2004

FIELD TESTING OF REMOTE SENSOR GAS LEAK DETECTION SYSTEMS FINAL REPORT

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FINAL REPORT

SwRI® Project No. 18.10485

Prepared for:

U.S. Department of Energy
Rocky Mountain Oilfield Testing Center
907 North Poplar, Suite 150
Casper, Wyoming 82601

U.S. Department of Transportation
Office of Pipeline Safety
400 Seventh Street S.W., Room 7128
Washington, DC 20590-0001

December 2004

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ACKNOWLEDGEMENTS

The authors wish to express sincere gratitude to the many people that helped to make this project successful. We specifically would like to thank:

- Rodney Anderson and Rick Baker (DOE NETL) who provided valuable guidance and support throughout the project.
- Doug Tunison, Jim States, and Lorri Kirby (DOE RMOTC) who provided valuable guidance for the project direction and excellent support for the field tests.
- The DOE RMOTC field site personnel who spent countless hours preparing the field site for the testing, conducting safety training sessions, and assisting during the testing.
- The industry advisors who took the time to complete questionnaires, attend meetings, and attend the field test.
- Randy Stewart (DOE Headquarters) for developing a very thorough Aviation Safety Document in a very short period of time.
- The DOE NETL personnel who conducted the plume modeling efforts that were very helpful in setting appropriate leak rates.
- Teresa Walvoord (SwRI) for her skillful preparation of the many project documents, including this report.

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EXECUTIVE SUMMARY

The natural gas pipeline industry routinely checks their pipeline right-of-ways to ensure that leaks are detected. Pipeline companies use various processes to detect signs of leaking pipes, including using vehicles or low-flying aircraft. The leak detection methods range from directly sensing the gas to looking for indirect signs of leakage. The U.S. Department of Energy (DOE) and the U.S. Department of Transportation's Office of Pipeline Safety (OPS) have provided funding to several commercial companies and research laboratories to develop advanced remote sensor systems to provide high quality, cost-effective leak detection information. To aid in the development and availability of these remote detection systems, the DOE funded a project to conduct field testing of five remote sensor leak detection systems. OPS provided co-funding for this project.

The five systems chosen to be included in the field test were being developed by En'Urga Inc., ITT Industries, Inc., LaSen, Inc., Lawrence Livermore National Laboratories, and Physical Sciences Inc. The technologies included passive infrared multi-spectral scanning, laser-based differential absorption LIDAR (Light Detection and Ranging), hyperspectral imaging, and tunable diode laser absorption spectroscopy. The sensor systems were mounted in an unmodified automobile, a helicopter, or a fixed-wing aircraft.

A "virtual pipeline," that simulated conditions of an actual pipeline was created at the Rocky Mountain Oilfield Testing Center field site at NPR-3, north of Casper, Wyoming. The pipeline route was approximately 7.5 miles long and was marked by 14 direction change markers and 22 sets of road crossing markers. Fifteen leak sites, which included three types of gas releases, were established along the route, with natural gas leak rates ranging from 1 scfh to 5,000 scfh. One leak site was designated as a "calibration" site, and the location and leak rate for this site were provided to the equipment providers. Leak sites that were designed to cause plant stress were on continuously from August 30, 2004 through September 17, 2004. The remaining leak sites were set daily during the test week of September 13 to 17, 2004.

Four equipment providers were scheduled to collect data along the pipeline path twice each test day. One equipment provider, at their request, was scheduled to collect data once each day for one of their platforms and twice during the entire week for their other platform. Reports of the findings for the individual equipment providers were due to Southwest Research Institute® (SwRI®) within two weeks after the testing period and are included in this report as Appendix I. Based on the data provided, leaks at many of the leak sites were successfully detected. Leak rates of 500 scfh or higher were detected at least 50% of the time. Leak rates of 100 scfh were only detected 15% of the time. Leak rates of 15 scfh and 10 scfh were only detected about 5% of the time. The 1-scfh leak was never detected. There were also a large number of "false positive" leak sites identified by the equipment providers.

Some of the equipment providers made system improvements during the week including repairing malfunctioning equipment, mechanical modifications to improve performance in field applications, and developing improved data handling schemes. Other modifications have been defined for future work by some of the equipment providers.

Improvements for potential future testing efforts have been identified and include improving the pipeline route and adding more leak sites.

1. INTRODUCTION

The natural gas pipeline industry routinely checks their pipeline right-of-ways to ensure that leaks are detected. Pipeline companies use various processes to detect signs of leaking pipes, including using vehicles for driving along the pipeline path or using low-flying aircraft. The detection methods range from "measuring" the presence of gas to assessing the presence of leaks by "looking" for dead vegetation.

During recent years, the U.S. Department of Energy (DOE) and the U.S. Department of Transportation's Office of Pipeline Safety (OPS) have provided funding to several commercial companies and research laboratories that have been developing advanced remote sensor systems to provide high quality, cost-effective leak detection information. To aid in the development and availability of these remote detection systems, the DOE funded a project to conduct field testing of six remote sensor leak detection systems. OPS provided co-funding for this project.

The six systems chosen by DOE and OPS to be included in the project were being developed by En'Urga Inc., ITT Industries, Inc. (formerly Eastman Kodak Commercial and Government Systems), LaSen, Inc., Lawrence Livermore National Laboratories (LLNL), Ophir Corporation, and Physical Sciences Inc. (PSI). Although all six companies (hereafter referred to as "equipment providers") were involved with the planning process, only five conducted tests with their system. Ophir was not able to attend the test due to equipment delivery problems with a major component of their system.

The project testing was conducted at DOE's Rocky Mountain Oilfield Testing Center (RMOTC) field site at Naval Petroleum Reserve No.3 (hereafter referred to as "RMOTC field site"), north of Casper, Wyoming. Southwest Research Institute (SwRI) and RMOTC staff:

- Investigated the various detection systems.
- Developed an advisory panel of interested gas company personnel.
- Developed a test plan, with input from the advisory panel and equipment providers.
- Determined how best to conduct the testing at the RMOTC field site, including the development of a "virtual" pipeline and leak site-specific designs.
- Designed and fabricated the equipment necessary for the field test and prepared the test site.
- Conducted the field tests, where the equipment providers collected their own data, including providing their own data collection platform.

Subsequent to the field test, the equipment providers supplied test reports to SwRI, which are included in Appendix I and Appendix J. It is important to note that the results provided by the equipment providers were prepared prior to SwRI revealing any information regarding actual leak sites or leak rates. Therefore, the results in these appendices reflect the opinion of the equipment providers regarding the leaks that they believe they found.

It is important to note that this report is intended to summarize the entire project, including the results of the field testing of the various technologies. However, this report is not intended to serve as an analysis of the effectiveness of any technology. Furthermore, it is not intended to endorse any technology or equipment provider.

The overall test plan can be found in Section 2 of this report. Section 3 contains the test facility description. Details regarding the actual test plan experiments, and results provided by the equipment providers are provided in Section 4. Section 5 provides a summary of the project results.

2. TEST PLAN DEVELOPMENT

The test plan was developed over several months with the help of the advisory panel. Initial input was gathered from a survey that was sent to the equipment providers and the project advisors. This information was reviewed at the first project meeting and a brainstorming session was held to identify the key test parameters. After this meeting, more information was collected from advisors and plume modeling was conducted to finalize the test plan conditions.

2.1 Advisory Panel

An advisory panel was established to provide guidance to the project team. The project advisors are listed in Table 2.1.

Table 2.1 Advisory Panel.

The advisory panel consisted of representatives from DOE, trade organizations, and gas companies.

COMPANY	ADVISOR
American Gas Association	Ted Williams
Department of Energy, National Energy Technology Laboratory	Rodney Anderson, Richard Baker
Department of Energy, Rocky Mountain Oilfield Testing Center	Jim States, Doug Tunison, Lorri Kirby
El Paso Pipeline Group	Daron Moore, John Cordaway
Northeast Gas Association	Angelo Fabiano
Office of Pipeline Safety, Department of Transportation	Robert Smith, Jim Merritt
Pacific Gas & Electric Company	Donald Price
Pipeline Research Council International, Inc.	Keith Leewis
Southwest Research Institute	J. Christopher Buckingham, Terrence Grimley

The first input from the advisors was requested in a survey that asked for information on critical issues such as recommended leak rates, leak location (underground, aboveground, etc.), ambient conditions, surface features, gas composition, operating platform, detection limits, detection ranges, and detection features.

During the first project meeting, the advisors were part of a brainstorming exercise that was intended to generate a "complete" list of test parameters and considerations that could be factored into the test program design. These ideas were organized into a list of topics, where similar ideas were placed together. Recognizing that a test matrix including all variables was not practical, each company then voted to prioritize the importance of the various test parameters. This same voting procedure was sent to the advisors that were not in attendance at the meeting.

During the second project meeting, the advisors were part of the discussions regarding the test plans and participated in suggesting the leak rates, leak locations, time slots for the equipment providers, local gas concentration measurements at the leak sites, and the establishment of a "calibration" leak site.

2.2 Identification of Variables

As mentioned above, a general list of potential test parameters was developed during the first project meeting with the equipment providers, the DOE team, the SwRI team, and a subset of the industry advisors. The list was randomly developed using a brainstorming method. The individual items in the list were then divided into groups, using a rationale developed by the meeting participants. The resulting list, in voting ballot form, is provided in Appendix A on pages A-3 through A-5.

The participants present at the meeting then voted for the parameters that they felt were most important to include in the testing. The 24 topics that could receive votes are identified with lines in the left margin of the list of parameters in Appendix A. Each organization (company) was allowed to complete one voting sheet. Each voting organization was allowed 20 total votes, with a maximum of three votes allowed for any one single item. Subsequent to the meeting, the voting sheet and voting requirements were provided to the industry advisors who were not able to attend the meeting.

In total, 12 organizations (equipment providers and industry advisors) provided votes for the test parameters. The results of the voting can be found in Appendix A on Page A-7. This list is presented with the item that was most important to the voters at the top. It was used to develop the overall test plan conditions, where more emphasis was placed on including the items higher in the rankings.

2.3 Initial Test Plan Conditions

Based on the voting results and discussions with the industry advisors and equipment providers, a general guide for the test plan conditions was developed (see Appendix B). The purpose of this plan was to guide the development of specifications for the pipeline and specific test plans for the field testing.

This test plan provided qualitative information on leak rates, leak sources, gas composition, calibration targets, data collection time slots, environmental conditions, measurements that should be taken each day, and safety issues. After careful review of the initial test plan conditions and the RMOTC field site, it was determined that the RMOTC site would be an appropriate, and preferable, site for this testing activity. The major factors that led to this decision were the layout of the RMOTC field site that allowed for a reasonable pipeline route, the availability of natural gas, the availability of the resources to properly prepare the virtual pipeline, and the support to obtain the required permissions to conduct this test.

During the discussion of the test plan, several of the industry advisors indicated that detection of leak rates as low as 0.02 scfh (standard cubic feet per hour) would be preferable. Since the intent of this project was to have a portion of the leak sites that every company would be able to detect, it was important to understand gas dispersion under conditions similar to the RMOTC field site. Therefore, preliminary plume modeling (using computational fluid dynamics) was conducted by DOE NETL personnel. Since the modeling results were used as guidance only, and not validated, they will not be provided in this report. The important result from the modeling studies was that the leak rates needed to be higher than the original plan in order to develop gas plumes that could be detected by most of the technologies being tested. This result was considered when the final test conditions were developed.

The details regarding the test facility and test matrix that resulted from the test plan conditions and the selection of the RMOTC field site are presented in the next two sections of the report.

3. TEST FACILITY DESCRIPTION

The remote sensor leak detection test facility consisted of a “virtual” natural gas pipeline and a variety of natural gas leaks along the virtual pipeline route. The virtual pipeline and associated natural gas leaks were set up along the main north-south roads through the RMOTC field site.

3.1 RMOTC Field Site

The RMOTC field site is a U.S. Department of Energy field test site located 35 miles north of Casper, Wyoming, within the Naval Petroleum Reserve No. 3 in the Teapot Dome Oilfield. The RMOTC field site provides a test site for energy-related technologies and techniques for the federal government, private sector producers, service companies, equipment manufacturers, and research organizations. The RMOTC field site is a 10,000-acre operating oilfield with approximately 1,200 well bores and approximately 600 producing wells. Produced natural gas is currently processed, compressed, and reinjected via the RMOTC gas plant. The produced natural gas was used as the gas source for many of the leak sites.

The climate and terrain at the RMOTC field site can be characterized as a high desert plain with an elevation of approximately 5,200 feet above sea level. The average high and low temperatures for the Casper, Wyoming area for September are 73°F and 42°F, respectively (www.weather.com). Based on the RMOTC field site weather station data, the prevailing winds in September are from west-southwest, southwest, and south-southwest. Wind speeds are variable during September, generally ranging from 6 mph to 13 mph. The minimum and maximum average wind speeds (averaged over 10-minute periods) recorded during September 2003 were 1 mph to 32 mph, with the peak occurring at mid-day. Wind speeds generally increase rapidly after 6:00 AM and decrease rapidly after 5:00 PM.

3.2 Leak Site Details and Locations

Fifteen leak sites were created along the virtual pipeline route. Three basic types of leaks (aboveground, below ground, and below ground side-drilled) and two types of gas sources (high-pressure gas cylinders and RMOTC-produced gas) were used. Details of each leak site, including leak site location, are given in Table 3.1. Detailed drawings of the leak site configurations are located in Appendix C. Photographs of the leak sites are located in Appendix D. The leak site locations are shown on the RMOTC field site maps provided in Appendix E.

The leak sites were specifically designed and placed in locations to provide a range of “challenges” to the equipment being tested. For example, some leak sites were very close to the road, while others were more than 100 feet away, and some sites were level with the road, while others were on elevated bluffs.

Leak Site 1 was the “calibration leak,” and all equipment providers were given the leak rate and exact location (GPS coordinates) of this leak site for every test period. The remainder of the leak site hardware was hidden to the fullest extent possible. In particular, the high-pressure gas bottles were installed in cased holes in the ground such that the regulator was approximately at ground level. Other leak site hardware was somewhat hidden in tall grass and/or bushes; some leak site locations offered little cover to hide leak site hardware.

Table 3.1 Leak Site Details

Leak Site	Gas Source	Leak Type	Latitude (N)	Longitude (W)	Distance from Leak Site to Center of Road (ft)	Side of Road
1	RMOTC gas	Below ground	43 14 53.6	106 11 12.1	36	East
2A	Cylinder	Below ground	43 15 12.9	106 11 50.1	76	West
2B	Cylinder	Below ground	43 15 26.3	106 11 59.9	78	West
2C	Cylinder	Below ground	43 15 46.0	106 12 09.1	122	East
3	RMOTC gas	Aboveground	43 16 15.7	106 12 19.5	44	East
4	RMOTC gas	Below ground	43 16 20.1	106 12 24.6	90	East
2D/1F	Cylinder	Below ground	43 16 34.4	106 12 43.2	100	East
5	RMOTC gas	Below ground	43 17 44.1	106 13 15.8	59	East
P1	RMOTC gas	Side-drilled	43 18 12.7	106 13 06.3	78	West
P2	RMOTC gas	Side-drilled	43 18 37.0	106 13 17.9	240	West
6	RMOTC gas	Below ground	43 18 56.4	106 13 30.4	170	West
2E	Cylinder	Below ground	43 19 12.4	106 13 40.3	74	East
P3	RMOTC gas	Side-drilled	43 19 44.5	106 13 51.5	116	West
P4	RMOTC gas	Side-drilled	43 20 13.2	106 13 37.8	66	West
P5	Cylinder	Side-drilled	43 20 27.7	106 13 36.3	39	West
			DD MM SS.S[1]	DDD MM SS.S		
			NAD 27	WAAS Enabled[2]		

[1] Latitude and longitude are noted in degrees, minutes, and decimal seconds.
[2] The GPS datum used for this project was NAD 27 with the WAAS feature enabled.

At the aboveground leak site (Leak Site 3), the pipe connected to the rotameter assembly was laid on the ground and ended in an upward-facing elbow (and flame arrestor). See drawing 18-10485-400 located in Appendix C.

At the below ground leak sites (Leak Sites 1, 2A, 2B 2C, 4, 2D/1F, 5, 6, and 2E), holes approximately 10 inches in diameter were drilled approximately 2-feet deep with a posthole auger. After installation of the appropriate tubing or pipe, the holes were backfilled with 1-inch washed gravel. See drawings 18-10485-100, 18-10485-300, and 18-10485-700 located in Appendix C.

Below ground, side-drilled leak sites (Leak Sites P1, P2, P3, P4, and P5) were set up in order to specifically accommodate evaluating devices that detect vegetation stress. However, they were also applicable as typical underground leaks for all of the other leak detection technologies. The leak site tubing was installed in a directionally drilled hole approximately 30 feet in length and ending about 3 feet below the surface so that the vegetation near the leak site was not disturbed. After the tubing was installed in the drilled hole, the inner wall of the hole was agitated in order to encourage the hole to collapse around the installed tubing so that the gas would not escape from the hole along the tubing. See drawings 18-10485-500 and 18-10485-600 located in Appendix C. The below ground, side-drilled leaks were initiated August 30, 2004 and were on continuously until the conclusion of testing on September 17, 2004.

Depending on the gas source and available pressure, the leak rate was controlled by either a regulator and orifice restrictor combination or a rotameter and metering valve combination. Leak sites with high-pressure gas cylinder sources (Leak Sites 2A, 2B, 2C, 2D/1F, 2E, and P5) used choked flow through an orifice restrictor (0.017-inch or 0.005-inch orifice diameter) to control leak rate. In addition, Leak Site 5 was supplied from a high-pressure (~500 psi – 680 psi) gas plant source and used choked flow though an orifice restrictor (0.276-inch orifice diameter) to control leak rate. The pressure upstream of the orifice restrictor was controlled to a constant value with a pressure regulator. The pressure downstream of the orifice restrictor was measured with a pressure gauge to ensure that the flow remained choked. The remaining leak sites (Leak Sites 1, 3, 4, P1, P2, 6, P3, and P4), which used lower pressure RMOTC gas sources, used a rotameter and metering valve combination to control leak rate (see drawing 18-10485-200). The measured flowrates were corrected for natural gas specific gravity and rotameter outlet pressure in accordance with the rotameter manufacturer's recommendations. Although not accounted for, gas temperature corrections could affect the reported flow rates by only about 1%.

The RMOTC gas plant processed gas is routinely characterized by gas chromatograph analysis. In general, this gas contains approximately 87% methane and 5.5% ethane. The high-pressure gas cylinders (Leak Sites 2A, 2B, 2C, 2D, 2E, and P5) contained a mixture of 95% methane and 5% ethane to somewhat mimic the expected gas plant processed gas composition. In addition, a methane-only "phantom" leak (Leak Site 1F) was produced from high-pressure gas cylinders containing 100% methane. The purpose of the methane-only leak was to test several equipment providers' stated abilities to distinguish between a natural gas leak and a non-natural gas, methane-only source (i.e., a land-fill). This phantom leak (1F) was located at Leak Site 2D and used the Leak Site 2D hardware on two days when Leak Site 2D was not in use.

In addition to the actual leak sites, several "decoy" sites were set up to discourage close observation of particular areas based on visual clues. The decoy sites were intended to look like potential leak sites, but no gas was actually supplied to the decoy sites. In all decoy sites, black HDPE pipe (the same pipe used in many actual leak sites) was run from a plausible gas source (or an area with potential gas sources) to or towards a location near the pipeline route. The decoy site locations are given in Table 3.2. The GPS latitude and longitude coordinates given for the decoy sites indicate the end point of the decoy piping. The decoy site locations are shown on the RMOTC field site maps provided in Appendix E (pages E-3, E-5, and E-7).

Table 3.2 Decoy Site Details

Decoy Site	Latitude (N)	Longitude (W)	Description
D1	43 16 18.6	106 12 22.6	Between Leak Site 3 and Leak Site 4
D2	43 16 22.2	106 12 28.2	Between Leak Site 4 and RC5
D3	43 17 03.1	106 12 53.3	From drip pot near ES&H building, near M6
D4	43 17 37.7	106 13 16.7	From gas plant source, near M8
D5	43 19 43.8	106 13 53.6	Across service road, near RC14
D6	43 19 58.5	106 13 45.3	Over well containment berm, near RC15
	DD MM SS.S	DDD MM SS.S	
	NAD 27 WAAS Enabled		

The pipeline route was communicated to the equipment providers using a series of 14 pipeline markers (M1 – M14). The pipeline marker locations and headings are given in Table 3.3. The "Marker-Based Pipeline" map (page E-3), which defines the pipeline route as straight-line segments through the pipeline markers, is given in Appendix E. The pipeline markers were comprised of 4-foot x 8-foot sheets of plywood painted with the pipeline marker number (i.e., M1 – M14) and an arrow indicating pipeline heading to the next pipeline marker. A picture of a pipeline marker is given in Figure 3.1.

