. In addition, flags were assigned to results values to indicate events that resulted in invalidation or that may have affected data quality. The identity and a description of these flags are provided below.

- S:** Sample collected in syringe, but the needle did not seal on septum at end of sampling period; samples were not invalidated for this cause.
- N:** Sample collected in syringe, but needle was found missing during the sampler retrieval check; samples were invalidated for this cause.
- F:** Partial or no sample was collected; syringe did not operate or operated only for partial stroke; samples were invalidated for this cause.
- L:** Late sampler deployment; deployed at site after designated sampler start time for the test; samples were invalidated for this cause.
- T:** Error in Clock Time or Alarm (Start) Time observed during the sampler retrieval check; samples were not invalidated for this cause if available data permitted making a time correction; samples were invalidated for this cause if insufficient information was available to correct the time error.
- E:** Sampler operation initiated at unknown time before the designated sampler start time for the test; samples were invalidated for this cause.
- B:** Sampler apparently operated properly, but low battery voltage was measured during the sampler retrieval check; samples were not invalidated for this cause.
- D:** Poor agreement between replicate sample analysis or between results of collocated measurements; samples were not invalidated for this cause. The quantitative limits used in assigning this flag was as follows:

Sample Conc., ng/m³	Relative Difference, %
MDC to 239	>100%
240 to 1196	>50%
1197 to 4784	>25%
>4784	>15%

Table 4-4 presents a summary of the flags applied to the syringe samples. The table shows for each test, the number (NO.) of each flag type applied to the test samples and the percentage (%) of the total test samples labeled with each flag type. Cumulative totals of applied flags (all tests) and the average percentage of the total samples from the 12 tests containing each flag are shown at the bottom of the table.

For final reporting, SF₆ concentrations were converted from ppt to ng/m³ using the following equation:

$$(\text{ppt SF}_6) (4.784) = \text{ng/m}^3 \text{ SF}_6.$$

The conversion factor was derived using a barometric pressure of 24 in. Hg (6,000 ft) and a temperature of 25 C.

The minimum detectable concentration (MDC) for SF₆ in the syringe samples is estimated to be 7 ppt or 33 ng/m³. Results of all samples for which the analyzed value was at or below the MDC are reported as $\leq 33 \text{ ng/m}^3$.

Results of the fixed site tracer measurements are provided in Appendix G.

Table 4-4
Summary Of Results Flags

TEST NO.	TOTAL VALUES	S		N		F		L		T		E		TYPES OF FLAGS			
		NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%
1	1406	106	7.5	0	0.0	145	10.3	0	0.0	59	4.2	18	1.3	69	4.9	12	0.9
2	1264	53	4.2	0	0.0	92	7.3	5	0.4	2	0.2	27	2.1	30	2.4	11	0.9
3	1458	10	0.7	1	0.1	237	16.3	0	0.0	10	0.7	43	2.9	137	9.4	22	1.5
4	1446	61	4.2	1	0.1	166	11.5	0	0.0	1	0.1	35	2.4	15	1.0	12	0.8
5	1482	22	1.5	0	0.0	104	7.0	0	0.0	9	0.6	18	1.2	0	0.0	11	0.7
6	1538	5	0.3	0	0.0	110	7.2	0	0.0	3	0.2	21	1.4	17	1.1	10	0.7
7	1544	15	1.0	0	0.0	47	3.0	0	0.0	4	0.3	18	1.2	9	0.6	2	0.1
8	1547	18	1.2	0	0.0	42	2.7	0	0.0	0	0.0	0	0.0	0	0.0	5	0.3
9	1542	19	1.2	0	0.0	65	4.2	0	0.0	4	0.3	18	1.2	0	0.0	7	0.5
10	1521	6	0.4	1	0.1	34	2.2	0	0.0	0	0.0	9	0.6	18	1.2	21	1.4
11	1532	12	0.8	1	0.1	52	3.4	0	0.0	1	0.1	27	1.8	9	0.6	0	0.0
12	1542	0	0.0	0	0.0	12	0.8	0	0.0	1	0.1	0	0.0	0	0.0	5	0.3
TOTAL																	
	17822	327	-	4	-	1106	-	5	-	94	-	234	-	304	-	118	-
AVERAGE																	
	-	-	1.8	-	0.0	-	6.2	-	0.0	-	0.5	-	1.3	-	1.7	-	0.7

4.1.3 Syringe Sample Analysis

The SF₆ concentration in the syringe samples collected at fixed, ground-level sites was determined by gas chromatographic analysis using an electron capture detector (GC/EC). A field laboratory containing seven GC/EC systems was established in office space at the Broomfield Manor Motel located at the intersection of Route 287 and West Midway Boulevard. Each of the GC systems consisted of a Hewlett-Packard Model 5890, Series II gas chromatograph with an EC detector and special valve assembly for injection of an ambient air sample, an IBM AT PC equipped with Axlom hardware and software for data acquisition and analysis, and a bar code reader to enter the syringe sample identification before analysis. A detailed description of the GC system operating procedures is provided in Appendix K.