Table 3.3 Pipeline Marker Details

Marker	Latitude (N)	Longitude (W)	Heading (deg)[1]
M1	43 14 53.3	106 11 10.9	295
M2	43 15 02.3	106 11 42.7	332
M3	43 15 38.3	106 12 08.3	355
M4	43 16 09.6	106 12 11.7	317
M5	43 16 40.9	106 12 51.6	358
M6	43 17 03.7	106 12 52.3	317
M7	43 17 15.5	106 13 07.1	342
M8	43 17 40.5	106 13 17.7	20
M9	43 18 07.3	106 13 03.6	340
M10	43 18 39.5	106 13 19.1	335
M11	43 19 14.3	106 13 41.5	339
M12	43 19 38.9	106 13 54.6	19
M13	43 20 15.2	106 13 36.9	2
M14	43 20 30.8	106 13 36.2	N/A
	DD MM SS.S	DDD MM SS.S	
	NAD 27 WAAS Enabled		

[1] Approximate heading is given from current marker location to next marker location (basis is true North).

Figure 3.1 Pipeline Marker (M2)

A series of 14 pipeline markers defined the pipeline route.

In addition to the pipeline markers, a series of 22 road crossing markers (RC1 – RC19) were used to indicate the pipeline route. The road crossing marker locations and directions are given in Table 3.4. The road crossing markers are shown on the "Marker-Based Pipeline" map located in Appendix E (page E-3). The road crossing markers were wooden sticks (approximately 1-inch square and 3-feet tall) painted fluorescent orange to resemble road crossing markers typically used for actual gas pipelines. The GPS latitude and longitude coordinates given for the road crossing markers indicate the location where the pipeline crosses the center of the road. One road crossing marker was placed on each side of the road such that an imaginary line between the two markers was essentially perpendicular to the road. The road crossing markers were not used to indicate the pipeline heading at the road crossing point. The pipeline heading is defined by the pipeline markers (M1 - M14) and the heading is constant (i.e., the pipeline is straight) between pipeline markers. A picture of a road-crossing marker is given in Figure 3.2.

Table 3.4 Road Crossing Marker Details

Marker	Latitude (N)	Longitude (W)	Side[1]
RC1	43 14 57.4	106 11 26.1	R TO L
RC2	43 15 02.5	106 11 42.8	L TO R
RC3	43 15 11.7	106 11 49.4	R TO L
RC4	43 15 40.8	106 12 08.6	L TO R
RC5	43 16 37.3	106 12 47.1	R TO L
RC6	43 17 10.1	106 13 00.4	L TO R
RC6A	43 17 38.5	106 13 17.4	R TO L
RC6B	43 17 41.7	106 13 17.4	L TO R
RC7	43 17 47.8	106 13 13.9	R TO L
RC8	43 18 26.5	106 13 12.7	L TO R
RC9	43 18 33.9	106 13 16.4	R TO L
RC9A	43 18 53.6	106 13 28.4	L TO R
RC10	43 18 54.6	106 13 28.8	R TO L
RC11	43 19 09.4	106 13 38.4	L TO R
RC12	43 19 14.4	106 13 41.6	R TO L
RC13	43 19 39.0	106 13 54.5	L TO R
RC14	43 19 42.1	106 13 53.0	R TO L
RC15	43 19 59.1	106 13 44.6	L TO R
RC16	43 20 08.3	106 13 40.2	R TO L
RC17	43 20 14.6	106 13 37.2	L TO R
RC18	43 20 20.5	106 13 36.6	R TO L
RC19	43 20 30.2	106 13 36.2	L TO R
	DD MM SS.S	DDD MM SS.S	
	NAD 27 WAAS Enabled		

[1] Side = the side of the road that the pipeline crosses from and to, when traveling south to north.

Three weather stations (provided and operated by ITT) were distributed along the pipeline route to continuously record local weather conditions. The weather station locations are given in Table 3.5 and are shown on the "Marker-Based Pipeline" map provided in Appendix E (page E-3). A picture of a weather station is given in Figure 3.3. Data collected by these stations included wind speed and direction, temperature, relative humidity, and ground moisture. The data were provided directly to the equipment providers during the test week, usually in the middle of the test day.

Figure 3.2 Road Crossing Marker

The road crossing markers indicate where the pipeline crosses the center of the road; the road crossing markers do not indicate pipeline heading at the road crossing point.

Table 3.5 Weather Station Locations

Weather Station	Latitude (N)	Longitude (W)	Location
WS1	43 15 33.6	106 12 05.2	South, near M3
WS2	43 16 59.0	106 12 51.2	Central, near ES&H building
WS3	43 19 55.9	106 13 43.1	North, near RC15
	DD MM SS.S	DDD MM SS.S	
	NAD 27	WAAS Enabled	

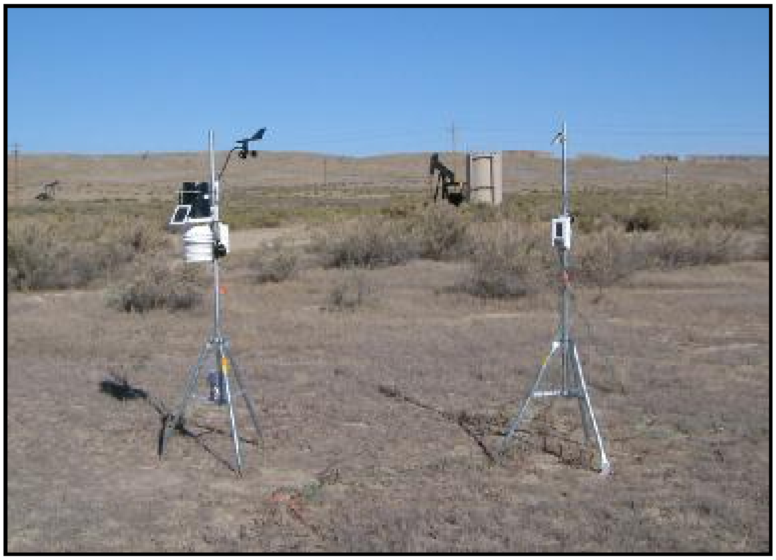


Figure 3.3 Weather Station WS3

Three weather stations were distributed along the pipeline route to continuously record local weather conditions.

4. EXPERIMENTS

The experiments were conducted at the RMOTC field site during the middle of September 2004. One equipment provider conducted their first flight on Thursday, September 9. The remainder of the testing was conducted during the week of September 13 through September 17. The actual test conditions, including leak rates, leak locations, local concentration measurements, local wind conditions, and general site wind conditions are discussed below. In addition, the results of the testing, summarized from the reports from the equipment providers, are also presented.

4.1 Overall Plan

Based on the test plan conditions (see Section 2.3) and the leak site details (see Section 3.2) developed to this point in the project, specific plans were developed for the testing. The detailed plans included developing a schedule for the data collection periods for each equipment provider and the specific leak rates planned for each test day at each leak site.

4.1.1 Pre-Testing Plan

The originally planned detailed testing schedule for the data collection periods is provided in Appendix F. The notes on the final page of this schedule indicate the details regarding how to interpret the chart. In general, the plan included time slots for the four technologies that relied on aircraft and the two technologies that required ground transportation. The basic plan was that all of the data collection would be conducted during daylight hours. Also, time was left between flights so that no two aircraft would be over the site at the same time. The only exception was that simultaneous flights of the LLNL Unmanned Autonomous Vehicle (UAV) and LLNL Twin Otter were allowed, since they were separated by at least 4,000 feet of vertical distance. The driving times were allotted such that the two equipment providers using ground transportation would not pass each other during the data collection period.

Special considerations for the schedule that were a result of specific requests by the equipment providers included:

- En'Urga requested that their driving times start at about 10:00 AM and 2:30 PM, in order to take advantage of the best lighting conditions for their technology.
- ITT, LaSen, and Ophir requested flight times when the wind speed would likely be the lowest and there was enough light to be considered daylight.
- LLNL requested flight times around Solar Noon, which closely corresponds to Noon local time during the test dates in September. Rather than two shorter flying times, they requested one longer data collection period for both the Twin Otter and UAV platforms. LLNL further indicated that they would only need two time slots for the Twin Otter flights, preferably one early in the week and one later in the week.
- PSI requested a variety of start times during the morning and afternoon driving times in order to test their system over a variety of lighting and wind conditions.

The plan included two data collection periods each day for all but one of the equipment providers, with one data collection time in the morning and one in the afternoon. Statistics were used to fairly assign time slots for the equipment providers that used aircraft, since wind speed data from September 2003 (RMOTC field site weather station) showed that wind conditions would possibly be more favorable in the early morning and the late evening. Each equipment provider was assigned a fair number of likely wind conditions.

The nominal leak rates planned for each leak site during every day of the test program are summarized in Appendix F. The general plan included the following important criteria:

- The below ground, side-drilled leak sites that were meant to cause plant stress were started on August 30, which was 15 days before the first scheduled survey. The leak rates at these sites, which are labeled P1 through P5, were scheduled to remain constant each day of the test program. These leak rates ranged from 1 scfh (standard cubic feet per hour) to 1,000 scfh.
- The remaining leak sites were started each morning at least 30 minutes before the first data collection period and were turned off at the end of the day. The leak rates were scheduled to remain constant throughout the entire test day.
- The southern-most leak site (Leak Site 1) was identified as the “calibration leak site.” The GPS coordinates of this leak site and the daily leak rate were given to the equipment providers. The leak rate for the calibration leak site started at 5,000 scfh on the first day of testing and was decreased to a lower flow rate each day.

4.1.2 Safety Plans

Prior to initiating the testing, a Job Hazard Analysis and a Flight Readiness Review Board (FRRB) were conducted to identify and address all of the safety issues related to the test operations. The Job Hazards Analysis was conducted at the RMOTC field site offices and included representatives from RMOTC’s Casper office, RMOTC field personnel (including safety personnel), and a representative from SwRI. The action items that resulted from this meeting were assigned to various personnel at the meeting and all were properly addressed prior to the testing.

A representative from DOE Headquarters in Washington, D.C. conducted the Flight Readiness Review Board. This review included collecting detailed information regarding the flight profiles for each of the equipment providers and detailed information on the leak sites and test plans. The Chair of the FRRB also toured the test site to look for potential hazards, attended the testing kickoff meeting prior to the first day of testing, and observed the first day of testing. Prior to conducting the testing, an Aviation Safety Document was prepared and provided to SwRI personnel, RMOTC personnel, and the equipment providers. This document included background information and safety requirements to ensure the safety of the aircraft personnel during the test week. The recommendations of this document were followed during the testing period.

In addition, as a courtesy, test plan information was provided to the Wyoming Department of Environmental Quality on the conduct of this test. The information provided included detailed plans for the test days, the virtual pipeline route, leak sites details, the leak rates for each day, and expected daily gas and H_2S emissions.

4.1.3 Actual Testing Plan

During the actual testing period, small changes were made to the daily testing schedule and the leak rate plan. The details regarding the changes that resulted in the final plan are discussed below.

The actual detailed testing schedule for the data collection periods is provided in Appendix G. Changes from the original plan include:

- Ophir was not able to attend the test due to equipment delivery problems with a major component of their system.
- The flight and driving times were slightly modified to allow for the longer flight time required by one of the equipment providers to get from the airport to the test site. This shift of 15 minutes eliminated the potential safety issues with the planes flying during marginal lighting conditions.
- The afternoon driving times were slightly modified to allow for the equipment providers to drive from the daily coordination meeting in Casper to the site, to sign-in, and get to the start of the pipeline route before their designated starting time.
- Several of the equipment providers were not able to collect data during their allotted time periods. This was often due to technical problems with their systems. In addition, one of the equipment providers chose not to collect data during all of the allotted time periods on the last day of the test week.

The actual "nominal" leak rates for each leak site during every day of the test program are summarized in Appendix G. Changes from the original plan include:

- The leak rate on Monday, September 13 at Leak Site 5 was changed from 2,000 scfh to 2,500 scfh. This change was made due to a delivery problem with the correct orifice for setting the leak rate at 2,000 scfh.
- Since the major leaks were being easily identified during the early portion of the testing, on Thursday, September 16 the leak rate for Leak Site 5 was changed from 5,000 scfh to zero. Another reason for this change was to remove a major leak (that most of the equipment providers were finding every day) from the pipeline and determine how the equipment providers responded.
- The calibration leak on Friday afternoon was changed from 15 scfh to 5,000 scfh. This change was to accommodate one of the equipment providers, whose equipment was not working properly to detect the 5,000-scfh calibration site on the first day of the test. The other equipment provider that was still taking data on Friday afternoon agreed to this change.

- The leak flow rate at Leak Site 3 was not consistent throughout the day on Wednesday, September 15 and Thursday, September 16. The well site in line with the leak site source gas was undergoing a workover operation, and the source valve feeding the leak site was turned off by the well workover crew. On Wednesday, the leak site was turned off at approximately 1:30 PM and remained off for the rest of the day. On Thursday, the leak site was off for only a few minutes at about 8:40 AM.

Throughout the testing week, various data were collected to support the test operations and data reduction. All of this information, which is included in Appendix H, includes:

- Actual Leak Rates – During each day, the leak rates at each leak site were monitored. In many cases, the flow rates changed very little throughout the test day. However, the leak rate at a few of the leak sites had changed significantly during the preceding hours. In these cases, the flow rate was reset to the planned value at the times noted in Appendix H. Since most of the equipment providers presented only qualitative data regarding the size of the leaks, these relatively minor leak rate variations had little impact on the assessment of the leak site.

- Local Hydrocarbon Gas Concentration Measurements ("Ground Truth") – At some point during each testing day, hydrocarbon gas concentration measurements at the leak sites were recorded. The measurements were generally made during the same time windows used by the equipment providers. The measurements were taken using a commercially available flame ionization detector (FID) system (Heath Detecto-Pak® III). The data in Appendix H indicate the range of measurements recorded at sites approximately 10 feet and 30 feet downwind of the leak site and about 1 foot to 2 feet above the ground. The gusty winds made these measurements challenging.

- Local Weather Conditions – Measurements of local weather conditions (wind speed and direction, temperature, barometric pressure, etc.) at the leak sites were recorded in conjunction with local hydrocarbon concentration measurements. This was accomplished by using a commercially available hand-held weather tracker (Nielsen-Kellerman Kestrel® 4000 Pocket Weather Tracker) to gather weather data. A compass was used to measure wind direction. The data in Appendix H include the minimum and maximum wind speed, wind direction, temperature, humidity, and barometric pressure recorded while at the leak site.

- RMOTC Gas Analyses – Many of the leak sites were fed from gas from the RMOTC gas plant. Gas chromatograph analyses for this gas for each of the five testing days are provided in Appendix H. The methane content of the gas remained very close to 88 mol% (the molar mass of methane divided by the molar mass of the gas mixture) throughout the entire week. The relative amount of other components in the gas also stayed very consistent.

- Test Site Weather Data – As mentioned earlier, three weather stations were set up along the pipeline route. The wind speed data for each day has been plotted and is presented in Appendix H. These data (recorded once per minute) are unfiltered and are meant to give a general indication of the relative wind speed at the three sites throughout the test days.

Since these tests were conducted within a working oilfield, there were a number of exposed pipes, valves, and other fittings that could provide unintentional leaks within the virtual pipeline route. Leak sites identified during the daily debriefing sessions with each equipment provider that did not correspond to known leak sites were investigated. The inspections consisted of surveying a several-hundred foot wide region near the reported area with the same FID instrument used for the ground truth measurements. In two cases, leak sites reported during the debriefing sessions were subsequently verified as real, unintentional leaks. Although it was not verified, because of the type of leaks, it was reasonable to expect that these unintentional leaks were present throughout all of the testing. These leaks were not considered for the overall summary of leaks "found," but are specifically mentioned per equipment provider in Section 4.2. Locations of these unintentional leaks are provided in Table 4.1.

Table 4.1 Unintentional Leak Site Locations

Two leak sites were found by the equipment providers that were along the virtual pipeline path but not part of the planned leaks for the project.

Unintentional Leak Site	Latitude (N) NAD 27	Longitude (W) NAD 27	Description
ULS 1	43 17 3.1	106 12 53.3	Drip pot near ES&H Building adjacent to decoy site D3.
ULS 2	43 17 37.7	106 13 16.7	From Leak Site 5 gas source in front of gas plant adjacent to decoy site D4.
	DD MM SS.S	DDD MM SS.S	
	NAD 27	WAAS Enabled	

4.2 Equipment Providers' Reports

Each of the equipment providers was required to submit a report on the results of the field test of their equipment. The general format of the report and the requirement that the report would be due two weeks after the end of the testing week were provided to the equipment providers at the June project meeting. About one week before the testing began, detailed templates, customized for the various sensing systems, were provided to each of the equipment providers. The resulting reports, as received from the equipment providers are provided in Appendix I. Only the footers were changed.

Besides the required documents in the SwRI format, the equipment providers were also given the option to provide a company-specific, customized report in their own format. The company-specific reports (which were only provided by ITT) are provided in Appendix J.

After the equipment provider reports were received, the test conditions (leak sites, leak rates, etc.) were supplied to the equipment providers. The equipment providers were then allowed to review the data and submit final comments on their results. Their comments are provided in Appendix K.

It is important to note that the reports provided in Appendix I and Appendix J were completed by the equipment providers prior to SwRI divulging the actual leak sites and leak rates. That is, they included "blind" test results. Therefore, the equipment provider reports include their claims regarding leak detections, some of which may be incorrect. The proper analysis of these results is provided in Section 4.3.

The equipment provider comments in Appendix K were completed after SwRI had divulged the leak sites and leak rates, but prior to receiving SwRI's evaluation. Therefore, the "claims" and comments in these letters are based on the data provided, and not SwRI's evaluation.

4.2.1 En'Urga Inc. (En'Urga)

En'Urga utilized a passive system that sensed background emissions at four mid infrared wavelengths using a multi-spectral scanning arrangement. The presence of methane was detected by analyzing the emission intensities of the detected wavelengths. The sensor assembly was tripod-mounted and transported in a vehicle driven along the road near the virtual pipeline. The system was designed to detect leaks within 50 feet of the sensor. The complete test report from En'Urga is located in Appendix I, Section 1, but important items to note are as follows:

- En'Urga reported that, in general, only one side of the road was scanned during each of the passes because of the time consumed by re-orienting the sensor from side to side on the vehicle.
- En'Urga completed a single pass within each of their allotted driving times each day.
- En'Urga did not collect any additional data after the morning run on Wednesday, September 15th. En'Urga reported that their optics were contaminated by the dusty conditions at the site and resulted in degradation of the signal.
- The GPS leak locations reported were based on interpolated values between road crossing locations since the data were not analyzed in "real-time."
- Leak sites were described as small, medium, and big.
- En'Urga reported that they replaced a detector after the end of data collection on the first testing day and that they were required to frequently clean dust from their optics.
- The test report was provided prior to the requested date.

The daily results for En'Urga are summarized, along with the results of the other equipment providers, in Section 4.3.

4.2.2 ITT Industries, Inc. (ITT)

ITT's system consists of an aircraft-mounted, laser-based, differential absorption LIDAR (Light Detection and Ranging) imaging system. Laser pulses at two different wavelengths were generated at a 1,000-Hz rate and the reflected energy was sensed and recorded by the system. The scanning portion of the system allowed imaging over the right-of-way area along the virtual pipeline path, while the aircraft did not have to follow the path exactly. Data were not analyzed in real-time. The complete test report from ITT is located in Appendix I, Section 2, but important items to note are as follows:

- Although ITT surveyed the route on Monday, no data were provided for these flights.
- ITT made multiple passes (ranging from five to nine) over the virtual pipeline during each of their scheduled time slots, but reported aggregate information for each day. The aggregate leak site data included the pass numbers for which a particular leak site was found.
- Data were segregated into tables of "large and medium emissions" (where leaks were observed on multiple passes) and "relatively small emissions" (where leaks were detected on fewer passes).
- In addition to aircraft position information and sensor data, ITT collected video data during the flights.
- ITT reported that they solved two mechanical problems early in the test week and improved their data processing algorithms in the middle of the week.
- The test report was not provided by the requested date.

The daily results for ITT are summarized, along with the results of the other equipment providers, in Section 4.3.

4.2.3 LaSen, Inc. (LaSen)

LaSen utilized a helicopter-mounted, laser-based differential absorption LIDAR system to detect the presence of methane. The sensor measured the amount of reflected energy at two different wavelengths at a rate of 10 to 20 times per second. The wavelengths were chosen such that the amount of light energy absorbed by methane was distinct for each wavelength. The ratio of the energy levels at the two wavelengths was related to the magnitude of the leak. The helicopter traversed the virtual pipeline using the pipe markers and other visual references. The complete test report from LaSen is located in Appendix I, Section 3, but important items to note are as follows:

- Sensor data were recorded along with GPS, video, and rangefinder information for later analysis. The data were analyzed in "real-time" for the presence of strong leaks, as well as reviewed more comprehensively after completing the survey flights.
- LaSen reported no data on Monday, September 13th, or for the morning of Tuesday, September 14th. They reported system problems, and problems with their GPS unit.
- Data were typically reported for two passes along the virtual pipeline.
- LaSen indicated that the combination of the measurement update rate and traversing velocity combined to give a location uncertainty of up to 100 ft. They

also indicated that plume dispersion and migration further increased the reported location uncertainty.