The valving used in the GC systems is shown in Figure 4.1. With the valve in position A, the sample from the syringe was injected through a 1cc sampling loop. The operator switched the valve to Position B, and this valve position was maintained until the SF₆ passed onto Column 2 (analytical column). The timer then triggered the valve return to position A, thus backflushing possible interfering compounds from Column 1 (precolumn) while the sample proceeded through Column 2, and on to the EC detector. The entire cycle required four minutes and was automatically controlled by the GC after operator initiation.

Columns 1 and 2 used for the analysis were both 1 meter x 6.25mm stainless steel tubing containing Molecular Sieve 5A. Temperature conditions and carrier gas used for the GC analysis were as follows:

Injector Temperature - 35°C
Valve Temperature - 100°C
Column Temperature - 35°C (Isothermal)
Detector Temperature - 100°C
Carrier Gas - Argon/5% Methane
Carrier 1 and 2 Flow - 30cc/min

Column 1 = Pre-Column
Column 2 = Analytical Column

Position A. Fill sample loop with sample.

Position B. Inject sample into column 1 to Column 2 to detector using carrier 1.

Position A. Carrier to Column 2 to detector.

Backflush column 1 to vent with carrier 1.

Figure 4.1 GC System Value Arrangement for SF_6 Analysis

Calibration of the GC systems was performed using zero air and six standards having the following SF₆ concentrations:

<u>ppt</u>	<u>ug/m³</u>
55.6	266
251	1201
998	4774
2470	11816
5300	25355
7300	34923

A typical calibration curve for the GC systems is shown in Figure 4.2. A composite calibration curve for one of the systems is shown in Figure 4.3. This plot shows the variation among calibrations performed during the 12 tests. The bars show the standard deviation about the average values for all tests. The relative standard deviation (coefficient of variation) values range from 4.5 to 9.6 percent.

Quantification of the SF₆ in the syringe samples was performed by the Axlom software from the peak area counts of the sample and the SF₆ standards. As shown in Figures 4.2 and 4.3, the response of the GC systems was not a linear function of concentration over the entire concentration range of the standards (0 to 7300 ppt). Therefore, a linear least squares fit could not be used to accurately describe the GC system calibration curves. Consequently, sample concentrations were computed by comparison of the sample peak area to the peak area of the two standards that bracketed the sample concentration. For example, samples with peak area counts that fell in range of the peak area counts for the 55.6 to 251 ng/m³ SF₆ standards were quantified by comparison to these standards. The concentration was assumed to be linear between the two calibration points as shown in Figures 4.2 and 4.3.

A series of typical chromatograms obtained with the GC systems is shown in Figure 4.4. The figure shows results obtained for QC samples and several actual syringe samples that contained various concentrations of SF₆.

Quality control activities conducted during sample analysis are discussed in Section 3.3.

SF6 Standard Responses for GC #1 for Feb 4, 1991

Figure 4.2 Typical Calibration Curve

SF6 Standard Responses (GC #1, Tests 1-12)

Figure 4.3 Composite Calibration Curve

TEST NO. 8
QCC SAMPLE
SF6 CONC. - 4731 ng/m3

SEQ 2 INJ 1/ 1 SYSTEM(1)
DATA FILE: 8803307.021
ORIG: 2010-- 02/14/1991
CURR: 20110-- 02/14/1991

TEST NO. 8
ZERO AIR BLANK
SF6 CONC. - 0 ng/m3

SEQ 4 INJ 1/ 1 SYSTEM(1)
DATA FILE: 8801205.041
ORIG: 2014-- 02/14/1991
CURR: 20113-- 02/14/1991

Figure 4.4 Typical SF₆ Chromatograms

Figure 4.4 Continued Typical SF₆ Chromatograms

TEST NO. 8
STAKE NO. 2025
SAMPLER NO. 4120
SF6 CONC. - 83 ng/m3

SEQ 1 INJ 1/ 1 SYSTEM[1]
DATA FILE: 8111901.011
ORIG. 20:38-- 02/14/1991
CURR. 20:39-- 02/14/1991

TEST NO. 8
STAKE NO. 2025
SAMPLER NO. 4120
SF6 CONC. - 770 ng/m3

SEQ 1 INJ 1/ 1 SYSTEM[1]
DATA FILE: 8111904.011
ORIG. 21:11-- 02/14/1991
CURR. 21:12-- 02/14/1991

Figure 4.4 Continued Typical SF₆ Chromatograms

4.2 Continuous Mobile Samplers Data Processing

The continuous SF_6 data measured by the mobile van were analyzed using a computer program developed at NAWC. This program uses the baseline voltage during a zero air injection as a zero reference and linearly interpolates back to the last zero baseline voltage. This baseline offset, determined by the slope of the line, is then applied to the raw data and the correction equation is applied. Zero air was injected every two minutes for a period of ten seconds. During injection a flag was turned on and recorded in the data file. This flag was used by the computer program to find the zero periods. The time interval between zero air injections was sufficiently short that baseline drift caused by elevation changes was accounted for. Two types of corrected SF_6 data are found in the data files. The first type contains the zero periods. The second type has the zero period "filled in" with a linear interpolation between the start and stop of the zero period.