- Leak sites were described qualitatively (e.g., small, medium, large, and very large).
- LaSen reported that they made minor hardware modifications during the first three days of testing.
- The test report was provided on the requested date.

The daily results for LaSen are summarized, along with the results of the other equipment providers, in Section 4.3.

LaSen identified one unintentional leak site (ULS 1) near decoy site D3 on Tuesday afternoon, and during both time slots on Wednesday.

4.2.4 Lawrence Livermore National Laboratories (LLNL)

LLNL utilized hyperspectral imaging of vegetation to sense plant stress related to the presence of natural gas. The spectral signature of sunlight reflected from vegetation was used to determine vegetation health. Two different platforms were used for imaging the virtual pipeline path: a Twin Otter aircraft flying at an altitude of about 5,000 feet above ground level that imaged the entire site in strips, and an unmanned autonomous vehicle (UAV) flying at an altitude of approximately 1,000 feet above ground level that imaged an area surrounding the virtual pipeline. The complete test report from LLNL is located in Appendix I, Section 4, but important items to note are as follows:

- The UAV flew during one of the five time slots for which it was scheduled. The LLNL report does not mention the UAV and no data were reported for the UAV flight.
- The Twin Otter completely surveyed the site twice (September 9th and September 15th), but data were reported only for the second flight. Although not mentioned in LLNL's report, an additional flight on September 16th was used to fill in an area of the site covered by clouds on September 15th. LLNL's report indicates that only the data collected on September 15th were reviewed.
- LLNL indicated that vegetation at the test site was largely dormant, except in gully areas that maintain moisture. Therefore, the gully areas were the only areas reviewed for potential leak sources, since those areas provided the best indication of a difference between healthy and unhealthy vegetation.
- Additional potential leak areas away from the virtual pipeline path were indicated in the LLNL report; however, because the report indicated that the sites were not along the pipeline, they were not included in the data summarized in Section 4.3.
- Leak sites were described qualitatively and in terms of a vegetation patch size measurement.
- LLNL did not report that they made any system modifications.

- The test report was not provided by the requested date. Leak sites were not identified using the requested coordinate system and were not reported in the requested tabular format. Parts of the report were left blank.

The results for LLNL are summarized, along with the results of the other equipment providers, in Section 4.3.

4.2.5 Physical Sciences Inc. (PSI)

PSI utilized a hand-held, laser-based instrument with a swept laser frequency to detect the presence of methane. The laser frequency was swept through the region where methane absorbs the energy so that the reflected energy measured by the sensor would change in proportion to the amount of methane in the path. Although normally used for walking surveys, for these tests, the device was held and aimed by an operator positioned in a vehicle that drove along the road next to the virtual pipeline. PSI reported that the effective range of the system was between 100 feet and 150 ft, and that the sensitivity was 10 ppm-m. The complete test report from PSI is located in Appendix I, Section 5, but important items to note are as follows:

- The data were analyzed in real-time and GPS locations were based on the vehicle location at the time the leak was found. A rangefinder was used to estimate the distance from the vehicle to the leak site.
- Leak sites were described in qualitative terms and, in some cases, with a range of path concentration levels (ppm-m).
- PSI surveyed the virtual pipeline during each of their scheduled testing periods, except for Friday, when they elected to check only the calibration leak site in the morning.
- PSI did not report that they made any system modifications.
- The test report was provided prior to the requested date.

The daily results for PSI are summarized, along with the results of the other equipment providers, in Section 4.3.

In addition to the leak sites created specifically for this test, PSI identified two unintentional leak sites. The unintentional leaks were identified as ULS 1 (near site D3 on Wednesday morning, and on both passes on Thursday) and as ULS 2 (near site D4 on Tuesday afternoon).

4.3 Daily Test Results

The daily test results for all of the equipment providers are summarized in the following ten tables. Each table includes the data that were collected by each of the equipment providers that either flew over or drove the pipeline route during that time period (either the morning or evening). As mentioned in the previous section, some equipment providers did not participate each day and some participated but had equipment problems that prevented data collection.

The center columns of Table 4.2 through Table 4.11 present a simple "yes" or "no" indication regarding whether the leak was detected by the equipment providers. Each of the equipment providers summarized their results in slightly different ways. Some only presented qualitative information regarding the size of the leak (i.e., large, medium, or small) and others provided quantitative data regarding the concentration path length (e.g., 1,500 ppm-m to 2,500 ppm-m). Due to the inconsistency in this reporting, the qualitative and/or quantitative comments are not provided in these tables. These details are contained in the equipment provider reports in Appendix I.

The last two columns of these tables represent the percentage of leaks found and the number of leak sites found during the various data collection periods. For both of these columns, the only data included is for leaks that were meant to be part of the virtual pipeline leaks. The "% Found" column was calculated by dividing the number of leaks found at each leak site by the number of times the leak could have been detected by the equipment providers that collected data during that time period. Since the leak site and leak rate for the calibration leak site (Leak Site 1) were supplied to the equipment providers before each test, the "found" columns are not calculated.

The leaks summarized in these tables only represent the occasions when the leak coordinates (provided in NAD 27 GPS) indicated by the equipment providers “matched” the GPS co-ordinates of the actual leak sites. Some judgment was required to determine if a reported leak could be associated with an actual leak site. The criterion used was to compare both the latitude and longitude of the actual leak site (in NAD 27 GPS datum) with the latitude and longitude of the reported leak sites. If these coordinates in both directions were within about 150 feet, then “credit” was given for finding the leak.

In a very few cases, additional judgment was required to take into account the leak site information given by the equipment providers. For example, if an identified leak site was very close to an actual leak site, but the leak rate was identified as very large and the leak rate was actually very small, this was recorded as a false positive.

Special consideration was also required when reviewing the data from En’Urga and PSI. These companies were required to drive along the roads, and the leak site notations were coordinates on the roadway. The fact that some of the leak sites were as much as 220 feet from the road was considered when evaluating the reported leaks.

For some of the data supplied by the equipment providers, it was also necessary to apply these same criteria to the reported leak sites. That is, multiple leak sites were sometimes presented that were within 150 feet of each other. These individual leaks were considered as one leak site in the data presented in this section. This methodology did not impact the number of actual leak sites found by any of the equipment providers. However, this methodology did minimize the number of leak sites that otherwise would have been considered as “false positives.” A reported leak site was deemed to be a false positive if (1) the leak site coordinates provided by equipment providers were not within the criteria to be associated with actual leak sites, and (2) no gas was present, based on FID measurements taken in the field. (The same 150-foot criterion, as mentioned above, was used to evaluate reported leak sites that were false positives.)

Table 4.2 Daily Results for Monday Morning

En'Urga and PSI provided data for the Monday morning data collection period. In addition to the calibration site, which was known by all equipment providers, a total of five actual leaks sites were found.

Leak Site	Nom Leak Rate (scfh)	Leaks Found: En'Urga	Leaks Found: PSI	% Found	# Found
1	5,000	yes	yes	note A	note A
2B	15	no	no	0	0
3	1,000	no	yes	50	1
4	100	no	no	0	0
5	2,500	no	yes	50	1
6	500	no	yes	50	1
P1	1,000	no	yes	50	1
P2	100	no	no	0	0
P3	10	no	no	0	0
P4	500	no	yes	50	1
P5	1	no	no	0	0

NOTES:
A - Leak Site 1 location and leak rate information was given to all equipment providers.
B - LaSen reported that they flew, but data were not presented due to a malfunction in the GPS unit.
C - LLNL reported that they did not fly the UAV or Twin Otter.
D - ITT reported that they flew, but data were not presented due to hardware, software, and operational problems.
E - En'Urga reported that they looked at Leak Site 1 and then only to the left.

Table 4.3 Daily Results for Monday Afternoon

En'Urga and PSI provided data for the Monday afternoon data collection period. In addition to the calibration site, which was known by all equipment providers, a total of five actual leak sites were found.

Leak Site	Nom Leak Rate (scfh)	Leaks Found: En'Urga	Leaks Found: PSI	% Found	# Found
1	5,000	yes	yes	note A	note A
2B	15	no	no	0	0
3	1,000	no	yes	50	1
4	100	no	no	0	0
5	2,500	no	yes	50	1
6	500	no	yes	50	1
P1	1,000	no	yes	50	1
P2	100	no	no	0	0
P3	10	no	no	0	0
P4	500	no	yes	50	1
P5	1	no	no	0	0

NOTES:
A - Leak Site 1 location and leak rate information was given to all equipment providers.
B - LaSen reported that they flew, but data were not presented due to a malfunction in the GPS unit.
C - LLNL reported that they did not fly the UAV or Twin Otter.
D - ITT reported that they flew, but data were not presented due to hardware, software, and operational problems.
E - En'Urga reported that they looked only to the right.

Table 4.4 Daily Results for Tuesday Morning

En'Urga and PSI provided data for the Tuesday morning data collection period. In addition to the calibration site, which was known by all equipment providers, a total of six actual leak sites were found.

Leak Site	Nominal Leak Rate (scfh)	Leaks Found: En'Urga	Leaks Found: PSI	% Found	# Found
1	1,000	yes	yes	note A	note A
2D	15	no	no	0	0
3	2,000	no	yes	50	1
4	500	no	yes	50	1
5	5,000	no	yes	50	1
6	100	no	yes	50	1
P1	1,000	no	yes	50	1
P2	100	no	no	0	0
P3	10	no	no	0	0
P4	500	no	yes	50	1
P5	1	no	no	0	0

NOTES:
A - Leak Site 1 location and leak rate information was given to all equipment providers.
B - LLNL reported that they did not fly the Twin Otter. The UAV was flown, but data were not available to place in the report.
C - ITT flew both in the morning and afternoon, but only presented combined results for each day. The ITT data are presented with the afternoon data.
D - En'Urga reported that they looked only to the right.
E - LaSen reported that they flew, but data were not presented due to a malfunction in the GPS unit.

Table 4.5 Daily Results for Tuesday Afternoon

En'Urga, ITT, LaSen, and PSI provided data for the Tuesday afternoon data collection period. In addition to the calibration site, which was known by all equipment providers, a total of 11 actual leak sites were found.

Leak Site	Nominal Leak Rate (scfh)	Leaks Found: En'Urga	Leaks Found: ITT	Leaks Found: LaSen	Leaks Found: PSI	% Found	# Found
1	1,000	no	yes	yes	yes	note A	note A
2D	15	no	no	no	no	0	0
3	2,000	no	yes	no	yes	50	2
4	500	no	no	yes	yes	50	2
5	5,000	yes	yes	yes	yes	100	4
6	100	no	yes	no	no	25	1
P1	1,000	no	no	no	yes	25	1
P2	100	no	no	no	no	0	0
P3	10	no	no	no	no	0	0
P4	500	no	no	no	yes	25	1
P5	1	no	no	no	no	0	0

NOTES:
A - Leak Site 1 location and leak rate information was given to all equipment providers.
B - LLNL reported that they did not fly the UAV or Twin Otter.
C - En'Urga reported that they looked only to the left, but reported two leak sites that were to the right.

Table 4.6 Daily Results for Wednesday Morning

En'Urga, LaSen, LLNL (Twin Otter), and PSI provided data for the Wednesday morning data collection period. In addition to the calibration site, which was known by all equipment providers, a total of 12 actual leak sites were found.

		Leaks Found					
Leak Site	Nominal Leak Rate (scfh)	En'Urga	LaSen	LLNL Twin Otter	PSI	% Found	# Found
1	500	yes	yes	note C	yes	note A	note A
2C	15	yes	no	note C	no	33	1
3	100	no	no	note C	yes	33	1
4	2,000	no	yes	note C	yes	67	2
5	5,000	no	yes	note C	yes	67	2
6	1,000	no	yes	note C	yes	67	2
P1	1,000	no	yes	no	yes	50	2
P2	100	no	no	no	no	0	0
P3	10	no	no	no	no	0	0
P4	500	no	yes	no	yes	50	2
P5	1	no	no	no	no	0	0
1F	15	no	no	note C	no	0	0

NOTES:
A - Leak Site 1 location and leak rate information was given to all equipment providers.
B - En'Urga reported that they looked only to the right.
C - LLNL only expected to find leaks at Leak Sites P1 through P5. LLNL reported that there was a "large leak" very close to Leak Site P5. This was not considered a "find" since the actual leak rate was very small and no other leaks were found.
D - ITT flew both in the morning and afternoon, but only presented combined results for each day. The ITT data are presented with the afternoon data.

Table 4.7 Daily Results for Wednesday Afternoon

ITT, LaSen, and PSI provided data for the Wednesday afternoon data collection period. In addition to the calibration site, which was known by all equipment providers, a total of 15 actual leak sites were found.

		Leaks Found				
Leak Site	Nominal Leak Rate (scfh)	ITT	LaSen	PSI	% Found	# Found
1	500	no	yes	yes	note A	note A
2C	15	no	no	no	0	0
3	0/100*	no	N/A	N/A	0	0
4	2,000	yes	yes	yes	100	3
5	5,000	yes	yes	yes	100	3
6	1,000	no	yes	yes	67	2
P1	1,000	no	yes	yes	67	2
P2	100	no	no	yes	33	1
P3	10	no	no	yes	33	1
P4	500	yes	yes	yes	100	3
P5	1	no	no	no	0	0
1F	15	no	no	no	0	0

NOTES:
* - Leak Site 3 was unintentionally turned off during evening runs but on for ITT's morning flight.
A - Leak Site 1 location and leak rate information was given to all equipment providers.
B - LLNL reported that they did not fly the UAV or Twin Otter.
C - En'Urga reported that they did not drive.

Table 4.8 Daily Results for Thursday Morning

LaSen and PSI provided data for the Thursday morning data collection period. In addition to the calibration site, which was known by all equipment providers, a total of nine actual leak sites were found.

		Leaks Found			
Leak Site	Nominal Leak Rate (scfh)	LaSen	PSI	% Found	# Found
1	100	yes	yes	note A	note A
2E	15	no	yes	50	1
3	2,000	yes	yes	100	2
4	1,000	yes	no	50	1
5	0	N/A	N/A	N/A	N/A
6	500	yes	yes	100	2
P1	1,000	no	yes	50	1
P2	100	no	no	0	0
P3	10	no	no	0	0
P4	500	yes	yes	100	2
P5	1	no	no	0	0

NOTES:
A - Leak Site 1 location and leak rate information was given to all equipment providers.
B - LLNL reported that they did not fly the UAV or Twin Otter.
C - En'Urga reported that they did not drive.
D - ITT flew both in the morning and afternoon, but only presented combined results for each day. The ITT data are presented with the afternoon data.

Table 4.9 Daily Results for Thursday Afternoon

LaSen and PSI provided data for the Thursday afternoon data collection period. In addition to the calibration site, which was known by all equipment providers, a total of 16 actual leak sites were found.

		Leaks Found				
Leak Site	Nominal Leak Rate (scfh)	ITT	LaSen	PSI	% Found	# Found
1	100	yes	yes	yes	note A	note A
2E	15	no	no	no	0	0
3	2,000	yes	yes	yes	100	3
4	1,000	yes	yes	yes	100	3
5	0	N/A	N/A	N/A	N/A	N/A
6	500	no	yes	yes	67	2
P1	1,000	yes	yes	yes	100	3
P2	100	no	no	yes	33	1
P3	10	no	no	yes	0	0
P4	500	yes	yes	yes	100	3
P5	1	no	no	no	0	0

NOTES:
A - Leak Site 1 location and leak rate information was given to all equipment providers.
B - LLNL reported that they did not fly the UAV or Twin Otter.
C - En'Urga reported that they did not drive Thursday evening.

Table 4.10 Daily Results for Friday Morning

Only LaSen provided data for the Friday morning data collection period. In addition to the calibration site, which was known by all equipment providers, a total of five actual leak sites were found.

		Leaks Found			
Leak Site	Nominal Leak Rate (scfh)	LaSen	PSI	% Found	# Found
1	15	yes	yes	note A	note A
2A	15	no	note E	0	0
3	500	no	note E	0	0
4	2,000	yes	note E	100	1
5	5,000	yes	note E	100	1
6	1,000	yes	note E	100	1
P1	1,000	yes	note E	100	1
P2	100	no	note E	0	0
P3	10	no	note E	0	0
P4	500	yes	note E	100	1
P5	1	no	note E	0	0
1F	15	no	note E	0	0

NOTES:
A - Leak Site 1 location and leak rate information was given to all equipment providers.
B - LLNL reported that they did not fly the UAV or Twin Otter.
C - En'Urga reported that they did not drive.
D - ITT flew both in the morning and afternoon, but only presented combined results for each day. The ITT data are presented with the afternoon data.
E - PSI reported that they only looked at the calibration site and did not drive Friday morning.

Table 4.11 Daily Results for Friday Afternoon

ITT and LaSen provided data for the Friday afternoon data collection period. In addition to the calibration site, which was known by all equipment providers, a total of eight actual leak sites were found.

		Leaks Found			
Leak Site	Nominal Leak Rate (scfh)	ITT	LaSen	% Found	# Found
1	5,000	yes	yes	note A	note A
2A	15	no	no	0	0
3	500	yes	yes	100	2
4	2,000	no	no	0	0
5	5,000	yes	yes	100	2
6	1,000	yes	yes	100	2
P1	1,000	no	yes	50	1
P2	100	no	no	0	0
P3	10	no	no	0	0
P4	500	no	yes	50	1
P5	1	no	no	0	0
1F	15	no	no	0	0

NOTES:
A - Leak Site 1 location and leak rate information was given to all equipment providers.
B - LLNL reported that they did not fly the UAV or Twin Otter.
C - En'Urga reported that they did not drive.
D - PSI reported that they did not drive.

If coordinates of an actual leak site were reported, but the leak site was turned off, this was also considered a false positive. The false positive leaks reported by the equipment providers are summarized in Table 4.12.

In two cases, FID measurements at reported leak sites resulted in positive gas measurements. In these cases, the leak rate was unknown. These actual leaks that were not part of the intended leak sites were identified as "unintentional leaks." These leaks were discussed in the previous section and are not summarized here.

Table 4.12 "False Positive" Leaks Reported by Equipment Providers

Out of the 209 leak sites reported by the equipment providers during the entire week of testing, 110 of the reported leak sites were false positives.

Test Day		En'Urga		ITT		LaSen		LLNL Twin Otter		PSI	
		Total Reported Leaks	Number False Positives	Total Reported Leaks	Number False Positives	Total Reported Leaks	Number False Positives	Total Reported Leaks	Number False Positives	Total Reported Leaks	Number False Positives
Monday	Morning	2	2	No data	No data	No data	No data	No data	No data	6	1
	Afternoon	2	2	No data	No data	No data	No data	No data	No data	5	0
Tuesday	Morning	3	3	Note D	Note D	No data	No data	No data	No data	7	1
	Afternoon	2	1	20	17	4	1	No data	No data	6	0
Wednesday	Morning	3	2	Note D	Note D	9	3	4	4	7	0
	Afternoon	No data	No data	32	29	9	3	No data	No data	9	2
Thursday	Morning	No data	No data	Note D	Note D	6	2	No data	No data	8	2
	Afternoon	No data	No data	26	22	5	0	No data	No data	8	0
Friday	Morning	No data	No data	Note D	Note D	6	1	No data	No data	No data	No data
	Afternoon	No data	No data	14	11	6	1	No data	No data	No data	No data
	Totals	12	10	92	79	45	11	4	4	56	6

NOTES:
A - "Total Reported Leaks" was the total number of leak sites reported, not including the calibration leak.
B - "Number False Positives" was the total number of sites identified as leaks where no gas was present.
C - "No data" indicates that data were not provided by equipment provider.
D - ITT flew both in the morning and afternoon, but only presented combined results for each day. The ITT data are presented with the afternoon data.
E - LLNL did not provide data from the UAV.

The information presented in Table 4.2 through Table 4.11 have been summarized to determine the overall ability of the technologies included in this project to "find" leaks at the various leak rates in the test program. Obviously, wind conditions had an impact on the ability to sense leaks of various sizes. However, this comparison only looked at how many equipment providers were able to find leaks of various sizes throughout the week, regardless of time of day, wind conditions, etc. The results of this analysis are shown in Table 4.13, Figure 4.1, and Figure 4.2.

The number of leaks "presented" for each leak rate was calculated based on how many times that leak rate could have been detected by the equipment providers. If an equipment provider did not collect data, this was not counted in the number of leaks presented. If an equipment provider only presented summarized leak information for each day, this was only counted as one leak being presented.

The number of leaks "found" for each leak rate was extracted from the previous tables. Since each of the equipment providers was notified of the calibration leak site location and leak rate before each day, this information was not included as a "find" in Table 4.13, Figure 4.1, or Figure 4.2. However, it is important to note that not every equipment provider was able to find the calibration leak site each day, even when the leak rate was relatively high.

Figure 4.1 and Figure 4.2 show that there was a major difference in the ability of current equipment to be able to detect leak rates of 100 scfh or less and leaks rates of 500 scfh or higher. Leak rates of 500 scfh or higher were detected at least 50% of the time. Note that there were only four presentations of the 2,500-scfh leak rate, and this was on the first testing day. Also note that the 5,000-scfh leak rate, which was a very large leak, was only detected 87% of the time.

Table 4.13 Leak Determination by Leak Rate

Leak Rate	No. of Leaks Presented	No. of Leaks Found	Leak Find %	No. of Calibration Leaks	No. of Calibration Leaks Found	Calibration Leak Find %
5,000	15	13	87	6	6	100
2,500	4	2	50	0	0	N/A
2,000	20	14	70	0	0	N/A
1,000	43	27	63	6	5	83
500	43	27	63	6	5	83
100	39	5	13	5	5	100
15	33	2	6	3	2	67
10	25	2	8	0	0	N/A
1	25	0	0	0	0	N/A

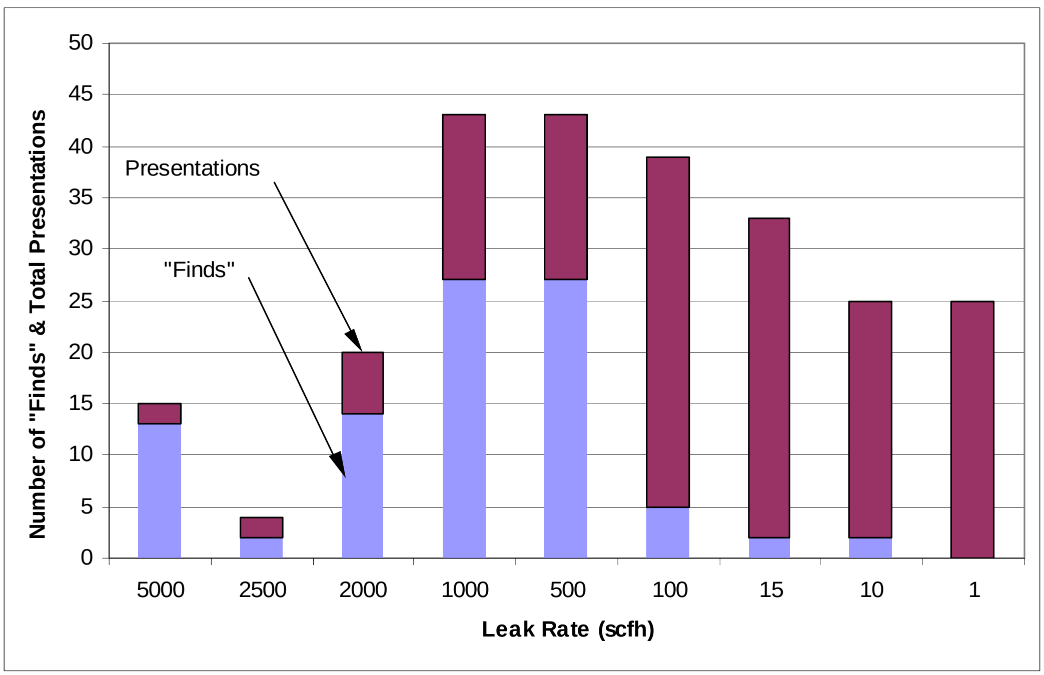


Figure 4.1 Instrumentation Sensitivity to Leak Rates – Bar Chart

There was a major difference in overall performance of the leak detection equipment to detect leaks between 100 scfh and 500 scfh.

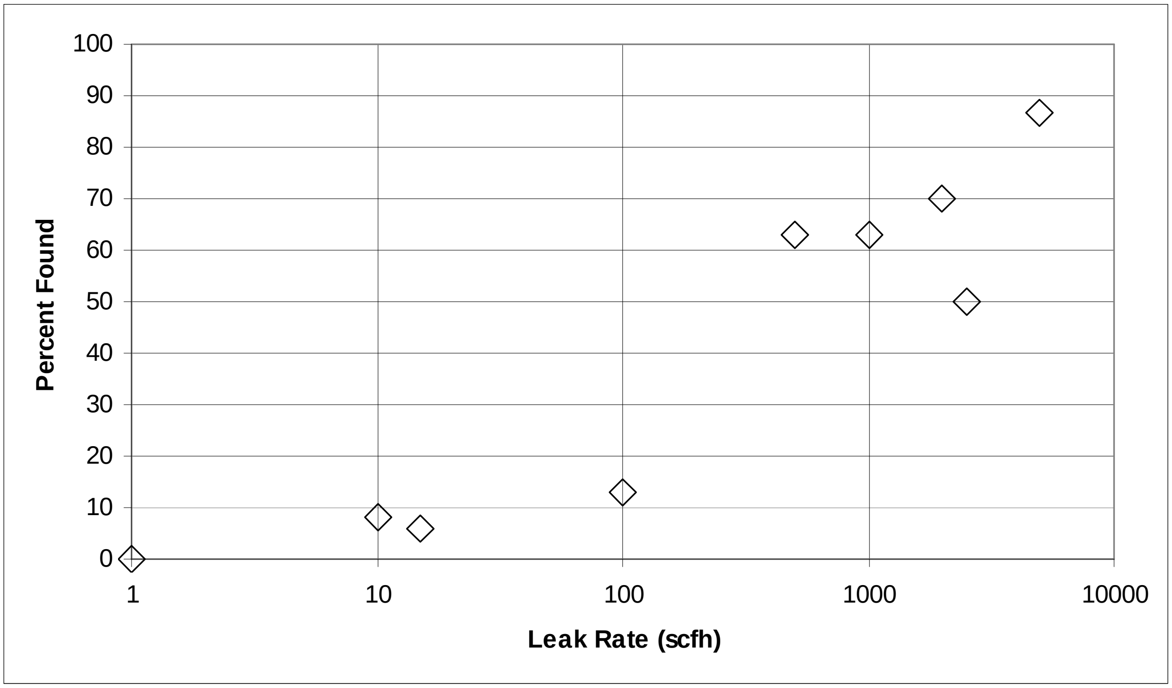


Figure 4.2 Instrumentation Sensitivity to Leak Rates – Percent Found
On a cumulative basis, leak sites where leak rates were 500 scfh or more were generally found 50% to 87% of the time. In comparison, leak sites where leak rates were 100 scfh or less were generally found less than 15% of the time.

In comparison, sites where a 100-scfh leak rate existed were only detected 13% of the time. Similarly, sites where 10-scfh or 15-scfh leak rates existed were only detected about 5% of the time (a total of three "finds" out of 58 possible detections). In addition, the 1-scfh leak rate site was never detected during the entire test.

During the testing week, a total of 247 leaks were "presented" to the combination of all of the equipment providers. (That is, if every equipment provider found each leak that they drove or flew past, they would have reported a total of 247 leaks.) After applying the rules (mentioned earlier in this section) for interpreting distinct leak reporting, the equipment providers reported finding a total of 209 leaks during the week, of which 92 were actual leak sites, 110 were false positives, and seven were unintentional leak sites. The majority of the leaks found were those that were leaking at a rate of 500 scfh or greater. The leaks that were set at 100 scfh or less were rarely detected.

While reviewing the detailed data in the reports from the equipment providers, the following important points should be noted.

- The reports were completed by the equipment providers prior to SwRI divulging the actual leak sites and leak rates. That is, they include "blind" test results. Any claims of leaks detected should be considered preliminary, and the review of the results is provided earlier in this section. The claims and comments of the equipment providers do not reflect the opinions of the Department of Energy.

- The only true “blind” test day was the first that was flown or driven by each equipment provider. Due to the limited number of leak sites in the test plan, gas was flowing from most of the leak sites each day. When a leak rate at a specific leak site was set high on one of the first testing days, that leak site, no matter what the leak rate later in the week, was found almost all of the rest of the days of testing. There was evidence, especially later in the week, that the equipment providers targeted leak sites that had been found in previous days but were turned off that day. This was especially true in situations where data collection methods did not support high-resolution of GPS coordinates, yet numbers repeat within ±0.1 GPS seconds. In some cases, what would normally be considered “signal noise” early in the week might have been interpreted as an actual leak later in the week at these “proven” leak sites.

- Each day of the test, equipment providers were asked to provide sites that they believed were natural gas pipeline leaks. These sites were matched up with the intended leaks for that day. “Positive” indications received from the equipment providers that did not correspond with leak sites were investigated during the test week. Most of these sites did not contain gas (as verified by FID), but were old water pipes sticking out of the ground, fence posts, abandoned well sites, patches of dirt, etc.

- There was evidence during the data collection periods that some of the equipment providers may have been using ground-based visual clues to look for leaks, as opposed to conducting a “blind” search for possible leak sites. This may account for some of the false positives reported by the equipment providers.

- Further evidence of the equipment providers using visual clues to detect leak sites was that leaks were reported at the decoy sites. The only unintentional leaks detected during the entire testing effort were at decoy sites where the decoy piping was obvious. Higher local gas concentrations were measured by SwRI at actual leak sites that were not in obvious locations.

- During the planning stages of the testing program, several equipment providers indicated that their systems would be capable of detecting ethane (as well as methane). This was important because it could have allowed for detection of methane-only false positives. However, none of the equipment providers had this capability during the testing program.

DOE NETL supported the development of a web site specifically for this project. As of the writing of this report, the web site can be accessed at:

http://www.netl.doe.gov/scngo/Natural%20Gas/TD&S/T&D/RMOTC/index.html

This web site includes project background information, sites maps, and links to web sites for DOE NETL, DOE RMOTC, SwRI, and the equipment providers. It also includes several videos that were developed during the testing week, showing some of the technology in operation.

5. SUMMARY

The primary objective of this project was to provide a forum where developers of remote sensor, natural gas leak detection systems would be able to test or demonstrate the operation of their systems. In order to accomplish this objective:

- An advisory panel was developed to guide the development of the test “facility” and the test conditions. This panel included advisors from private companies, gas-oriented industry groups, DOE NETL, DOE RMOTC, equipment providers, and SwRI.

- A comprehensive list of variables to be considered for the testing was identified and ranked according to importance. Based on this information, a general guide for the test plan conditions was developed to guide the detailed development of the virtual pipeline, leak sites, and data collection time periods.

- The RMOTC field site was chosen as the field demonstration site for this project. The major factors that led to this choice were the layout of the RMOTC field site that allowed for a reasonable pipeline route, the availability of natural gas, the availability of the resources to properly prepare the virtual pipeline, and the support to obtain the required permissions to conduct this test.

- The “virtual pipeline” route was defined, including leak sites, markers, and road crossings. The pipeline route generally followed available roads and included a number of bends, some of which were more frequent than on a typical pipeline. The leak sites were placed in a variety of locations, in order to offer various challenges to the detection capabilities and the equipment being tested.

- Specific leak details were developed for the 15 different leak sites, including three different types of leak release point options. Some of the leak sites were designed to release gas at the roots of plants in order to provide the required test conditions for one of the detection systems. The leak rates ranged from 1 sfch to 5,000 scfh and the test plan included the entire range of leak rates on most days.

- The field site was prepared and leak site equipment was installed to provide natural gas to the leak site areas. Where appropriate, leak equipment was hidden from plain view when traveling along the road. In addition, decoy piping was installed at sites that were not intended as true leak sites.

- The testing was conducted during the week of September 13, 2004 for a period of five days. The test matrix allowed for about 11 leak sites each day, covering the range of available leak rates. The data collection periods for the various equipment providers generally included either one or two data collection periods per day. Although all of the time slots were available for data collection, some of the equipment providers were not able to collect or provide data for each of scheduled time slots. This was sometimes due to equipment malfunctions and sometimes due to a conscious decision not to collect data.

Equipment providers documented their test results in reports that are included in this report. After the reports were received, the test conditions (leak sites, leak rates, etc.) were provided to the equipment providers. The equipment providers were then allowed to review the data and provide final comments on their results, which are also included in this report.

Many of the leak sites were found. Leak rates of 500 scfh or higher were detected at least 50% of the time. Leak rates of 100 scfh were only detected 15% of the time. Leak rates of 15 scfh and 10 scfh were only detected about 5% of the time. The 1-scfh leak was never detected. There were a large number of "false positive" leak sites identified by the equipment providers.

Some of the equipment providers made system improvements during the week including repairing malfunctioning equipment, mechanical modifications to improve performance in field applications, and developing improved data handling schemes. Other modifications have been defined for future work by some of the equipment providers.

Improvements to future testing efforts might include:

- Developing separate data collection areas for distribution-based and transmission-based piping systems. The distribution pipeline might be designed so that it mimics a typical distribution system. This system might be shorter, have leaks very close to the side of the road, and have frequent turns. The transmission piping might be designed so that it is longer and straighter. This system also might be designed so that the right-of-way more closely resembles that of a typical pipeline.

- Adding more leak sites, with more options for leak sites to be off each day. This would minimize the concerns about equipment providers using results from previous test days to target their search for leaks.

- Adding more leak sites that are revealed to the equipment providers during the testing. This would help in the development or "calibration" of the various systems and allow equipment providers to refine the identification of signatures of various leaks.

- Choosing a different time of year for the test (e.g., spring time). This would particularly benefit the system that was looking for the impact of a natural gas leak on the vegetation.

- More active involvement and input from industry advisors. Valuable input was received from industry advisors on this project. However, the project would have benefited from involvement from a broader audience at the meetings and field test.

APPENDIX A

Test Parameters

Section 1 - Test Parameter Voting
Section 2 - Voting Results

Section 1

Test Parameter Voting

Voting Ballot for Test Parameter Importance
(Only Items with Red Dashes in Margin Can Receive Votes)

VOTE

LEAK CHARACTERISTICS

- **Point sources vs. linear sources (pinhole vs. long crack)**
- **Duration of leak for saturation**
- **Underground & above-ground leak sources**
  - leak migration underground
- **Leak rate**
  - presence of some (or at least one) very large leak
  - various sizes of leaks
- **Range of leak site topography**
- **Observed leak**

SAMPLE DESIGN

- Blind test
- Camouflage sources
- Trick leak
- Multiple passes to determine trends
- Repeated leak patterns
- Ability to conduct multiple passes in same day
- Statistically significant number of samples

METEOROLOGICAL / ENVIRONMENTAL TEST CONDITIONS

- **Set boundary conditions for test (environmental condition)**
  - humidity
  - no dusty conditions
  - weather conditions – no rain, no fog
  - wind speed
- **Illumination (time of day, sunlight)**
  - measure solar radiation at test site
  - sunlight
  - time of day
  - solar noon +/- 1 hour (specific need of Pickles)
  - light levels
- **Atmospheric turbulence**
  - ambient air quality measurements
  - stable atmosphere
- **Measure wind data**
  - independent weather conditions recording (temperature, pressure)
  - meteorological monitoring along the “pipeline route”
  - weather station (wind speed recording)
  - monitor meteorology before, during, and often tests
  - upper air data for wind speeds

PIPELINE PHYSICAL CHARACTERISTICS

- Side hill leak
- Underground leaks
- "Hiding" of leaks from all parties
- Standard gas pipeline markers
- Underwater pipeline
- Right-of-Way characteristics
- Length of pipeline
- Above water "suspension" pipeline
- Tortuosity (wigglyness) of pipe
- Real pipeline
- Topography
- Visibility of the pipe line
- Pipe above and below ground

TERRAIN VARIABILITY

- Uniformity of terrain
- Flight altitude < 10,000 MSL …..

SOIL AND VEGETATION

- **Soil**
  - soil moisture
  - soil permeability
  - sandy non-vegetated leak of long duration greater than one week looking for microbiological activity
- **Vegetation**
  - ground cover
  - disturbed soil minimized
  - vegetation cover intact above leak point
  - vegetation height and density

AIRBORNE PLATFORM OPERATIONAL ISSUES

- Proximity to an airport (general aviation support)
- Air space controls
- "Good" flying conditions for small aircraft
- Vehicle access with small impact
- Line of site test area section from an unmanned autonomous vehicle (aircraft)
- Aircraft control responsibility must be worked early – RMOTC and Casper controller have to work together

TEST SITE SELECTION

PIPELINE LOCATION MAPPING

- All GPS locations in a standard datum
- Hard-to-see pipes

- Ground control points
- Geolocation of pipeline
- Total station survey of sample sites

CALIBRATION TARGETS

- Quick (during tests) feedback on test results allow multiple tests
- Calibration test leak (known leak rate and location)
- Tuning day (to adjust equipment for field elevation, etc.)
- At least one two-week saturated, known, steady leak
- Calibration leak that is easily found by all
- Determine “ground truth” in ppm
- Include test and control areas

ETHANE AND FALSE POSITIVES

- Gas composition with ethane presence
- Presence or absence of fugitive or “unplanned” sources
- False alarms (positives)
- Presence of some other petrochemical
- Concentration level of ethane in natural gas (variable amount?)

PIPELINE INSPECTION RATE

SCHEDULING OF TESTS / DAY (TIME SLOTS)

- Time of day
- Pre-test setups
- Scheduling of leaks for different providers

PERIODIC MEETINGS DURING TESTING

- Meeting before and after each trial period
- Morning and evening meetings every day

DATA PROCESSING TIME BETWEEN RUNS

- Post-test reporting schedule
- Test and then potential retest

Section 2

Voting Results

TEST PARAMETER VOTING RESULTS – PRIORITIZED

ITEM TO BE RANKED	INDIVIDUAL RANKINGS												TOTAL	FINAL RANK
	A	B	C	D	E	F	G	H	I	J	K	L		
Leak Rate	1	2	3	1	2	3	3		3	2		3	23	**1**
Sample Design	3	3	3	3		3	2		1	1			19	**2**
Pipeline Physical Characteristics	1	1	3	1	1			3	1	1	3	3	18	**3**
Ethane and False Positives	1		3		1		3			3	3	3	17	**4**
Underground & Above-Ground Leak Sources	1		2	3		1		3	2	1		3	16	**5**
Calibration Targets		3		1	3		2		2	2		3	16	**6**
Pipeline Location Mapping	1	2		1	2		2		2	2	1	2	15	**7**
Duration of Leak for Saturation	1		2	3				3				3	12	**8**
Set Boundary Conditions (Environmental Conditions)	2	1	3		2	1	2			1			12	**9**
Observed Leak	1	3	1	1		2			1	2			11	**10**
Scheduling of Test/Day (Time Slots)	1	3				1	2	1	2				10	**11**
Illumination (Time of Day, Sunlight)				2		2		3	2				9	**12**
Vegetation	1			1	1			3	1		1		8	**13**
Airborne Platform Operational Issues	1	2			1					1	3		8	**14**
Measure Wind Data	1				1		2			1	2		7	**15**
Test Site Selection	1					2		3		1			7	**16**
Terrain Variability					2	2			1	1			6	**17**
Point Sources vs. Linear Sources				2							3		5	**18**
Pipeline Inspection Rate					2				1	1	1		5	**19**
Periodic Meetings During Testing	1				1		2	1					5	**20**
Range of Leak Site Topography				1		3							4	**21**
Soil	1								1		1		3	**22**
Atmospheric Turbulence	1										1		2	**23**
Data Processing Time Between Runs					1						1		2	**24**

APPENDIX B

Initial Test Plan Conditions – July 2004

Initial Test Plan Conditions – July 2004
(Based on Voting Results and Discussions with Industry Advisors and Equipment Providers)

General Test Plan

- Testing to be conducted at RMOTC site during September 13 to September 17. Trial runs will be made on September 12.
- Transport methods for systems to be tested include both vehicles and airplanes.
- DOE NETL, DOT OPS, industry advisors, equipment providers, and SwRI personnel will be on site during testing.
- Simulated pipeline leaks (both underground and aboveground) will be initiated along the main north-south roads through the RMOTC facility.

Test Plan Conditions

Pipeline Location Mapping

- The path of the simulated pipeline is shown on the attached map of the RMOTC facility.
- GPS coordinates of the simulated pipeline will be provided to all equipment providers.
- We may also need to provide the altitude at each leak site.

Leak Rates

- The eventual leak rates at the various leak sites will be based on the results of gas plume modeling being conducted by staff from DOE NETL. The leaks rates currently under consideration range from 1 scfh to 1,000 scfh.
- Leak rates are meant to represent a range of conditions of interest to the industry advisors, some of which may be below the detection limit of some or all of the devices.
- A range of leak rates will be provided during each testing day.

Leak Sources

- Leak sources will include bottled gas and RMOTC gas. The RMOTC gas may be before or after the gas is processed (where some propane, and some of the heavier components, are removed) at the gas plant.
- Number – about 8 to 11 leak sites, with random leak rates (including “off”) for each day.
- General location – the leak sites will generally follow RMOTC roads.
- Specific location – the leak sites will include a mix of aboveground and underground leaks (the leaks will be in open areas, not hidden by buildings, under trees, or underwater). The types of leak sources are described below.
    - Aboveground leaks – The tubing connected to the flow control devices will be laid on the ground and end in an upward-facing elbow.
    - Underground leaks – In order to control the soil permeability variable at the leak sites, small holes (e.g., the diameter of a post hole digger) will be dug to about 2-feet deep and backfilled with gravel, sand, or dirt (details yet to be determined).
    - “Drilled” underground leaks – In order to specifically accommodate evaluating devices that detect vegetation stress, the tubing will be installed in a horizontally

"drilled" hole that is about 30 feet to the side (so that the vegetation near the leak site will not be disturbed.) After the tubing is installed in the drilled hole, a "patch" will need to be used so that the gas will not escape from the hole where the tubing is inserted.