Since the continuous SF_6 data measured from the helicopter contains no automatic zero periods a different analysis program was used to determine the baseline. This program differs from the program used for the mobile van because it uses a numerical filter to eliminate the low frequency noise while preserving the high frequency SF_6 signal associated with SF_6 plumes. By selecting the appropriate frequency cut-off of the filtering process and minimum sensitivity of the SF_6 analyzer the computer automatically identifies the plumes in the raw data. After plume identification, baseline drift was eliminated from the raw data and horizontal plume dimensions were calculated based on a technique reported by Hanna, 1986. In addition, every plume identified by the reduction program was visually inspected before it was included in the plume dimension table.

Calibration data used in the analyses of the van and helicopter data are found in Appendices I and J, respectively. Plots found in these appendices contain statistics regarding the correction equations derived from field calibrations. Due to a contaminant, some baseline drift occurred in the first four experiments which caused some signal degradation to occur. To minimize the resultant error if only one calibration were to be used over the entire experiment, more than one correction equation was used if required. For instance, for experiment number one, two correction equations are used for the mobile van. The first was applied from 22:30 to 01:15 LST, and the second was applied to data collected from 01:50 to 07:00 LST. In addition, the correction equations use only those calibration gases which bracketed the voltage output of the instrument. Higher values were discarded

to create an equation which better fit the data. The plots contain statistics regarding the correction equation. The average error was calculated by measuring the concentration predicted by the correction equation versus the actual concentration of the calibration gas. Average errors were much smaller after experiment number 4.

From the corrected SF₆ data, graphs were developed to display the data. These graphs are described in Section 5. Due to the unpressurized environment of the helicopter, a minimum detectable limit of 1000 ng/m³ was used for all the helicopter data. This limit corresponds to approximately 200 ppt of SF₆. The threshold in the mobile van was set at 100 ng/m³. The conversion from ppt to ng/m³ was accomplished by using an average pressure of 812 millibars and an average temperature of 0°C. The equation used was:

$$(\text{ppt SF}_6) (5.222) = \text{ng/m}^3 \text{ SF}_6.$$

This conversion factor differs slightly from that used for the syringe sample analysis to account for the colder operating environment encountered during mobile sampling.

Latitude and longitude data from both sampling vehicles were taken directly from the GPS without any conversions and stored directly on the data file. Conversions to UTM coordinates were performed in real time and stored on the data file as well. Any time period when the GPS had not updated for ten or more seconds appears in Appendix H. Plume dimensions and locations encountered during these time periods are suspect and should be used with caution.

5.0 DATA SUMMARY

The tracer data are summarized graphically for each hour of the test. These figures are found in Volume II, arranged chronologically by experiment number. The data are displayed in the following order:

- 1) Fixed ground sampling network (3D plot view from SW)
- 2) Fixed ground sampling network (3D plot view from SE)
- 3) Mobile sampling van data (3D plot)
- 4) Mobile sampling van data (2D plot)
- 5) Helicopter sampling data (3D plot)
- 6) Helicopter plume transects (2D plot)
- 7) Helicopter cross sections (if available)
- 8) Helicopter plume dimension table
- 9) CDH stationary sampling plots (bar plots)

The fixed network is shown from two angles. The first angle looks at the network from the southwest toward the northeast. The second angle looks at the network from the southeast toward the northwest. The SF_6 data are plotted as vertical columns with column height proportional to the SF_6 concentration. The graph contains major roadways which were used during sampling and the location of the 8 km and 16 km arcs.

The van measurements are shown graphically as a view from the southwest toward the northeast, unless a second viewing angle was required to distinguish multiple plumes. In those cases a second view is shown looking from the southeast to the northwest. The Z-axis is depicted in concentration units. Drive tracks are plotted in red with start and finish points designated as "S" and "F", respectively. Multiple passes in the same area are distinguished by arrows plotted in the direction of travel. It should be noted that some mathematical smoothing may have been introduced by the plotting software so that the peak value on the plot may be less than the stated maximum value in the plot caption. This is also true of the helicopter plots. The van data are also presented as one hour plots of SF_6 concentration versus time. From these plots the reader can distinguish individual plume transects. Automatic zero air injections can be distinguished by dropouts while in SF_6 plume.

Helicopter data are displayed similarly to the van data (looking from the southwest to the northeast). A second viewing angle (southeast to northwest) was used if required. The flight track is shown in red with start and finish points designated as "S" and "F", respectively. Multiple passes in the same area are distinguished by arrows plotted in the direction of travel. The Z-axis is depicted in concentration units. If the GPS in the helicopter was not updating while in plume, then the plotted concentration of the SF₆ plume on the 3D plot will likely not correspond to the actual concentration encountered. Plumes greater than 1000 ng/m³ are plotted as individual transects. In these plots the X-axis is shown in distance, rather than time. A Gaussian curve has been laid over the data. If two plumes occurred over a relatively short time period, then the Gaussian fit curve may be truncated on the edges. Negative concentrations are a residual artifact of a rapid altitude change or a baseline overshoot after exiting a concentrated SF₆ plume. In either case, the reduction software does not change negative concentrations to zero. Plume cross sections (multiple passes at several levels) are shown where available. Although several cross sections were completed during the 12 experiments, only a few contained accurate location data. Only these cross sections were plotted.