Gas Composition

- For the larger leaks, the gas in the RMOTC gas plant piping would be identified by gas chromatograph. Samples of recent gas analyses have been forwarded to the equipment providers. In general, this gas contains about 87% methane and 5.5% ethane.
- For bottled gas leaks, a mixture of about 95% methane and 5% ethane will be used to somewhat mimic the gas plant gas composition.

Calibration Targets

- A "calibration leak" will be provided each day. The leak site will be one of the sites identified above.
- Each of the equipment providers will be told the leak rate and exact location (GPS coordinates) of this leak site.
- The leak rate may be changed each testing day, but will remain constant throughout the day.

Duration of Leaks

- Leaks will be initiated at each site either early each morning or at the end of the day before the testing for that leak rate. (We are trying to determine the "saturation" time required for the different leak rates. This will finalize the plans for when the leaks are initiated.)
- Leak rates at a given leak site will remain constant throughout the test day (i.e., about 14 hours).

Time Slots

- Within their allotted time slots, each equipment provider will be allowed to make multiple passes (for the same leak conditions) each day. The equipment providers will be required to provide all data (i.e., for each pass taken) in their reports to SwRI.
- The testing schedule is shown in the attached matrix. Morning and evening time slots are allocated for all but one of the equipment providers on each day. The remaining equipment provider requested one time slot near solar noon each day. The timing of these slots may be dictated by the wind speed during the testing period.
- The time slots for the ground-based systems will be handled so that they don't interfere with each other. The time slots for these two equipment providers have been staggered so that they will both start at the south end of the "pipeline" and not pass each other along the way. In some cases, the start times are staggered so that the two equipment providers won't be collecting data during the same time period, similar to the data collection for the air-based technologies.
- The limits on the morning and evening time slots were determined by daily light conditions that would accommodate flying during "light" times. That is, night flying is not required to fly the earliest or latest flight times.

Wind Speed and Direction

- Prevailing winds in September are from west-southwest, southwest, and south-southwest.
- Wind speeds are variable during September, generally ranging from 6 mph to 13 mph (2.2 m/s to 5.8 m/s).
- The minimum and maximum average wind speeds (averaged over 10-minute periods) recorded during September 2003 were 1 mph to 32 mph, with the peak occurring at 12:00 noon. The maximum individual wind speed reading during September 2003 was 47 mph.
- Wind speeds increase rapidly after 6:00 AM and decrease rapidly after 5:00 PM.
- Wind speeds at noon in September are typically about 13 mph.
- Arrangements will be made so that current wind information will be made available to each equipment provider just before their data collection time slots.

Measurement of “Ground Truth”

- During testing, the SwRI/RMOTC team will monitor concentrations at the leak sites several times per day. This may also include local wind speed measurements.
- The method and sampling details (such as detection height) are to be determined.

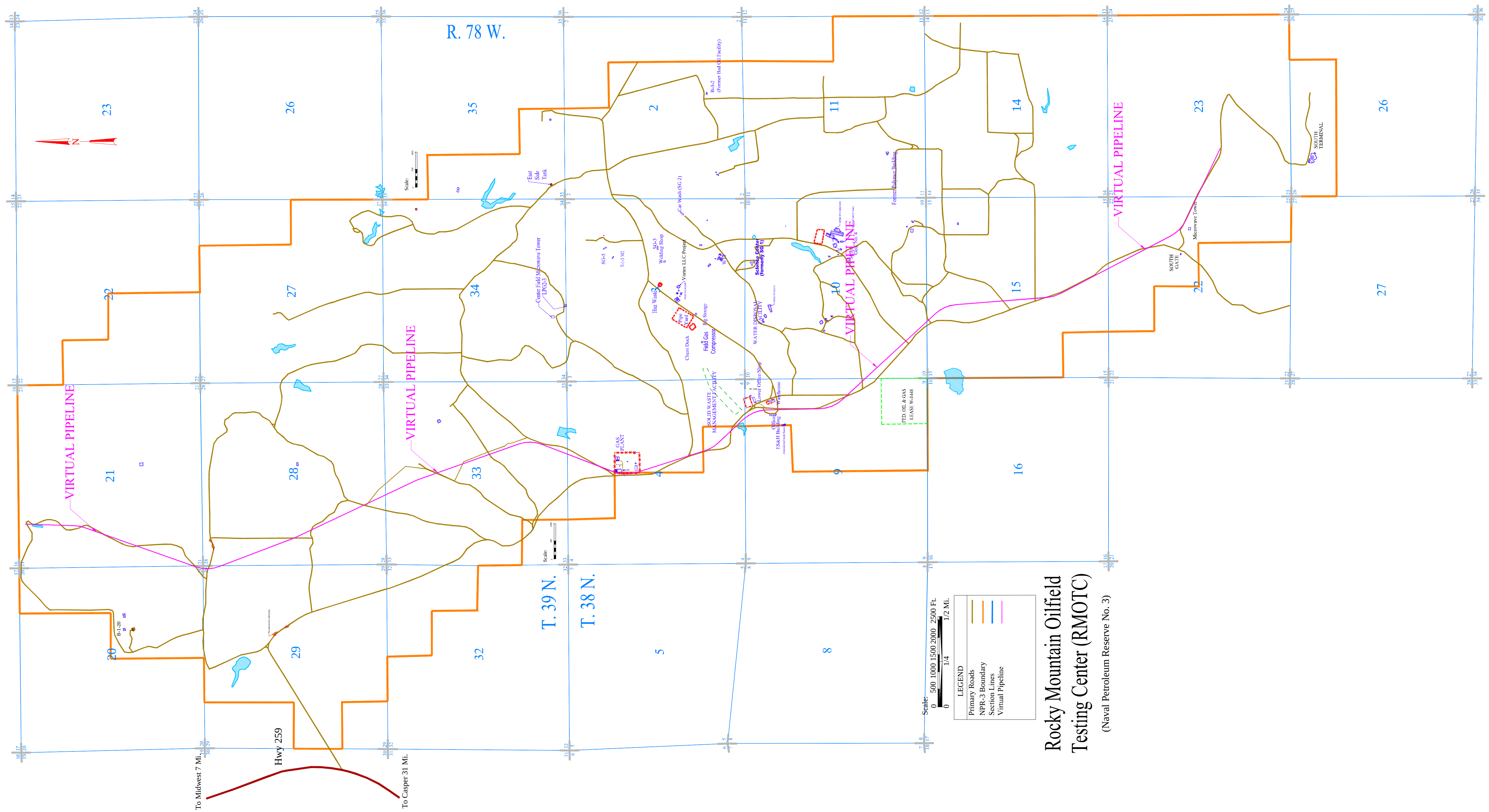
Measurements to be Recorded During the Testing

- Wind speed and direction (RMOTC weather station).
- Humidity (RMOTC weather station).
- Temperature (RMOTC weather station).
- Barometric pressure (add to RMOTC weather station?).
- Local wind speed at leak sites throughout the testing periods.
- In addition, Kodak expects to bring three additional weather stations that will be set up at three locations along the pipeline route (probably one each near the south end, center, and north end of the RMOTC facility). The data from each station will be downloaded each day (probably by SwRI) and provided to each equipment provider at a specific time each day.

Health, Safety, and Environment Issues

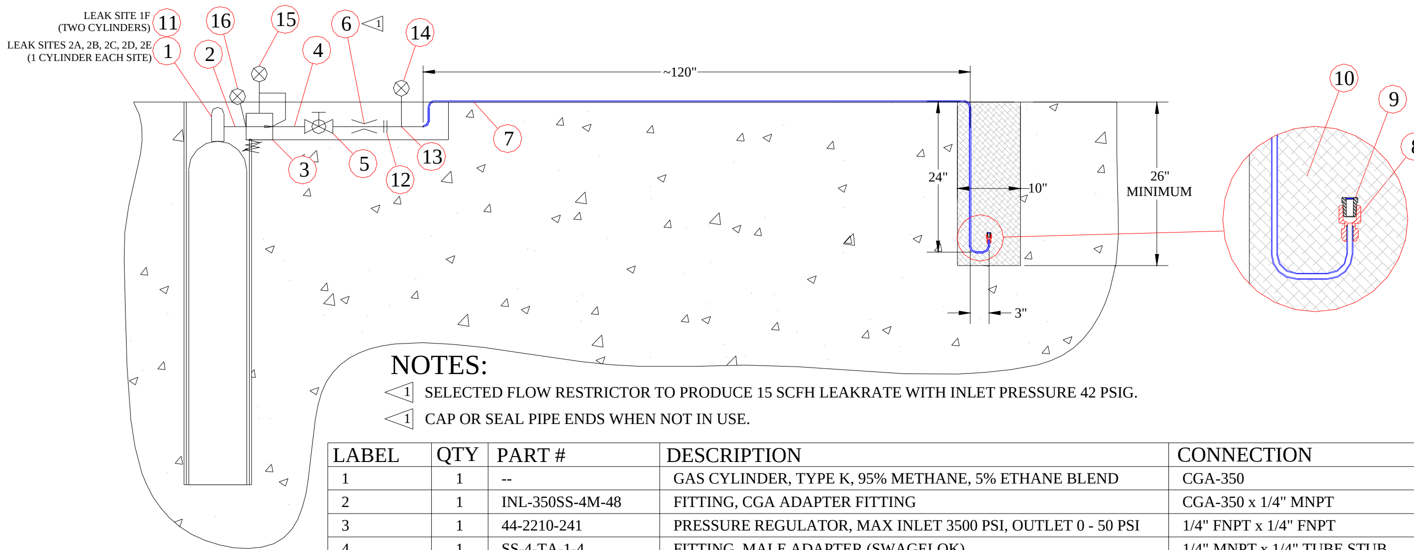
- Project, advisor, and equipment provider personnel working at the RMOTC site will be required to provide their own hard hats, safety glasses, and safety shoes.
- The project gas discharge scenario is being discussed with WYDEQ to receive approval. Initial indications are that the plans discussed above will be acceptable.

VIRTUAL PIPELINE MAP



APPENDIX C

Leak Site Details



NOTES:

1. SELECTED FLOW RESTRICTOR TO PRODUCE 15 SCFH LEAKRATE WITH INLET PRESSURE 42 PSIG.
1. CAP OR SEAL PIPE ENDS WHEN NOT IN USE.

LABEL	QTY	PART #	DESCRIPTION	CONNECTION
1	1	--	GAS CYLINDER, TYPE K, 95% METHANE, 5% ETHANE BLEND	CGA-350
2	1	INL-350SS-4M-48	FITTING, CGA ADAPTER FITTING	CGA-350 x 1/4" MNPT
3	1	44-2210-241	PRESSURE REGULATOR, MAX INLET 3500 PSI, OUTLET 0 - 50 PSI	1/4" FNPT x 1/4" FNPT
4	1	SS-4-TA-1-4	FITTING, MALE ADAPTER (SWAGELOK)	1/4" MNPT x 1/4" TUBE STUB
5	1	SS-43S4	VALVE, 1/4 TURN BALL	1/4" TUBE END x 1/4" TUBE END
6	1	IC-400R4-17-SS	FLOW RESTRICTOR, METAL ORIFICE ASSEMBLY, Ø0.017 ORIFICE	1/4" TUBE STUB x 1/4" TUBE END
7	1	SS-T4-S-035-20	STAINLESS TUBING, 1/4" OD x 0.035" WALL x 20' LENGTH	1/4" TUBE END
8	1	SS-400-7-6	FEMALE CONNECTOR	1/4" TUBE END x 3/8" FNPT
9	1	SS-MD-6	VENT PROTECTOR	3/8" MNPT
10	AR	--	1" WASHED GRAVEL, BACKFILL	--
11	1	--	GAS CYLINDER, TYPE K, 100% METHANE	CGA-350
12	1	SS-401-PC	PORT CONNECTOR, 1/4"	1/4" TUBE x 1/4" TUBE
13	1	SS-400-3-4TTF	FEMALE BRANCH TEE, 1/4" TUBE RUN, 1/4" FNPT BRANCH	1/4" TUBE x 1/4" TUBE x 1/4 FNPT BRANCH
14	1	20W-1005H02L-30	PRESSURE GAUGE, 0 - 30 PSI	1/4" MNPT
15	1	20W-1005H02L-60	PRESSURE GAUGE, 0 - 60 PSI	1/4" MNPT
16	1	20W-1005H02L-4000	PRESSURE GAUGE, 0 - 4000 PSI	1/4" MNPT

UNLESS OTHERWISE SPECIFIED:

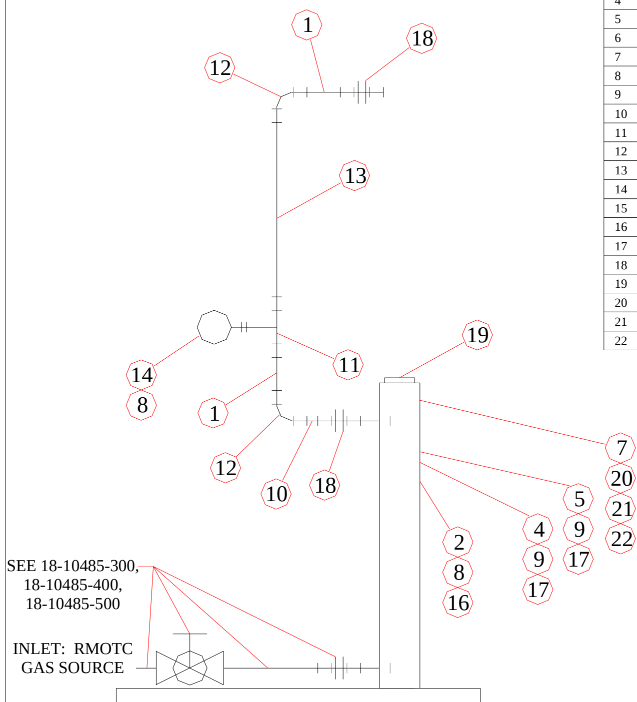
- ALL DIMENSIONS IN INCHES
- FINISH 125 √ OR STOCK FINISH ALL OVER
- ANGLES ±0.5°
  .XX DIMENSIONS ± .01
  .XXX DIMENSIONS ± .005
- REMOVE BURRS AND BREAK SHARP CORNERS

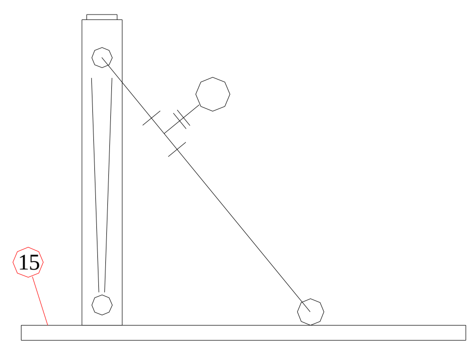
SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas USA

LEAK SOURCE, GAS CYLINDER, LEAK SITES 2A, 2B, 2C, 2D, 2E, 1F

ENGINEER:	APPROVAL:	SIZE	FSCM NO.	DWG NO.	REV
R.BURKEY		A		18-10485-100	—
DATE: 8/3/04		SCALE NONE	CONTRACT NO.	SHEET 1 OF 1	

LABEL	QTY	PART #	DESCRIPTION	CONNECTION
1	4	--	1" PIPE NIPPLE x 3" LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
2	1	RMB-51-BV	ROTAMETER, 2-20 SCFH AIR	1/4" FNPT x 1/4" FNPT
3	1	--	[REMOVED]	1/4" FNPT x 1/4" FNPT
4	1	RMC-103-BV	ROTAMETER, 20-200 SCFH AIR	1/2" FNPT x 1/2" FNPT
5	1	RMB-108-BV	ROTAMETER, 200-1800 SCFH AIR	1/2" FNPT x 1/2" FNPT
6	1	--	[REMOVED]	1" FNPT x 1" FNPT
7	1	VFC-123	ROTAMETER, 10-100 SCFM AIR	1" FNPT x 1" FNPT
8	3	--	HEX BUSHING, MALLEABLE IRON, BLACK PIPE, 1" x 1/4"	1" MNPT x 1/4" FNPT
9	4	--	HEX BUSHING, MALLEABLE IRON, BLACK PIPE, 1" x 1/2"	1" MNPT x 1/2" FNPT
10	1	--	1" CLOSE PIPE NIPPLE, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
11	1	--	1" TEE, MALLEABLE IRON, BLACK PIPE	1" FNPT x 1" FNPT x 1" FNPT
12	2	--	1" 90deg ELBOW, MALLEABLE IRON, BLACK PIPE	1" FNPT x 1" FNPT
13	1	--	1" PIPE NIPPLE x 10" LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
14	1	--	PRESSURE GAUGE, 0-30 PSI	1/4" MNPT
15	1	--	UNISTRUT BASE STRUCTURE	--
16	2	--	1/4" CLOSE PIPE NIPPLE, SCH 40, BLACK PIPE	1/4" MNPT x 1/4" MNPT
17	4	--	1/2" CLOSE PIPE NIPPLE, SCH 40, BLACK PIPE	1/2" MNPT x 1/2" MNPT
18	2	--	1" UNION, MALLEABLE IRON, BLACK PIPE	1" FNPT x 1" FNPT
19	1	--	BULL'S EYE LEVEL	--
20	1	--	1" PIPE NIPPLE x 6" LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
21	1	--	1" GLOBE VALVE, BRONZE	1" FNPT x 1" FNPT
22	2	--	1" CLOSE PIPE NIPPLE, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT





UNLESS OTHERWISE SPECIFIED:
- ALL DIMENSIONS IN INCHES
- FINISH 125 OR STOCK FINISH ALL OVER
- ANGLES ±0.5°
  .XX DIMENSIONS ± .01
  .XXX DIMENSIONS ± .005
- REMOVE BURRS AND BREAK SHARP CORNERS

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas USA

ROTAMETER ASSEMBLY
FOR LEAK SITES 1, 3, 4, 6, P1, P2, P3, P4

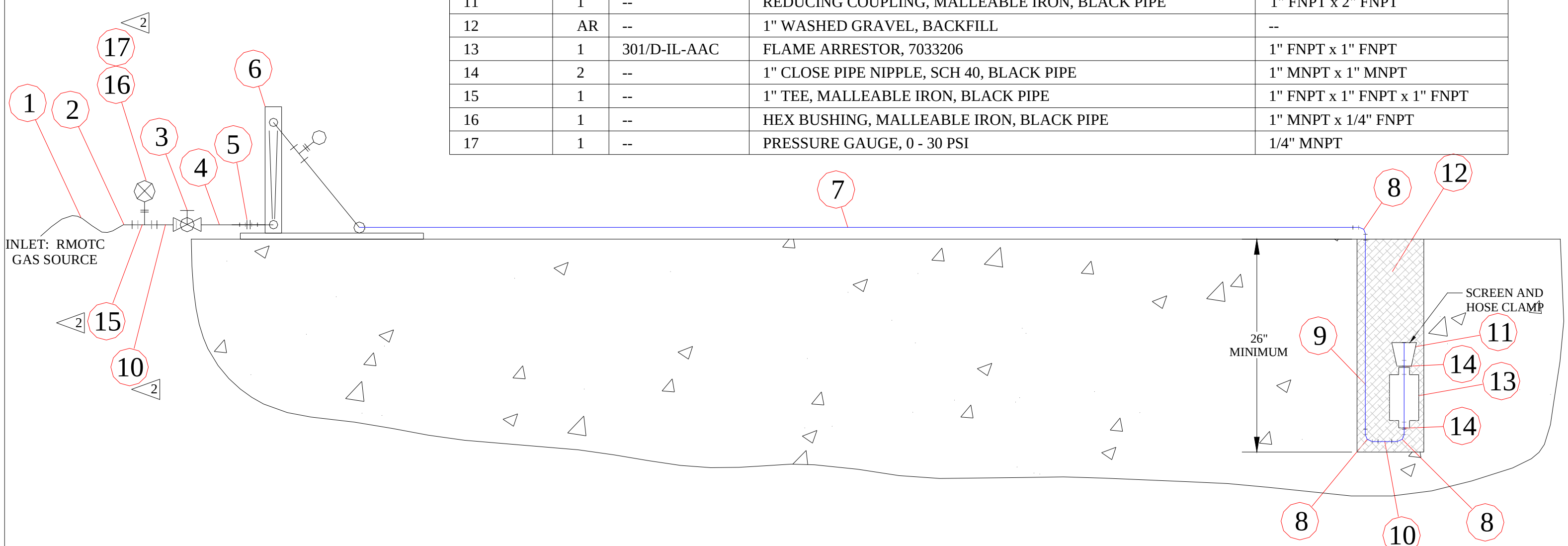
ENGINEER:	APPROVAL:	SIZE	FSCM NO.	DWG NO.	REV
R.BURKEY		A		18-10485-200	—

DATE:	SCALE	CONTRACT NO.	SHEET
8/3/04	NONE		1 OF 1

NOTES:

1. CAP OR SEAL PIPE ENDS WHEN NOT IN USE.
2. LEAK SITE 1 AND 4 ONLY

LABEL	QTY	PART #	DESCRIPTION	CONNECTION
1	1	--	1" SDR11 HDPE PIPE	BUTT FUSION
2	1	--	TRANSITION FITTING, HDPE x PIPE	BUTT FUSION x 1" MNPT
3	1	T-585-70	1" BALL VALVE (1/4 TURN), BRONZE, 600 PSI CWP	1" FNPT x 1" FNPT
4	1	--	1" PIPE NIPPLE x 6" LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
5	1	--	1" UNION, MALLEABLE IRON, BLACK PIPE	1" FNPT x 1" FNPT
6	1	18-10485-200	ROTAMETER ASSEMBLY	1" FNPT x 1" FNPT
7	1	--	1" PIPE x 10' LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
8	3	--	1" 90deg ELBOW, MALLEABLE IRON, BLACK PIPE	1" FNPT x 1" FNPT
9	1	--	1" PIPE NIPPLE x 24" LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
10	2	--	1" PIPE NIPPLE x 3" LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
11	1	--	REDUCING COUPLING, MALLEABLE IRON, BLACK PIPE	1" FNPT x 2" FNPT
12	AR	--	1" WASHED GRAVEL, BACKFILL	--
13	1	301/D-IL-AAC	FLAME ARRESTOR, 7033206	1" FNPT x 1" FNPT
14	2	--	1" CLOSE PIPE NIPPLE, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
15	1	--	1" TEE, MALLEABLE IRON, BLACK PIPE	1" FNPT x 1" FNPT x 1" FNPT
16	1	--	HEX BUSHING, MALLEABLE IRON, BLACK PIPE	1" MNPT x 1/4" FNPT
17	1	--	PRESSURE GAUGE, 0 - 30 PSI	1/4" MNPT



UNLESS OTHERWISE SPECIFIED:
- ALL DIMENSIONS IN INCHES
- FINISH 125 OR STOCK FINISH ALL OVER
- ANGLES ±0.5°
  .XX DIMENSIONS ± .01
  .XXX DIMENSIONS ± .005
- REMOVE BURRS AND BREAK SHARP CORNERS

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas USA

LEAK SITE LAYOUT,
LEAK SITES 1, 4, 6

ENGINEER:	APPROVAL:	SIZE	FSCM NO.	DWG NO.	REV
R.BURKEY		A		18-10485-300	—

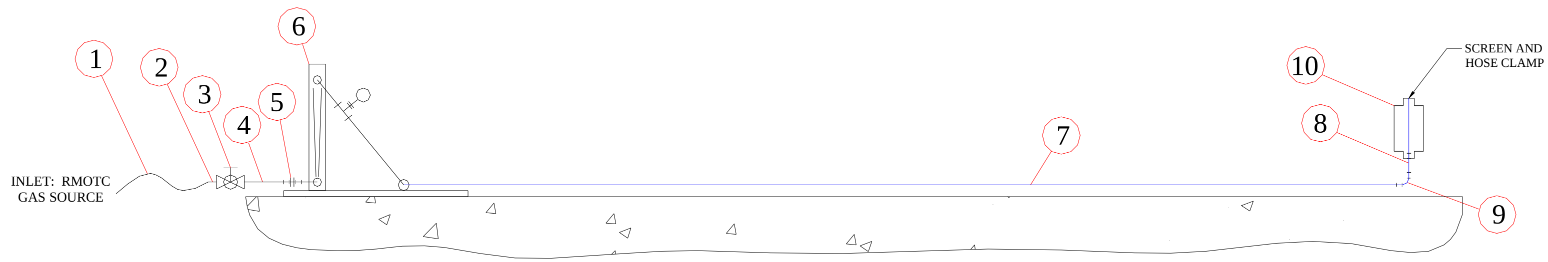
DATE:	SCALE	CONTRACT NO.	SHEET
8/3/04	NONE		1 OF 1

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED

NOTES:

1 CAP OR SEAL PIPE ENDS WHEN NOT IN USE.

LABEL	QTY	PART #	DESCRIPTION	CONNECTION
1	1	--	1" SDR11 HDPE PIPE	BUTT FUSION
2	1	--	TRANSITION FITTING, HDPE x PIPE	BUTT FUSION x 1" MNPT
3	1	T-585-70	1" BALL VALVE (1/4 TURN), BRONZE, 600 PSI CWP	1" FNPT x 1" FNPT
4	1	--	1" PIPE NIPPLE x 6" LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
5	1	--	1" UNION, MALLEABLE IRON, BLACK PIPE	1" FNPT x 1" FNPT
6	1	18-10485-200	ROTAMETER ASSEMBLY	1" FNPT x 1" FNPT
7	1	--	1" PIPE x 10' LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
8	3	--	1" 90deg ELBOW, MALLEABLE IRON, BLACK PIPE	1" FNPT x 1" FNPT
9	1	--	1" PIPE NIPPLE x 3" LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
10	1	301/D-IL-AAC	FLAME ARRESTOR, 7033206	1" FNPT x 1" FNPT



UNLESS OTHERWISE SPECIFIED:
- ALL DIMENSIONS IN INCHES
- FINISH 125 OR STOCK FINISH ALL OVER
- ANGLES ±0.5°
  .XX DIMENSIONS ± .01
  .XXX DIMENSIONS ± .005
- REMOVE BURRS AND BREAK SHARP CORNERS

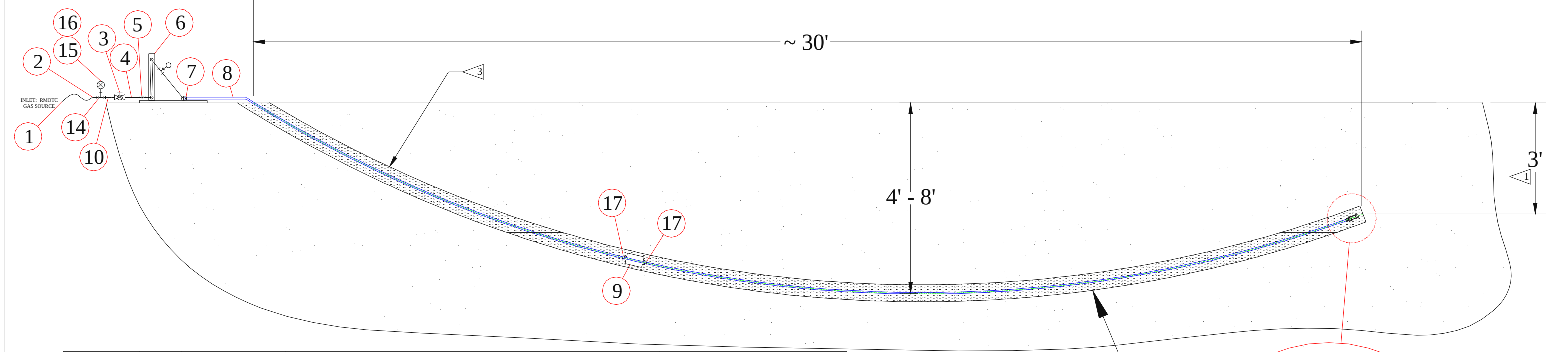
SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas USA

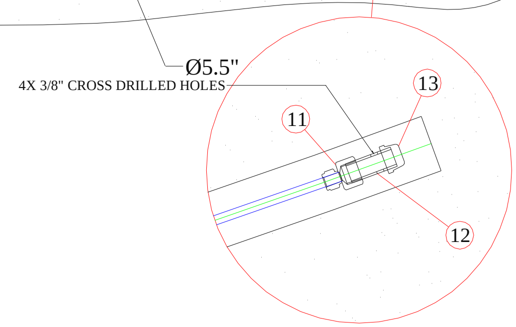
LEAK SITE LAYOUT, LEAK SITE 3

ENGINEER:	APPROVAL:	SIZE	FSCM NO.	DWG NO.	REV
R.BURKEY		A		18-10485-400	—
DATE: 8/3/04		SCALE NONE	CONTRACT NO.	SHEET 1 OF 1	

NOTES:

1. 3' DEPTH BELOW SURFACE IS THE MOST IMPORTANT DIMENSION TO MEET; OTHER DIMENSIONS MAY VARY +/- 2' TO ATTAIN 3' DEPTH BELOW SURFACE AT THE END OF THE DRILLED HOLE.
2. CAP OR SEAL PIPE ENDS WHEN NOT IN USE.
3. AFTER INSTALLATION OF TUBING, AGITATE INNER WALL OF HOLE AS MUCH AS POSSIBLE TO ENCOURAGE BENTONITE SOIL TO COLLAPSE AROUND INSTALLED TUBING TO PREVENT GAS FROM LEAKING OUT OF HOLE ALONG TUBING. IF GAS IS OBSERVED LEAKING OUT OF HOLE AROUND TUBING, POUR WATER AND/OR PACK ADDITIONAL BENTONITE SOIL AROUND THE PLACE WHERE THE TUBE ENTERS THE GROUND.





LABEL	QTY	PART #	DESCRIPTION	CONNECTION
1	1	--	1" SDR11 HDPE PIPE	BUTT FUSION
2	1	--	TRANSITION FITTING, HDPE x PIPE	BUTT FUSION x 1" MNPT
3	1	T-585-70	1" BALL VALVE (1/4 TURN), BRONZE, 600 PSI CWP	1" FNPT x 1" FNPT
4	1	--	1" PIPE NIPPLE x 6" LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
5	1	--	1" UNION, MALLEABLE IRON, BLACK PIPE	1" FNPT x 1" FNPT
6	1	18-10485-200	ROTAMETER ASSEMBLY	1" FNPT x 1" FNPT
7	1	SS-810-1-16	MALE CONNECTOR, 1" MNPT x 1/2" TUBE	1" MNPT x 1/2" TUBE
8	2	SS-T8-S-035-20	STAINLESS TUBING, 1/2" OD x 0.035" WALL x 20' LENGTH	1/2" TUBE x 1/2" TUBE
9	1	300.5/D-IL-AAC	FLAME ARRESTOR, 1/2"	1/2" FNPT x 1/2" FNPT
10	--	--	[REMOVED]	--
11	1	SS-810-7-12	FEMALE CONNECTOR, 3/4" FNPT x 1/2" TUBE	3/4" FNPT x 1/2" TUBE
12	1	--	3/4" PIPE NIPPLE x 2.5" LONG, SCH 40, BLACK PIPE, MODIFIED	3/4" MNPT x 3/4" MNPT
13	1	--	3/4" PIPE CAP, MALLEABLE IRON, BLACK PIPE	3/4" FNPT
14	1	--	1" TEE, MALLEABLE IRON, BLACK PIPE	1" FNPT x 1" FNPT x 1" FNPT
15	1	--	HEX BUSHING, MALLEABLE IRON, BLACK PIPE	1" MNPT x 1/4" FNPT
16	1	--	PRESSURE GAUGE, 0 - 30 PSI	1/4" MNPT
17	2	SS-810-1-8	MALE CONNECTOR, 1/2" TUBE x 1/2 MNPT	1/2" TUBE x 1/2" MNPT
18	1	--	1" PIPE NIPPLE x 3" LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT

UNLESS OTHERWISE SPECIFIED:

- ALL DIMENSIONS IN INCHES
- FINISH 125 √ OR STOCK FINISH ALL OVER
- ANGLES ±0.5°
  .XX DIMENSIONS ± .01
  .XXX DIMENSIONS ± .005
- REMOVE BURRS AND BREAK SHARP CORNERS

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas USA

LEAK SITE LAYOUT, LEAK SITES P1, P2, P3, P4

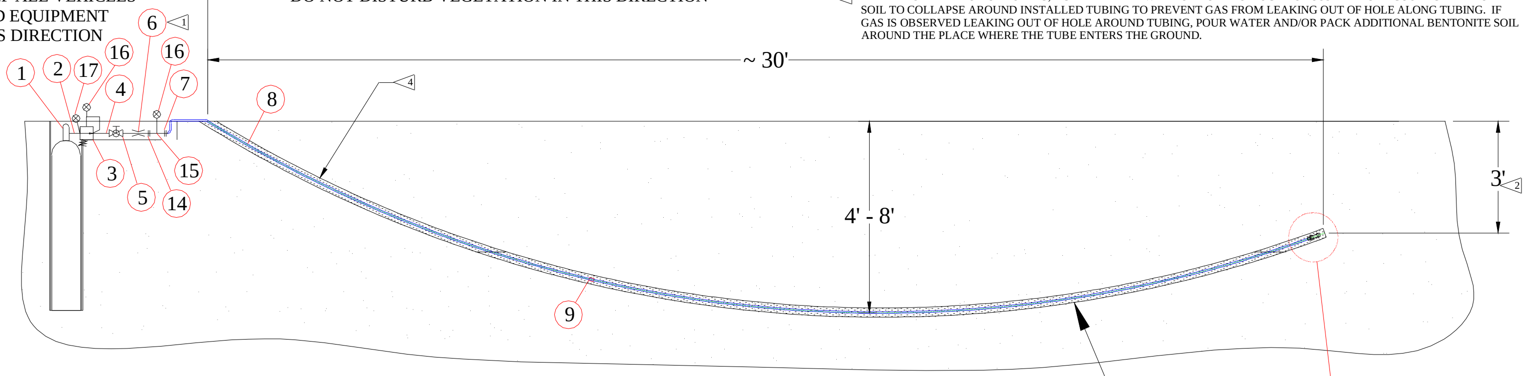
ENGINEER:	APPROVAL:	SIZE	FSCM NO.	DWG NO.	REV
R.BURKEY		A		18-10485-500	—
DATE: 8/3/04		SCALE: NONE	CONTRACT NO.	SHEET 1 OF 1	

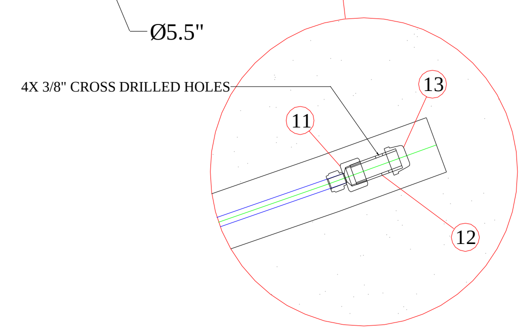
NOTES:

1. SELECTED FLOW RESTRICTOR TO PRODUCE 1 SCFH LEAKRATE WITH INLET PRESSURE 22 PSIG.
2. 3' DEPTH BELOW SURFACE IS THE MOST IMPORTANT DIMENSION TO MEET; OTHER DIMENSIONS MAY VARY +/- 2' TO ATTAIN 3' DEPTH BELOW SURFACE AT THE END OF THE DRILLED HOLE.
3. CAP OR SEAL PIPE ENDS WHEN NOT IN USE.

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED

4. AFTER INSTALLATION OF TUBING, AGITATE INNER WALL OF HOLE AS MUCH AS POSSIBLE TO ENCOURAGE BENTONITE SOIL TO COLLAPSE AROUND INSTALLED TUBING TO PREVENT GAS FROM LEAKING OUT OF HOLE ALONG TUBING. IF GAS IS OBSERVED LEAKING OUT OF HOLE AROUND TUBING, POUR WATER AND/OR PACK ADDITIONAL BENTONITE SOIL AROUND THE PLACE WHERE THE TUBE ENTERS THE GROUND.





LABEL	QTY	PART #	DESCRIPTION	CONNECTION
1	1	--	GAS CYLINDER, TYPE K, 95% METHANE, 5% ETHANE BLEND	CGA-350
2	1	INL-350SS-4M-48	FITTING, CGA ADAPTER FITTING	CGA-350 x 1/4" MNPT
3	1	44-2210-241	PRESSURE REGULATOR, MAX INLET 3500 PSI, OUTLET 0 - 50 PSI	1/4" FNPT x 1/4" FNPT
4	1	SS-4-TA-1-4	FITTING, MALE ADAPTER	1/4" MNPT x 1/4" TUBE STUB
5	1	SS-43S4	VALVE, 1/4 TURN BALL	1/4" TUBE END x 1/4" TUBE
6	1	IC-400R4-5-SS	FLOW RESTRICTOR, METAL ORIFICE ASSEMBLY, Ø0.005 ORIFICE	1/4" TUBE STUB x 1/4" TUBE
7	1	SS-810-R-4	REDUCER, 1/4" TUBE STUB x 1/2" TUBE	1/4" TUBE STUB x 1/2" TUBE
8	2	SS-T8-S-035-20	STAINLESS TUBING, 1/2" OD x 0.035" WALL x 20' LENGTH	1/2" TUBE x 1/2" TUBE
9	1	SS-810-6	1/2" UNION, 1/2" TUBE x 1/2" TUBE	1/2" TUBE x 1/2" TUBE
10	--	--	[REMOVED]	--
11	1	SS-810-7-12	FEMALE CONNECTOR, 3/4" FNPT x 1/2" TUBE	3/4" FNPT x 1/2" TUBE
12	1	--	3/4" PIPE NIPPLE x 2.5" LONG, SCH 40, BLACK PIPE, MODIFIED	3/4" MNPT x 3/4" MNPT
13	1	--	3/4" PIPE CAP, MALLEABLE IRON, BLACK PIPE	3/4" FNPT
14	1	SS-401-PC	PORT CONNECTOR, 1/4"	1/4" TUBE x 1/4" TUBE
15	1	SS-400-3-4TTF	FEMALE BRANCH TEE, 1/4" TUBE RUN, 1/4" FNPT BRANCH	1/4" TUBE x 1/4" TUBE x 1/4 FNPT BRANCH
16	2	20W-1005H02L-30	PRESSURE GAUGE, 0 - 30 PSI	1/4" MNPT
17	1	20W-1005H02L-4000	PRESSURE GAUGE, 0 - 4000 PSI	1/4" MNPT

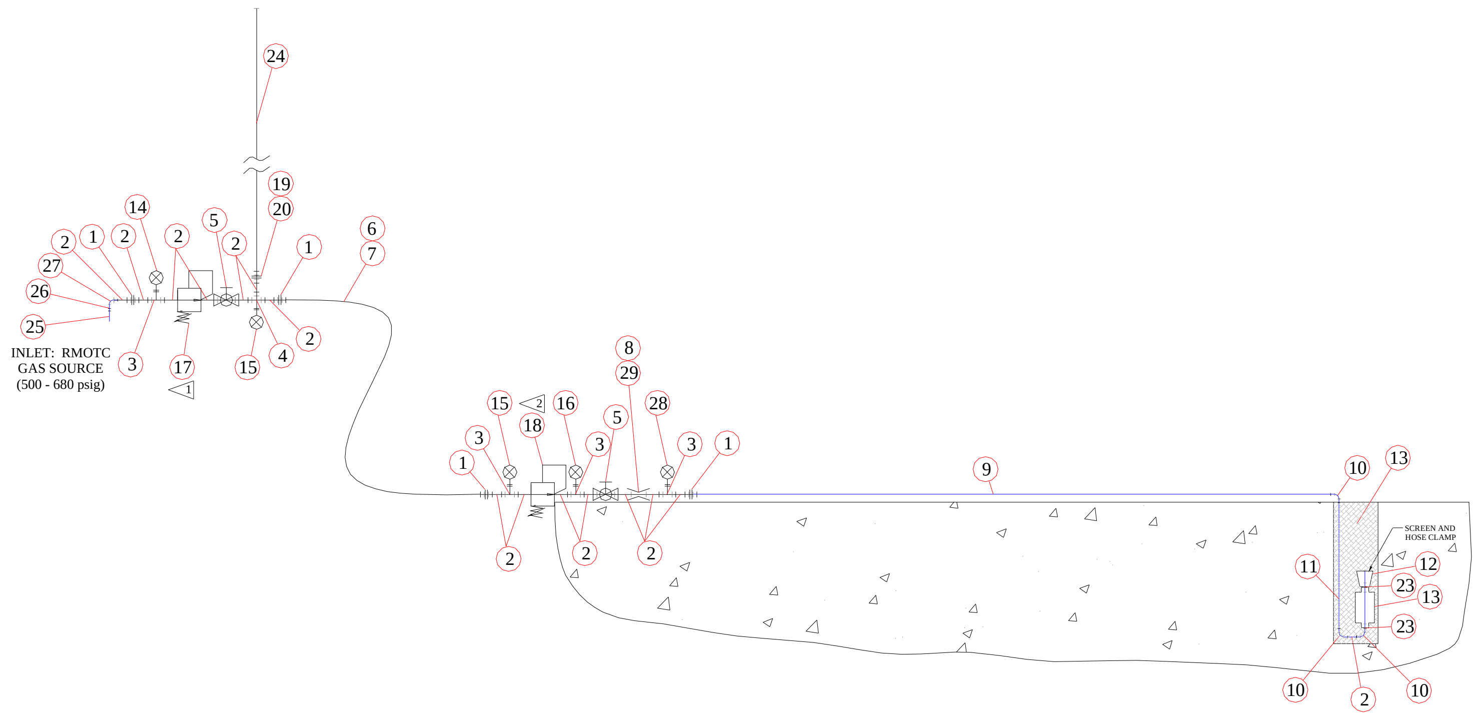
UNLESS OTHERWISE SPECIFIED:

- ALL DIMENSIONS IN INCHES
- FINISH 125 OR STOCK FINISH ALL OVER
- ANGLES ±0.5°
  .XX DIMENSIONS ± .01
  .XXX DIMENSIONS ± .005
- REMOVE BURRS AND BREAK SHARP CORNERS

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas USA

LEAK SITE LAYOUT, LEAK SITES P5

ENGINEER:	APPROVAL:	SIZE	FSCM NO.	DWG NO.	REV
R.BURKEY		A		18-10485-600	—
DATE: 8/3/04		SCALE NONE	CONTRACT NO.	SHEET 1 OF 1	



NOTES:

1. PRESSURE REGULATOR SET POINT = 65 - 80 PSIG.
2. PRESSURE REGULATOR SET POINT = 48 PSIG FOR 5,000 SCFH LEAK RATE; = 20 PSIG FOR 2,500 SCFH LEAK RATE.
3. CAP OR SEAL PIPE ENDS WHEN NOT IN USE.