A summary plume dimension table concludes the helicopter data section. Parameters listed in the dimension table are as follows:

Cross Section (CS) Number:

If a number is found in this column, it indicates that this particular plume was part of a series of vertical passes in roughly the same air space.

Begin Time:

The time at which the observed SF₆ concentration was first detected above a minimum level as specified in the reduction process.

Units: Hour and decimal hour (LST).

Altitude Begin Time:

The altitude associated with plume entry.

Units: meters MSL.

UTMN Begin Time Coordinate:

The north-south UTM at SF₆ plume entry.

Units: meters (m).

UTME Begin Time Coordinate:

The east-west UTM at SF₆ plume entry.

Units: meters (m).

Valid Location Begin Time:

If the positioning system was not updating on plume entry then this variable is set to "N".

Units: None.

End Time:

The time at which the observed SF₆ concentration was last detected above a minimum level as specified in the reduction process.

Units: Hour and decimal hour (LST).

Altitude End Time:

The altitude associated with plume exit.

Units: meters MSL.

UTMN End Time Coordinate:

The north-south UTM at SF₆ plume exit.

Units: meters (m).

UTME End Time Coordinate:

The east-west UTM at SF₆ plume exit.

Units: meters (m).

Valid Location End Time:

If the positioning system was not updating on plume exit, then this variable is set to "N".

Units: None.

1 Sigma Gaussian:

The width corresponding to one Sigma Y as calculated from a Gaussian fit placed over the observed SF₆ data.

Units: meters (m).

Minus 3 Sigma Observations:

The width corresponding to the area measured from -3 Sigma Y (0.2% of the area under the entire plume) to the midpoint (50% of the area under the entire plume). The observed SF₆ data are used for this calculation.

Units: meters (m).

Plus 3 Sigma Observations:

The width corresponding to the area measured from the midpoint (50% of the area under the entire plume) to +3 Sigma Y (99.8% of the area under the entire plume). The observed SF₆ data are used for this calculation.

Units: meters (m).

Maximum Concentration Gaussian:

The maximum concentration of the Gaussian curve placed over the observed SF₆ data.

Units: Nanograms per cubic meter (ng/m³).

Maximum Concentration Observations:

The maximum concentration of the observed SF₆ data.

Units: Nanograms per cubic meter (ng/m³).

Width:

The linear distance between the points the reduction software picks as roughly bracketing the SF₆ plume.

Units: meters (m).

Altitude:

The average altitude the helicopter maintained while SF₆ was measured.

Units: meters MSL.

Maximum Gaussian Plume Concentration UTM Coordinate:

The north-south UTM at which the maximum concentration of the Gaussian curve would have occurred.

Units: meters (m).

Maximum Gaussian Plume Concentration UTM Coordinate:

The east-west UTM at which the maximum concentration of the Gaussian curve would have occurred.

Units: meters (m).

Distance:

The straight line distance from the tracer gas source at which the maximum concentration of the Gaussian curve would have occurred. The tracer gas source coordinates used to calculate this distance were: 482850 (UTM east-west coordinate) and 4415050 (UTM north-south coordinate).

Units: meters (m).

Concentration 1 Sigma:

The concentration corresponding to 1 Sigma Y as measured from the Gaussian curve placed over the observed data. This is the boundary of area, centered on location of maximum Gaussian concentration, which contains 68% of the total area under mass curve.

Units: Nanograms per cubic meter (ng/m³).

Concentration 2 Sigma:

The concentration corresponding to 2 Sigma Y as measured from the Gaussian curve placed over the observed data. This is the boundary of area, centered on location of maximum Gaussian concentration, which contains 96% of the total area under mass curve.

Units: Nanograms per cubic meter (ng/m³).

Concentration 3 Sigma:

The concentration corresponding to 3 Sigma Y as measured from the Gaussian curve placed over the observed data. This is the boundary of area, centered on location of maximum Gaussian concentration, which contains 99.6% of the total area under mass curve.

Units: Nanograms per cubic meter (ng/m³).

TAS:

The average true air speed of the helicopter during a transect through the SF₆ plume as measured from the beginning to ending times. If starved, then a fixed air speed of 45 m/s was used.

Units: meters per second (m/s).

Stable Baseline:

This is a subjective determination by the data analyst on the stability of the baseline during the SF₆ plume encounter. It is presented as a source of guidance on the quality of the data collected for this particular plume. Unstable baselines are caused by turbulence, rapid altitude changes or rapid speed changes.

Units: None.

Valid Location:

If at any time during the plume transect the positioning system lost lock, then this variable is set to "No". If the position was lost, then the resulting plume dimensions and locations are suspect.

Units: None.

A summary plume dimension table concludes the mobile van data section. Parameters listed in the dimension table are as follows:

Begin Time:

The time at which the observed SF₆ concentration was first detected above 500 ng/m³.

Units: Hour and decimal hour (LST).

UTMN Begin Time Coordinate:

The north-south UTM at SF₆ plume entry.

Units: meters (m).

UTME Begin Time Coordinate:

The east-west UTM at SF₆ plume entry.

Units: meters (m).