UNLESS OTHERWISE SPECIFIED:
- ALL DIMENSIONS IN INCHES
- FINISH 125 OR STOCK FINISH ALL OVER
- ANGLES ±0.5°
  .XX DIMENSIONS ± .01
  .XXX DIMENSIONS ± .005
- REMOVE BURRS AND BREAK SHARP CORNERS

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas USA

LEAK SITE LAYOUT, LEAK SITE 5

ENGINEER: R.BURKEY	APPROVAL:	SIZE A	FSCM NO.	DWG NO. 18-10485-700	REV —
DATE: 8/3/04		SCALE NONE	CONTRACT NO.	SHEET 1 OF 2	

LABEL	QTY	PART #	DESCRIPTION	CONNECTION
1	4	--	1" UNION, CLASS 3000, BLACK PIPE	1" FNPT x 1" FNPT
2	15	--	1" PIPE NIPPLE x 3" LONG, SCH 80, SEAMLESS, BLACK PIPE	1" MNPT x 1" MNPT
3	4	--	REDUCING TEE, 1" RUN, 1/4" BRANCH, CLASS 3000, BLACK PIPE	1" FNPT x 1" FNPT x 1/4" FNPT BRANCH
4	1	--	1" CROSS, CLASS 3000, BLACK PIPE	1" FNPT x 1" FNPT x 1" FNPT x 1" FNPT
5	2	T-560-CS-R-25-LL	1" BALL VALVE (1/4 TURN), CARBON STEEL, 2000 PSI CWP	1" FNPT x 1" FNPT
6	2	--	TRANSITION FITTING, HDPE x PIPE	BUTT FUSION x 1" MNPT
7	1		1" SDR11 HDPE PIPE	BUTT FUSION
8	1	ROU-276-8-N-CS	RESTRICTION ORIFICE UNION	1" FNPT x 1" FNPT
9	2		1" PIPE x 10' LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
10	3	--	1" 90deg ELBOW, MALLEABLE IRON, BLACK PIPE	1" FNPT x 1" FNPT
11	1	--	1" PIPE NIPPLE x 24" LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
12	1		REDUCING COUPLING, MALLEABLE IRON, BLACK PIPE	1" FNPT x 2" FNPT
13	1	--	1" WASHED GRAVEL, BACKFILL	--
14	1	20W-1005H02L-1000	PRESSURE GAGE, 0 - 1000 PSI	1/4" MNPT
15	2	20W-1005H02L-200	PRESSURE GAGE, 0 - 200 PSI	1/4" MNPT
16	1	20W-1005H02L-100	PRESSURE GAGE, 0 - 100 PSI	1/4" MNPT
17	1	FS627-104	PRESSURE REGULATOR, MAX INLET 1000 PSI, OUTLET 70 - 150 PSI	1" FNPT x 1" FNPT
18	1	FS95H-49	PRESSURE REGULATOR, MAX INLET 250 PSI, OUTLET 25 - 75 PSI	1" FNPT x 1" FNPT
19	1	--	1" UNION TYPE RUPTURE DISK HOLDER	1" FNPT x 1" FNPT
20	1	--	RUPTURE DISK	--
21	1	20W-1005H02L-30	PRESSURE GAGE, 0 - 30 PSI	1/4" MNPT
22	1	301/D-IL-AAC	FLAME ARRESTOR, 7033206	1" FNPT x 1" FNPT
23	2	--	1" CLOSE PIPE NIPPLE, SCH 40, BLACK PIPE	--
24	1	--	1" PIPE NIPPLE x 48" LONG, SCH 40, BLACK PIPE	1" MNPT x 1" MNPT
25	1	--	1/2" PIPE NIPPLE x 3" LONG, SCH 80, SEAMLESS, BLACK PIPE	1/2" MNPT x 1/2" MNPT
26	1	--	HEX BUSHING, CLASS 3000, BLACK PIPE, 1" x 1/2"	1" MNPT x 1/2" FNPT
27	1	--	1" 90deg ELBOW, CLASS 3000, BLACK PIPE	1" FNPT x 1" FNPT
28	1	20W-1005H02L-30	PRESSURE GAGE, 0 - 30 PSI	1/4" MNPT
29	1	--	ORIFICE PLATE FOR RESTRICTION ORIFICE UNION, Ø0.276 ORIFICE	1" FNPT x 1" FNPT

UNLESS OTHERWISE SPECIFIED:
- ALL DIMENSIONS IN INCHES
- FINISH 125 √ OR STOCK FINISH ALL OVER
- ANGLES ±0.5°
  .XX DIMENSIONS ± .01
  .XXX DIMENSIONS ± .005
- REMOVE BURRS AND BREAK SHARP CORNERS

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas USA

LEAK SITE LAYOUT, LEAK SITE 5

ENGINEER:	APPROVAL:	SIZE	FSCM NO.	DWG NO.	REV
R.BURKEY		A		18-10485-700	—

DATE:	SCALE	CONTRACT NO.	SHEET
8/3/04	NONE		2 OF 2

APPENDIX D

Leak Site Photographs

Site 1 – Underground leak outlet is roughly 10 feet from rotometer location (in gravel area).

Site 2A – View of bottle and regulator (typical of all bottle fed leaks; 2A through 2E).

Site 2A – View from leak site to road. Underground leak located in the gravel area approximately 8 feet from bottle location.

Site 2B – Underground leak located in the gravel area approximately 8 feet from bottle location.

Site 2C – Underground leak located in gravel area approximately 8 feet from bottle location.

Site 2D/Site 1F – Three bottles (two with methane only, one with methane/ethane mix). Underground leak located in the gravel area approximately 8 feet from bottle location. Vehicle located on the road.

Site 2E – Underground leak located in the gravel area approximately 8 feet from bottle location. Vehicle located on the road.

Site 3 – View from the road.

Site 3 – Aboveground leak at the end of the 10-foot long pipe.

Site 4 – Underground leak emitting through gravel.

Site 4 – View towards road; vehicle located on the road.

Site 5 – View from the road.

Site 5 – Detail of pipe entering the ground in the gravel area.

Site 6 – View from the road. Note the rotometer outline on the horizon.

Site 6 – View at the top of the hill. Underground leak at gravel located approximately 10 feet from the rotometer.

Site P1 – Underground leak. Directionally drilled such that the leak emits under greasewood bush located approximately 20 feet from rotometer.

Site P1 – Detail of tubing entering the ground.

Site P2 – Source gas.

Site P2 – View of leak site and vegetation. The gas leak emits underground near the middle of the greasewood bushes.

Site P3 – View of leak site and vegetation. The gas leak emits near the middle of the greasewood bushes.

Site P4– View of leak site and vegetation. The gas leak emits near the middle of the greasewood bushes in the center of the picture.

Site P4 – View from the road.

Site P5 – View of site and vegetation. The leak emits beneath the greasewood bushes in the middle of the picture.

APPENDIX E

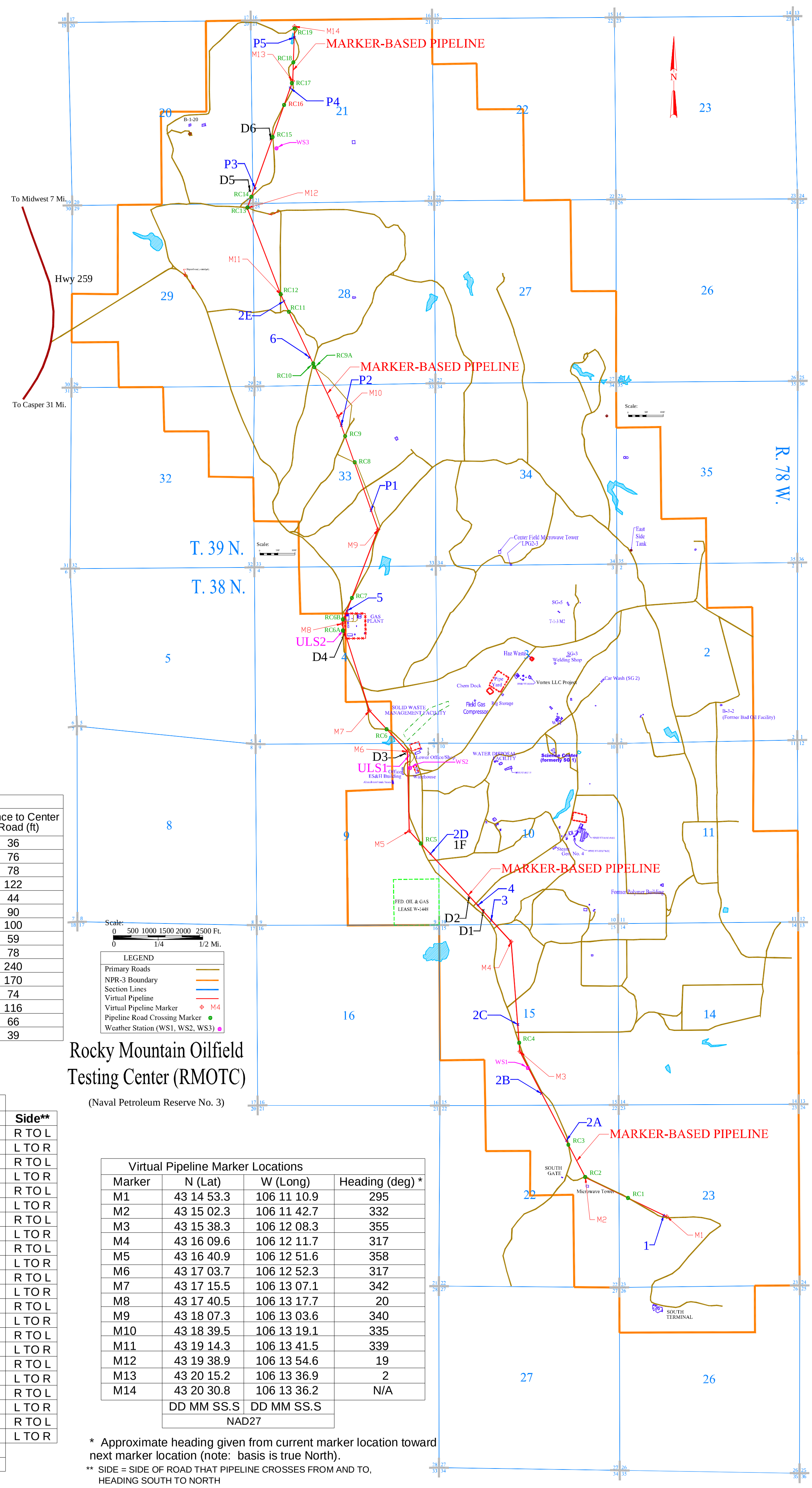
Leak Site Locations

Section 1 - Marker-Based Pipeline
Section 2 - Marker-Based Pipeline – Southern Portion
Section 3 - Marker-Based Pipeline – Northern Portion
Section 4 - Virtual Pipeline Map

Section 1

Marker-Based Pipeline

MARKER-BASED PIPELINE
Including Leak Sites, Decoy Sites, Unintentional Leak Sites, Markers, and Road Crossings



Leak Locations

LEAK SITE	N (Lat)	W (Long)	Distance to Center of Road (ft)
1	43 14 53.6	106 11 12.1	36
2A	43 15 12.9	106 11 50.1	76
2B	43 15 26.3	106 11 59.9	78
2C	43 15 46.0	106 12 09.1	122
3	43 16 15.7	106 12 19.5	44
4	43 16 20.1	106 12 24.6	90
2D	43 16 34.4	106 12 43.2	100
5	43 17 44.1	106 13 15.8	59
P1	43 18 12.7	106 13 06.3	78
P2	43 18 37.0	106 13 17.9	240
6	43 18 56.4	106 13 30.4	170
2E	43 19 12.4	106 13 40.3	74
P3	43 19 44.5	106 13 51.5	116
P4	43 20 13.2	106 13 37.8	66
P5	43 20 27.7	106 13 36.3	39
	DD MM SS.S	DD MM SS.S	
	NAD27		

Road Crossing Marker Locations

Marker	N (Lat)	W (Long)	Side**
RC1	43 14 57.4	106 11 26.1	R TO L
RC2	43 15 02.5	106 11 42.8	L TO R
RC3	43 15 11.7	106 11 49.4	R TO L
RC4	43 15 40.8	106 12 08.6	L TO R
RC5	43 16 37.3	106 12 47.1	R TO L
RC6	43 17 10.1	106 13 00.4	L TO R
RC6A	43 17 38.5	106 13 17.4	R TO L
RC6B	43 17 41.7	106 13 17.4	L TO R
RC7	43 17 47.8	106 13 13.9	R TO L
RC8	43 18 26.5	106 13 12.7	L TO R
RC9	43 18 33.9	106 13 16.4	R TO L
RC9A	43 18 53.6	106 13 28.4	L TO R
RC10	43 18 54.6	106 13 28.8	R TO L
RC11	43 19 09.4	106 13 38.4	L TO R
RC12	43 19 14.4	106 13 41.6	R TO L
RC13	43 19 39.0	106 13 54.5	L TO R
RC14	43 19 42.1	106 13 53.0	R TO L
RC15	43 19 59.1	106 13 44.6	L TO R
RC16	43 20 08.3	106 13 40.2	R TO L
RC17	43 20 14.6	106 13 37.2	L TO R
RC18	43 20 20.5	106 13 36.6	R TO L
RC19	43 20 30.2	106 13 36.2	L TO R
	DD MM SS.S	DD MM SS.S	
	NAD27		

Virtual Pipeline Marker Locations

Marker	N (Lat)	W (Long)	Heading (deg) *
M1	43 14 53.3	106 11 10.9	295
M2	43 15 02.3	106 11 42.7	332
M3	43 15 38.3	106 12 08.3	355
M4	43 16 09.6	106 12 11.7	317
M5	43 16 40.9	106 12 51.6	358
M6	43 17 03.7	106 12 52.3	317
M7	43 17 15.5	106 13 07.1	342
M8	43 17 40.5	106 13 17.7	20
M9	43 18 07.3	106 13 03.6	340
M10	43 18 39.5	106 13 19.1	335
M11	43 19 14.3	106 13 41.5	339
M12	43 19 38.9	106 13 54.6	19
M13	43 20 15.2	106 13 36.9	2
M14	43 20 30.8	106 13 36.2	N/A
	DD MM SS.S	DD MM SS.S	
	NAD27		

* Approximate heading given from current marker location toward next marker location (note: basis is true North).

** SIDE = SIDE OF ROAD THAT PIPELINE CROSSES FROM AND TO, HEADING SOUTH TO NORTH

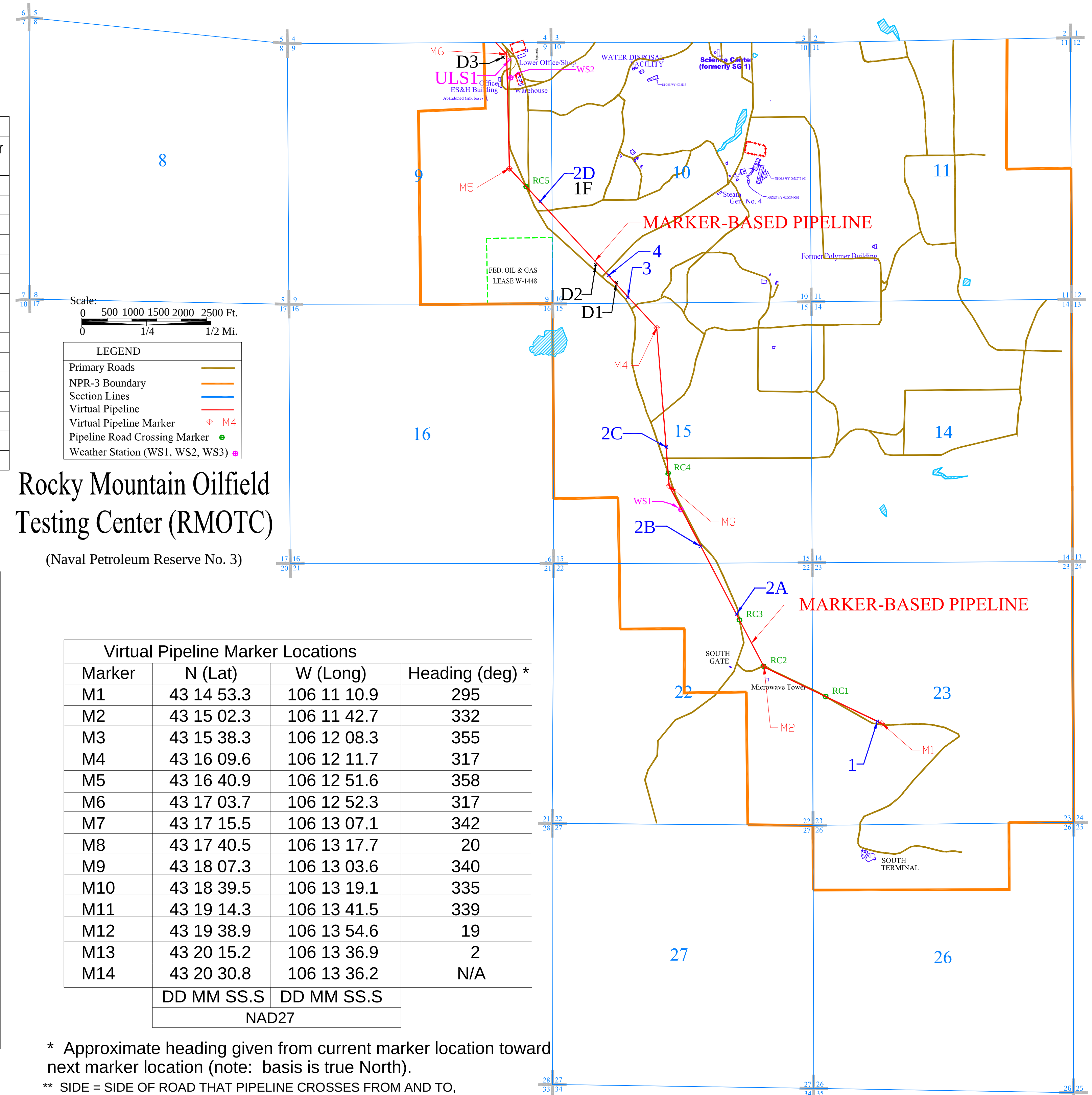
Section 2

Marker-Based Pipeline – Southern Portion

MARKER-BASED PIPELINE – SOUTHERN PORTION

Leak Locations			
LEAK SITE	N (Lat)	W (Long)	Distance to Center of Road (ft)
1	43 14 53.6	106 11 12.1	36
2A	43 15 12.9	106 11 50.1	76
2B	43 15 26.3	106 11 59.9	78
2C	43 15 46.0	106 12 09.1	122
3	43 16 15.7	106 12 19.5	44
4	43 16 20.1	106 12 24.6	90
2D	43 16 34.4	106 12 43.2	100
5	43 17 44.1	106 13 15.8	59
P1	43 18 12.7	106 13 06.3	78
P2	43 18 37.0	106 13 17.9	240
6	43 18 56.4	106 13 30.4	170
2E	43 19 12.4	106 13 40.3	74
P3	43 19 44.5	106 13 51.5	116
P4	43 20 13.2	106 13 37.8	66
P5	43 20 27.7	106 13 36.3	39
	DD MM SS.S	DD MM SS.S	
	NAD27		

Road Crossing Marker Locations			
Marker	**N (Lat)**	**W (Long)**	**Side****
RC1	43 14 57.4	106 11 26.1	R TO L
RC2	43 15 02.5	106 11 42.8	L TO R
RC3	43 15 11.7	106 11 49.4	R TO L
RC4	43 15 40.8	106 12 08.6	L TO R
RC5	43 16 37.3	106 12 47.1	R TO L
RC6	43 17 10.1	106 13 00.4	L TO R
RC6A	43 17 38.5	106 13 17.4	R TO L
RC6B	43 17 41.7	106 13 17.4	L TO R
RC7	43 17 47.8	106 13 13.9	R TO L
RC8	43 18 26.5	106 13 12.7	L TO R
RC9	43 18 33.9	106 13 16.4	R TO L
RC9A	43 18 53.6	106 13 28.4	L TO R
RC10	43 18 54.6	106 13 28.8	R TO L
RC11	43 19 09.4	106 13 38.4	L TO R
RC12	43 19 14.4	106 13 41.6	R TO L
RC13	43 19 39.0	106 13 54.5	L TO R
RC14	43 19 42.1	106 13 53.0	R TO L
RC15	43 19 59.1	106 13 44.6	L TO R
RC16	43 20 08.3	106 13 40.2	R TO L
RC17	43 20 14.6	106 13 37.2	L TO R
RC18	43 20 20.5	106 13 36.6	R TO L
RC19	43 20 30.2	106 13 36.2	L TO R
	DD MM SS.S	DD MM SS.S	
	NAD27		



Virtual Pipeline Marker Locations			
Marker	N (Lat)	W (Long)	Heading (deg) *
M1	43 14 53.3	106 11 10.9	295
M2	43 15 02.3	106 11 42.7	332
M3	43 15 38.3	106 12 08.3	355
M4	43 16 09.6	106 12 11.7	317
M5	43 16 40.9	106 12 51.6	358
M6	43 17 03.7	106 12 52.3	317
M7	43 17 15.5	106 13 07.1	342
M8	43 17 40.5	106 13 17.7	20
M9	43 18 07.3	106 13 03.6	340
M10	43 18 39.5	106 13 19.1	335
M11	43 19 14.3	106 13 41.5	339
M12	43 19 38.9	106 13 54.6	19
M13	43 20 15.2	106 13 36.9	2
M14	43 20 30.8	106 13 36.2	N/A
	DD MM SS.S	DD MM SS.S	
	NAD27		

* Approximate heading given from current marker location toward next marker location (note: basis is true North).