End Time:

The time at which the observed SF₆ concentration dropped below 100 ng/m³.

Units: Hour and decimal hour (LST).

UTMN End Time Coordinate:

The north-south UTM at SF₆ plume exit.

Units: meters (m).

UTME End Time Coordinate:

The east-west UTM at SF₆ plume exit.

Units: meters (m).

Maximum Concentration Observations:

The maximum concentration of the observed SF₆ data.

Units: Nanograms per cubic meter (ng/m³).

Maximum Plume Concentration UTMN Coordinate:

The north-south UTM at which the maximum concentration of SF₆ was measured.

Units: meters (m).

Maximum Plume Concentration UTME Coordinate:

The east-west UTM at which the maximum concentration of SF₆ was measured.

Units: meters (m).

Width Straight-Line:

The linear distance between the beginning and ending UTM coordinates.

Units: meters (m).

Width (Speed * Time):

The distance calculated using the number of seconds in plume by the average speed measured while in plume. If a straight line transect was performed this number should be very similar to the straight line width variable (see above). If the van made many turns while in plume then this number will be larger than the straight line width variable.

Units: meters (m).

Distance:

The straight line distance from the tracer gas source to the location of the maximum SF₆ concentration was measured. The tracer gas source coordinates used to calculate this distance were: 482850 (UTM east-west coordinate) and 4415050 (UTM north-south coordinate).

Units: meters (m).

Average Speed:

The average speed of the van during a transect through the SF₆ plume as measured from the beginning to ending times.

Units: meters per second (m/s).

Valid Location:

If at any time during the plume transect the positioning system lost lock, then this variable is set to "No".

Units: None.

Mode of Travel:

This variable can have four states:

- 1) N/A - GPS is not locked on, position is unknown
- 2) Stationary periods - the van appeared to be parked at times while in plume.
- 3) Stationary - the van was stationary during the entire plume measurement period.
- 4) Moving - the van appeared to be moving for the duration of the plume transect.

Table 5-1 is a listing of helicopter flight times. The mobile van typically sampled for nearly the entire experiment.

The sequential samplers located at the CDH sites are displayed as bar graphs for each station for each test case. Values equal to or less than 33 ng/m^3 were considered to be below the threshold of the gas chromatographs and are displayed as zeros on these plots. If no vertical column is present, the sample was missing.

5.1 Summary of Experiment #1

The first tracer experiment was conducted during the nighttime hours of February 3-4, 1991. Initial plume transport was to the north and then shifted to the east by the fourth hour, where it remained for the duration of the experiment. Winds were light early in the experiment and gradually increased with time.

The SF_6 release was started at 20:00 LST on February 3 and continued through 07:00 LST on February 4. The release rate averaged 13.7 kg/hr . Ground syringe sampling occurred from 22:00 on February 3 through 07:00 on February 4. Seven of these samplers were deployed at CDH sites and ran until 10:00 on February 4. The mobile sampling van and helicopter were both used on this test.

Ground-based syringe sampling showed initial transport to the north of the release site with SF_6 concentrations greater than $3,000 \text{ ng/m}^3$. Later in the experiment samplers to the east started to show SF_6 concentrations. Samplers recorded elevated SF_6 concentrations throughout the experiment over a wide arc from the north-northwest clockwise around to the southeast, suggesting the plume meandered. Samplers at CDH sites in Arvada, Platteville, and Welby all measured SF_6 concentrations.

Mobile ground tracking found the SF_6 plume to the north early in the experiment and to the east after midnight. SF_6 concentrations exceeded $10,000 \text{ ng/m}^3$ on some plume transects in the van. The helicopter found the plume close to the ground early in the test and by 05:00 on the 4th the plume was found above 1800 meters MSL. As with the other modes of sampling, the helicopter found the plume to the north and east of the release site after midnight. Near the end of the experiment, plumes were found to the southeast of the release site.

Table 5-1**Helicopter Flight Times (LST)**

	Experiment #1	Experiment #2	Experiment #3
FLT #1	22:30 - 24:00	22:26 - 23:03	22:40 - 01:16
FLT #2	00:55 - 02:22	01:31 - 03:36	02:36 - 04:21
FLT #3	04:10 - 05:58	-----	05:15 - 06:20
	Experiment #4	Experiment #5	Experiment #6
FLT #1	No flights	16:41 - 19:00	09:03 - 11:12
FLT #2		19:42 - 22:10	12:45 - 14:37
FLT #3		23:00 - 00:06	17:00 - 17:54
	Experiment #7	Experiment #8	Experiment #9
FLT #1	08:09 - 10:16	02:15 - 04:19	08:21 - 10:24
FLT #2	11:20 - 13:35	05:19 - 07:13	11:25 - 13:24
FLT #3	14:19 - 16:30	08:15 - 09:37	14:19 - 16:28
	Experiment #10	Experiment #11	Experiment #12
FLT #1	22:22 - 00:04	22:00 - 00:03	09:15 - 11:06
FLT #2	01:09 - 03:03	00:40 - 02:31	12:36 - 14:24
FLT #3	04:02 - 06:16	04:36 - 05:39	15:43 - 17:30

5.2 Summary of Experiment #2

The second tracer experiment was conducted during the nighttime hours of February 4-5, 1991. Plume transport was generally to the east for the duration of the experiment. Winds were light during the experiment with very stable atmospheric conditions.

The SF₆ release was started at 20:00 LST and continued through 07:00 LST on February 5. The release rate averaged 13.1 kg/hr. Ground syringe sampling occurred from 22:00 LST on February 4 through 07:00 LST on February 5. Seven of these samplers were deployed at CDH sites and ran until 10:00 LST on the February 5. The mobile sampling van and helicopter were both used on this test. The helicopter DAS computer failed late in the experiment. A replacement computer was placed in the helicopter prior to experiment #3 and the data from the second experiment were later retrieved.

Ground-based syringe sampling showed general transport to the east of the release site with SF₆ concentrations greater than 15,000 ng/m³ for many of the samples. Samplers showed elevated SF₆ concentrations throughout the experiment over an arc from the northeast clockwise around to the southeast. Samplers at CDH sites in Arvada, Camp, Englewood, Platteville, and Welby all measured SF₆ concentrations.

Mobile ground tracking found the SF₆ plume to the east for the duration of the experiment. SF₆ concentrations exceeded 30,000 ng/m³ on some plume transects in the van.

The helicopter found the plume close to the ground during the entire test. The highest altitude that the plume was measured was 1,710 meters MSL.

5.3 Summary of Experiment #3

The third tracer experiment was conducted during the nighttime hours of February 6-7, 1991. Plume transport was initially to the northeast. By the end of the experiment the plume was tracked to the southeast of the release. Winds were light during the experiment with very stable atmospheric conditions.

The SF₆ release was started at 20:00 LST and continued through 07:00 LST on February 7. The release rate averaged 13.7 kg/hr. Ground syringe sampling occurred from

22:00 LST on February 6 through 07:00 LST on the February 7. Seven of these samplers were deployed at CDH sites and ran until 10:00 LST on the February 7. The mobile sampling van and helicopter were both used on this test.

Ground-based syringe sampling showed general transport to the east of the release site with SF_6 concentrations higher than $20,000 \text{ ng/m}^3$ for many of the samples. Samplers showed elevated SF_6 concentrations throughout the experiment over an arc from the northeast clockwise around to the southeast. Samplers at CDH sites in Arvada, Carriage and Welby all measured SF_6 concentrations.

Mobile ground tracking found the SF_6 plume from the northeast clockwise through the southeast during the experiment. SF_6 concentrations exceeded $30,000 \text{ ng/m}^3$ on some plume transects in the van. The helicopter found the plume in significant concentrations to the southeast of the release site while the ground tracking vehicle mapped only weak values below the helicopter during the same time period. Unfortunately, the transducer box was not switched on in the helicopter so that altitude and temperature were not recorded.

5.4 Summary of Experiment #4

The fourth tracer experiment was conducted during the nighttime hours of February 7-8, 1991. Plume transport was initially to the east. By the end of the experiment the plume was tracked to the southeast of the release.

The SF_6 release was started at 20:00 LST and continued through 07:00 LST on February 8. The release rate averaged 16.5 kg/hr . Ground syringe sampling occurred from 22:00 LST on February 7 through 07:00 LST on February 8. Seven of these samplers were deployed at CDH sites and ran until 10:00 LST on February 8. Only the mobile sampling van was used on this test. SF_6 analyzer problems in the helicopter precluded measurements for this experiment.

Ground-based syringe sampling showed general transport to the east of the release site with SF_6 concentrations higher than $10,000 \text{ ng/m}^3$ for many of the samples. These values were lower than previous nighttime tests even though the SF_6 rate had been increased. Samplers showed elevated SF_6 concentrations throughout the experiment over an arc from

the northeast clockwise around to the southeast. Samplers at CDH sites in Arvada, Boulder, Camp, Carriage, Platteville, and Welby all measured SF₆ concentrations.

Mobile ground tracking found the SF₆ plume from the east clockwise through the southeast during the experiment. SF₆ concentrations exceeded 15,000 ng/m³ on some plume transects in the van.

5.5 Summary of Experiment #5

The fifth tracer experiment was the first of two experiments conducted under transitional conditions. The experiment occurred on February 9, 1991. Plume transport was initially to the east. By the end of the experiment the plume was tracked to the southeast of the release.

The SF₆ release was started at 13:00 LST and continued through midnight on February 9. The release rate averaged 23.6 kg/hr. Ground syringe sampling occurred from 15:00 LST through midnight on February 9. Seven of these samplers were deployed at CDH sites and ran until 03:00 LST on February 10. The mobile sampling van and helicopter were both used on this test.

Ground-based syringe sampling showed transport to the northeast and southwest of the release site with SF₆ concentrations higher than 30,000 ng/m³ for many of the samples. These values were the highest fixed-site ground samples measured during the field season. Samplers showed elevated SF₆ concentrations throughout the experiment over a wide arc suggesting that the wind flow reversed frequently. Samplers at CDH sites in Boulder, Carriage, Platteville, and Welby all measured SF₆ concentrations.

Mobile ground tracking found the SF₆ plume mainly to the northeast during the experiment. SF₆ concentrations were low early in the experiment but by the end of the experiment concentrations exceeded 40,000 ng/m³ on some plume transects in the van. Only one plume was mapped in the helicopter. This plume was to the northeast of the release site at an altitude of 1,680 meters MSL.

5.6 Summary of Experiment #6

The sixth tracer experiment was the first of four daytime experiments to be conducted. The experiment occurred on February 11, 1991. Plume transport was initially to the northeast. Early in the experiment a secondary, stronger plume was tracked to the northwest while a weaker plume persisted to the east. The split plume condition remained until the end of the experiment when the flow from the west began to dominate once again.

The SF₆ release was started at 07:00 LST and continued through 18:00 LST on February 11. The release rate averaged 23.6 kg/hr. Ground syringe sampling occurred from 09:00 LST through 18:00 LST on February 11. Seven of these samplers were deployed at CDH sites and ran until 21:00 LST on the February 11. The mobile sampling van and helicopter were both used on this test.

Ground-based syringe sampling showed plume transport to the northeast turning counterclockwise through the northwest with time. SF₆ concentrations were much weaker than in previous tests. Samplers showed elevated SF₆ concentrations through most of the experiment over two distinct areas. This suggests that two detached plumes existed for the majority of the experiment. Only the sampler at the Boulder CDH site measured SF₆ concentrations.

Mobile ground tracking found the SF₆ plume to the northwest clockwise to the southeast early in the experiment. The van then remained in the Boulder area for the majority of the experiment with a drive into the foothills as well. Several plumes were mapped in the helicopter. This is likely due to the increased mixing found during daylight hours. Most plumes were found to the north of the release and ranged from 1700 to 2200 meters MSL. Concentrations as high as 6,500 ng/m³ were located, much higher than the values found in the van.

5.7 Summary of Experiment #7

The seventh tracer experiment was the second of four daytime experiments to be conducted. The experiment occurred on February 12, 1991. Plume transport was initially to the northeast. Early in the experiment, the plume shifted to the southeast where it remained for the duration of the experiment.

The SF₆ release was started at 07:00 LST and continued through 18:00 LST on February 12. The release rate averaged 23.6 kg/hr. Ground syringe sampling occurred from 09:00 LST through 18:00 LST on February 12. Seven of these samplers were deployed at CDH sites and ran until 21:00 LST on February 12. The mobile sampling van and helicopter were both used on this test.

Ground-based syringe sampling showed transport to the northeast initially, then a persistent flow developed from the northwest. SF₆ concentrations were again low. Samplers at CDH sites in Arvada, Camp, Carriage, Englewood, and Welby all measured SF₆ concentrations.

As with the previous experiment, mobile ground tracking of the SF₆ plume was uneventful. The van remained in the east two quadrants for most of the experiment with very narrow plumes found east of the release site. Several strong plumes were mapped in the helicopter. Most plumes were found to the southeast of the release and ranged from 1700 to 2100 meters MSL. Concentrations as high as 4,500 ng/m³ were located, much higher than those values found in the van.

5.8 Summary of Experiment #8

The eighth tracer experiment was the second experiment conducted under transitional conditions. The experiment occurred on February 14. Plume transport was primarily to the southeast of the release site for the duration of the experiment.

The SF₆ release was started at 01:00 LST and continued through 12:00 LST on February 14. The release rate averaged 23.6 kg/hr. Ground syringe sampling occurred from 03:00 LST through 12:00 LST on February 14. Six of these samplers were deployed at CDH sites and ran until 15:00 LST on February 14. The mobile sampling van and helicopter were both used on this test.

Ground-based syringe sampling showed the majority of the plume was transported to the southeast of the release site with the majority of SF₆ concentrations well under 1,000 ng/m³. Samplers showed elevated SF₆ concentrations throughout the experiment over most of the eastern half of the sampling network. Samplers at CDH sites in Arvada, Camp, Carriage, and Welby all measured SF₆ concentrations.

Ground tracking found the SF₆ plume mainly to the southeast during the experiment. SF₆ concentrations were quite low early in the experiment but by the end of the experiment concentrations exceeded 4,000 ng/m³ on some plume transects in the van. Several plumes were mapped in the helicopter. The plumes were in the same general vicinity as the mobile sampling van. Plumes were found between 1,700 and 2,100 meters MSL. Concentrations of nearly 6,000 ng/m³ were mapped in the helicopter, much higher than those found in the van.

5.9 Summary of Experiment #9

The ninth tracer experiment was the third of four daytime experiments to be conducted. The experiment occurred on February 15, 1991. Plume transport was initially to the south-southwest. After several hours the plume shifted gradually to the southeast quadrant, where it remained for the duration of the experiment.

The SF₆ release was started at 07:00 LST and continued through 18:00 LST on February 15. The release rate averaged 23.6 kg/hr. Ground syringe sampling occurred from 09:00 LST through 18:00 LST on the 15th. Seven of these samplers were deployed at CDH sites and ran until 21:00 LST on February 15. The sampling van and helicopter were both used on this test.

Ground-based syringe sampling showed transport to the south-southwest initially. SF₆ concentrations were quite high for the first two hours of the experiment then quickly weakened. The entire southeast quadrant began to receive low SF₆ concentrations by the fourth hour and this pattern remained for the duration of the experiment. Samplers at CDH sites in Arvada, Camp, Carriage, Englewood, and Welby all measured SF₆ concentrations.

Ground tracking picked up very strong plumes to the southwest of the release site early in the experiment. SF₆ concentrations over 10,000 ng/m³ were common. The van remained to the south and east of the release site, and concentrations dropped off with time. Several strong plumes were mapped in the helicopter. Most plumes were found to the southwest of the release and ranged from 1,900 to 2,400 meters MSL. Concentrations as high as 11,000 ng/m³ were located, very similar to those values found in the sampling van. These are some of the strongest plumes mapped in the helicopter during the field study.

5.10 Summary of Experiment #10

The tenth tracer experiment was the fifth of six nighttime tracer experiments. The study was conducted during the nighttime hours of February 16-17, 1991. Plume transport was initially to the north. Within a few hours the plume moved to the east and remained there until the last two hours of the experiment, when it moved to the south.

The SF₆ release was started at 20:00 LST and continued through 07:00 LST on February 17. The release rate averaged 23.6 kg/hr. Ground syringe sampling occurred from 22:00 LST on the 16th through 07:00 LST on February 17. Seven of these samplers were deployed at CDH sites and ran until 10:00 LST on February 17. The sampling van and helicopter were both used on this test.

Ground-based syringe sampling showed general transport to the northeast of the release site with SF₆ concentrations gradually increasing with time. SF₆ concentrations higher than 10,000 ng/m³ were common. Samplers showed elevated SF₆ concentrations throughout the experiment over a wide arc from the north clockwise around to the southwest. Samplers at CDH sites in Arvada, Boulder, Camp, Carriage, Englewood, Platteville, and Welby all measured SF₆ concentrations.

Mobile ground tracking found the SF₆ plume to the north clockwise through the southeast during the experiment. SF₆ concentrations approached 10,000 ng/m³ on some plume transects in the van. The helicopter also found the plume to the northeast early in the experiment, but concentrations dropped off with time. Plumes found in the helicopter were much lower than those mapped at ground level, suggesting that the plume stayed quite close to the ground. Plumes were found within a narrow altitude band between 1850 and 2000 meters MSL. Concentrations as high as 4,100 ng/m³ were found.

5.11 Summary of Experiment #11

The eleventh tracer experiment was the final nighttime tracer experiment. The study was conducted during the nighttime hours of February 17-18, 1991. Plume transport was initially quite variable. Within a few hours the plume appeared to move to the north and then gradually over to the east.

The SF₆ release was started at 20:00 LST and continued through 07:00 LST on February 18. The release rate averaged 23.6 kg/hr. Ground syringe sampling occurred from 22:00 LST on February 17 through 07:00 LST on February 18. Seven of these samplers were deployed at CDH sites and ran until 10:00 LST on February 18. The sampling van and helicopter were both used on this test.

Ground-based syringe sampling showed transport to the north quadrants early in the experiment. The flow then appeared to become more organized from the south. SF₆ concentrations increased dramatically after the first two hours. SF₆ concentrations higher than 10,000 ng/m³ were common. Samplers at CDH sites in Arvada, Camp, Carriage, and Platteville all measured SF₆ concentrations.

Mobile ground tracking found the SF₆ plume to the west initially. Later in the experiment the plume was traced to the north, and by the end of the experiment the van was finding the plume to the northeast. Plumes exceeding 10,000 ng/m³ were mapped to the north of the release. The helicopter also found the plume to the west early in the experiment. Plumes found in the helicopter were lower in concentration than those mapped at ground level but still significant. Plumes were found as high as 1,950 meters MSL. Concentrations over 10,000 ng/m³ were found.

5.12 Summary of Experiment #12

The twelfth and final tracer experiment was the last of four daytime experiments to be conducted. The experiment occurred on February 19, 1991. Plume transport was to the southeast for the duration of the experiment. This experiment shows the least amount of plume meander of all 12 experiments.

The SF₆ release was started at 07:00 LST and continued until 18:00 LST on February 19. The release rate averaged 23.2 kg/hr. Ground syringe sampling occurred from 09:00 LST through 18:00 LST on February 19. Seven of these samplers were deployed at CDH sites and ran until 21:00 LST on February 19. The sampling van and helicopter were both used on this test.

Ground-based syringe sampling showed transport to the east-southeast during the entire experiment. SF_6 concentrations were quite low until late in the experiment. Samplers at CDH sites in Camp, Carriage, and Welby all measured SF_6 concentrations.

Mobile ground tracking found the SF_6 plume to the east and southeast of the release. Several strong plumes were mapped in the helicopter. Most plumes were found in the same general location as those located in the van. Plumes were mapped from 1800 to 2550 meters MSL. This was the highest altitude that a plume was encountered during the field studies. SF_6 concentrations as high as 3000 ng/m^3 were located, and were generally higher than those values found in the sampling van.

REFERENCES

Hanna, S. R., 1986: Lateral dispersion from tall stacks. J. Climate Appl. Meteor., 25, 1427-1433.

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