** SIDE = SIDE OF ROAD THAT PIPELINE CROSSES FROM AND TO, HEADING SOUTH TO NORTH

Section 3

Marker-Based Pipeline – Northern Portion

MARKER-BASED PIPELINE – NORTHERN PORTION

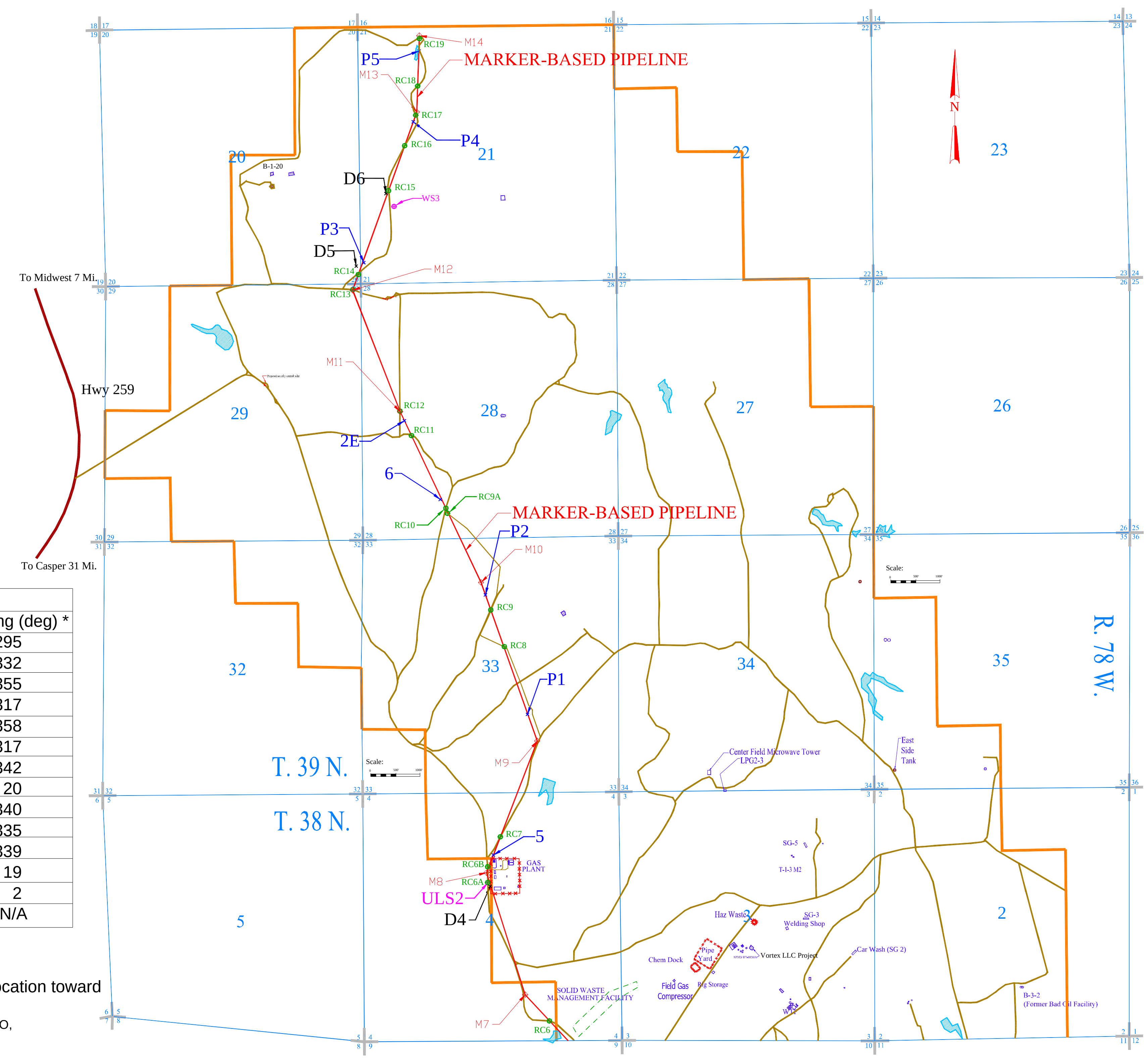
Leak Locations			
LEAK SITE	N (Lat)	W (Long)	Distance to Center of Road (ft)
1	43 14 53.6	106 11 12.1	36
2A	43 15 12.9	106 11 50.1	76
2B	43 15 26.3	106 11 59.9	78
2C	43 15 46.0	106 12 09.1	122
3	43 16 15.7	106 12 19.5	44
4	43 16 20.1	106 12 24.6	90
2D	43 16 34.4	106 12 43.2	100
5	43 17 44.1	106 13 15.8	59
P1	43 18 12.7	106 13 06.3	78
P2	43 18 37.0	106 13 17.9	240
6	43 18 56.4	106 13 30.4	170
2E	43 19 12.4	106 13 40.3	74
P3	43 19 44.5	106 13 51.5	116
P4	43 20 13.2	106 13 37.8	66
P5	43 20 27.7	106 13 36.3	39
	DD MM SS.S	DD MM SS.S	
	NAD27		

Road Crossing Marker Locations			
Marker	N (Lat)	W (Long)	Side**
RC1	43 14 57.4	106 11 26.1	R TO L
RC2	43 15 02.5	106 11 42.8	L TO R
RC3	43 15 11.7	106 11 49.4	R TO L
RC4	43 15 40.8	106 12 08.6	L TO R
RC5	43 16 37.3	106 12 47.1	R TO L
RC6	43 17 10.1	106 13 00.4	L TO R
RC6A	43 17 38.5	106 13 17.4	R TO L
RC6B	43 17 41.7	106 13 17.4	L TO R
RC7	43 17 47.8	106 13 13.9	R TO L
RC8	43 18 26.5	106 13 12.7	L TO R
RC9	43 18 33.9	106 13 16.4	R TO L
RC9A	43 18 53.6	106 13 28.4	L TO R
RC10	43 18 54.6	106 13 28.8	R TO L
RC11	43 19 09.4	106 13 38.4	L TO R
RC12	43 19 14.4	106 13 41.6	R TO L
RC13	43 19 39.0	106 13 54.5	L TO R
RC14	43 19 42.1	106 13 53.0	R TO L
RC15	43 19 59.1	106 13 44.6	L TO R
RC16	43 20 08.3	106 13 40.2	R TO L
RC17	43 20 14.6	106 13 37.2	L TO R
RC18	43 20 20.5	106 13 36.6	R TO L
RC19	43 20 30.2	106 13 36.2	L TO R
	DD MM SS.S	DD MM SS.S	
	NAD27		

Virtual Pipeline Marker Locations			
Marker	N (Lat)	W (Long)	Heading (deg) *
M1	43 14 53.3	106 11 10.9	295
M2	43 15 02.3	106 11 42.7	332
M3	43 15 38.3	106 12 08.3	355
M4	43 16 09.6	106 12 11.7	317
M5	43 16 40.9	106 12 51.6	358
M6	43 17 03.7	106 12 52.3	317
M7	43 17 15.5	106 13 07.1	342
M8	43 17 40.5	106 13 17.7	20
M9	43 18 07.3	106 13 03.6	340
M10	43 18 39.5	106 13 19.1	335
M11	43 19 14.3	106 13 41.5	339
M12	43 19 38.9	106 13 54.6	19
M13	43 20 15.2	106 13 36.9	2
M14	43 20 30.8	106 13 36.2	N/A
	DD MM SS.S	DD MM SS.S	
	NAD27		

* Approximate heading given from current marker location toward next marker location (note: basis is true North).

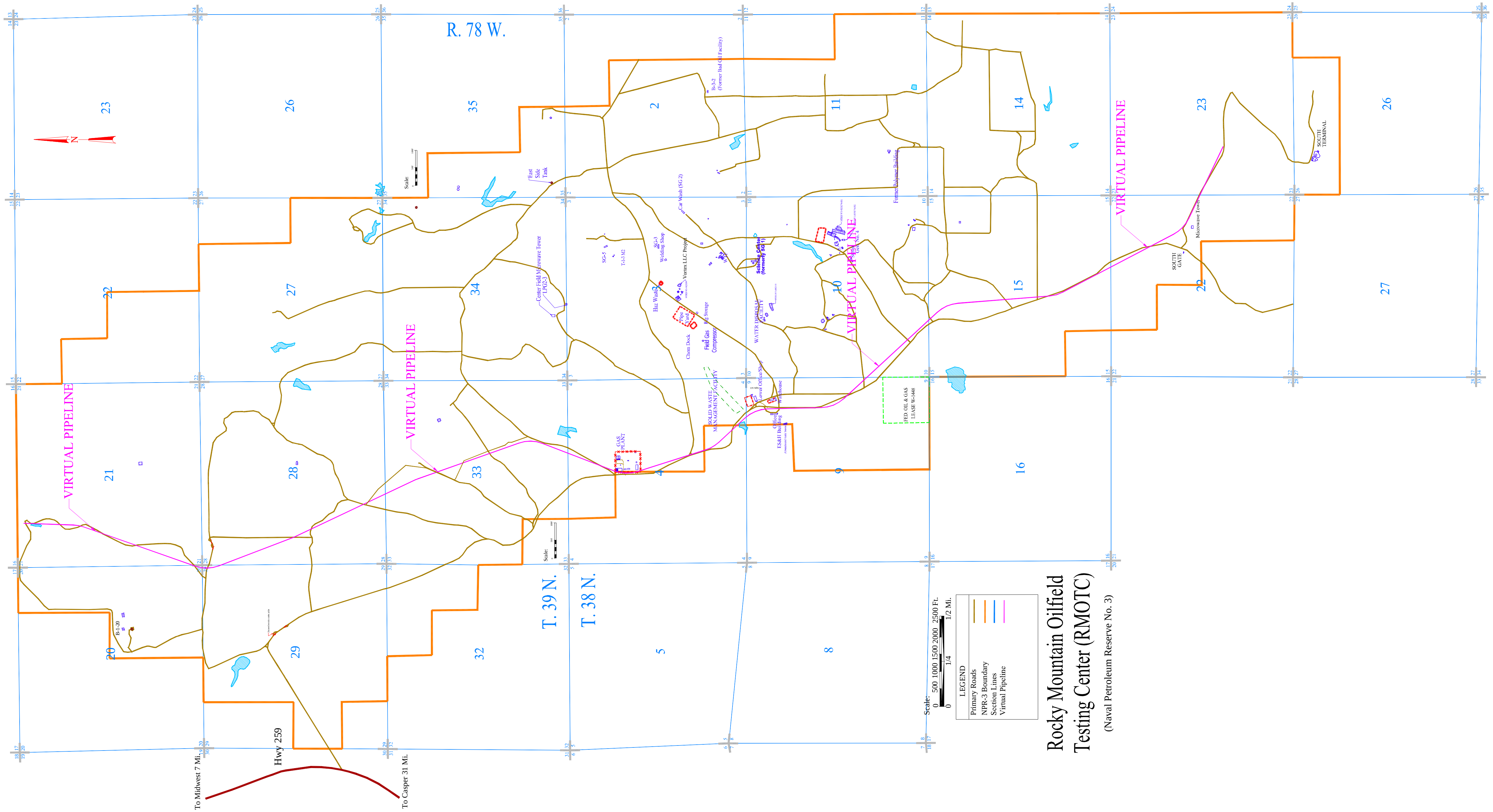
** SIDE = SIDE OF ROAD THAT PIPELINE CROSSES FROM AND TO, HEADING SOUTH TO NORTH



Section 4

Virtual Pipeline Map

VIRTUAL PIPELINE MAP



APPENDIX F

Original Plan

Section 1 - Flight Schedule and Driving Times
Section 2 - Daily Leak Rates for Each Leak Site

Section 1

Flight Schedule and Driving Times

DETAILED TESTING SCHEDULE FOR RMOTC REMOTE LEAK DETECTION TESTING - ORIGINAL PLAN

MONDAY September 13		6:00 AM	6:30 AM	7:00 AM	7:30 AM	8:00 AM	8:30 AM	9:00 AM	9:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM	5:30 PM	6:00 PM	6:30 PM	7:00 PM	7:30 PM	8:00 PM	8:30 PM
Ophir flights			■	■																					■	■					
LaSen flights					■	■																	■	■							
ITT flights							■	■																			■	■			
LLNL UAV flight											■	■	■																		
LLNLTwin Otter flight											■	■	■																		
PSI drives			■	■	■																				■	■	■				
En'Urga drives										■	■	■								■	■	■									
start leaks		■																													
coordination meeting																■															
individual meetings																	■														
monitor leaks													■	■	■	■	■	■													
set new leak rates																													■	■	

TUESDAY September 14		6:00 AM	6:30 AM	7:00 AM	7:30 AM	8:00 AM	8:30 AM	9:00 AM	9:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM	5:30 PM	6:00 PM	6:30 PM	7:00 PM	7:30 PM	8:00 PM	8:30 PM
Ophir flights	none				■	■																	■	■							
LaSen flights							■	■																			■	■			
ITT flights			■	■																					■	■					
LLNL UAV flight											■	■	■																		
LLNLTwin Otter flight	none																														
PSI drives											■	■	■												■	■	■				
En'Urga drives										■	■	■								■	■	■									
start leaks		■																													
coordination meeting																■															
individual meetings																	■														
monitor leaks													■	■	■	■	■	■													
set new leak rates																													■	■	

WEDNESDAY September 15		6:00 AM	6:30 AM	7:00 AM	7:30 AM	8:00 AM	8:30 AM	9:00 AM	9:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM	5:30 PM	6:00 PM	6:30 PM	7:00 PM	7:30 PM	8:00 PM	8:30 PM
Ophir flights							■	■																			■	■			
LaSen flights			■	■																					■	■					
ITT flights					■	■																	■	■							
LLNL UAV flight											■	■	■																		
LLNLTwin Otter flight											■	■	■																		
PSI drives						■	■	■																	■	■	■				
En'Urga drives										■	■	■								■	■	■									
start leaks		■																													
coordination meeting																■															
individual meetings																	■														
monitor leaks													■	■	■	■	■	■													
set new leak rates																													■	■	

THURSDAY September 16		6:00 AM	6:30 AM	7:00 AM	7:30 AM	8:00 AM	8:30 AM	9:00 AM	9:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM	5:30 PM	6:00 PM	6:30 PM	7:00 PM	7:30 PM	8:00 PM	8:30 PM
Ophir flights			■	■																					■	■					
LaSen flights					■	■																	■	■							
ITT flights							■	■																			■	■			
LLNL UAV flight											■	■	■																		
LLNLTwin Otter flight	none																														
PSI drives			■	■	■																	■	■	■							
En'Urga drives										■	■	■								■	■	■									
start leaks		■																													
coordination meeting																■															
individual meetings																	■														
monitor leaks													■	■	■	■	■	■													
set new leak rates																													■	■	

FRIDAY September 17		6:00 AM	6:30 AM	7:00 AM	7:30 AM	8:00 AM	8:30 AM	9:00 AM	9:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM	5:30 PM	6:00 PM	6:30 PM	7:00 PM	7:30 PM	8:00 PM	8:30 PM
Ophir flights																															
LaSen flights																															
ITT flights																															
LLNL UAV flight																															
LLNLTwin Otter flight	none																														
PSI drives																															
En'Urga drives																															
start leaks																															
coordination meeting																															
individual meetings																															
monitor leaks																															
stop all leaks																															

NOTES:

1. The time slots in the chart are set so that the time in the column is the beginning of the time slot. The "6:30 AM" column is meant to represent 6:30 AM to just before 7:00 AM.
2. In reality, the "one-hour" time slot for flights is only 50 minutes over the test site, assuming a 10-minute clear time.
3. The time slots were determined by a statistical technique for randomization called Latin Squares.

	Wind Condition		
Company	"Best"	"Average"	"Worst"
A	3	4	3
B	3	3	4
C	4	3	3

4. The companies were assigned to the time slots by the Random Number Generator in Excel.

Company	Assignment
C	ITT
B	LaSen
A	Ophir

5. Simultaneous flights for LLNL's UAV and Twin Otter are possible due to flight path elevations.

Section 2

Daily Leak Rates for Each Leak Site

Detailed Daily Leak Rate Plan for Each Leak Site - Original Plan

			Leak Rates (scfh)																		
			Dates																		
Leak Site	**Gas Source**	**Leak Type**	**8/30/04**	**8/31/04**	**9/1/04**	**9/2/04**	**9/3/04**	**9/4/04**	**9/5/04**	**9/6/04**	**9/7/04**	**9/8/04**	**9/9/04**	**9/10/04**	**9/11/04**	**9/12/04**	**9/13/04**	**9/14/04**	**9/15/04**	**9/16/04**	**9/17/04**
1	RMOTC gas	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5,000	1,000	500	100	15
2A	cylinder	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
2B	cylinder	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0
2C	cylinder	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0
3	RMOTC gas	aboveground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,000	2,000	100	2,000	500
4	RMOTC gas	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	500	2,000	1,000	2,000
2D	cylinder	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0
5	RMOTC gas	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,000	5,000	5,000	5,000	5,000
P1	RMOTC gas	side-drilled	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
P2	RMOTC gas	side-drilled	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
6	RMOTC gas	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	100	1,000	500	1,000
2E	cylinder	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0
P3	RMOTC gas	side-drilled	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
P4	RMOTC gas	side-drilled	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
P5	cylinder	side-drilled	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
"Phantom" Methane Leak																					
1F	cylinder	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	15

APPENDIX G

Final Testing Plan

Section 1 - Flight Schedule and Driving Times
Section 2 - Daily Leak Rates for Each Leak Site

Section 1

Flight Schedule and Driving Times

DETAILED TESTING SCHEDULE FOR RMOTC REMOTE LEAK DETECTION TESTING - FINAL PLAN

THURSDAY September 9		6:00 AM	6:30 AM	7:00 AM	7:30 AM	8:00 AM	8:30 AM	9:00 AM	9:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM	5:30 PM	6:00 PM	6:30 PM	7:00 PM	7:30 PM	8:00 PM	8:30 PM
LLNL D2 flight											■	■	■																		

MONDAY September 13		6:00 AM	6:30 AM	7:00 AM	7:30 AM	8:00 AM	8:30 AM	9:00 AM	9:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM	5:30 PM	6:00 PM	6:30 PM	7:00 PM	7:30 PM	8:00 PM	8:30 PM
Ophir flights	none																														
LaSen flights			■	■																			■	■							
ITT flights							■	■																			■	■			
LLNL UAV flight											■	■	■																		
LLNLTwin Otter flight	none																														
PSI drives								■	■	■												■	■	■							
En'Urga drives										■	■	■								■	■	■									
start leaks		■																													
coordination meeting																■															
individual meetings																	■														
monitor leaks													■	■	■	■	■	■													
set new leak rates																													■	■	

TUESDAY September 14		6:00 AM	6:30 AM	7:00 AM	7:30 AM	8:00 AM	8:30 AM	9:00 AM	9:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM	5:30 PM	6:00 PM	6:30 PM	7:00 PM	7:30 PM	8:00 PM	8:30 PM
Ophir flights	none																														
LaSen flights					■	■																					■	■			
ITT flights			■	■																					■	■					
LLNL UAV flight											■	■	■																		
LLNLTwin Otter flight	none																														
PSI drives											■	■	■												■	■	■				
En'Urga drives										■	■	■								■	■	■									
start leaks		■																													
coordination meeting																■															
individual meetings																	■														
monitor leaks													■	■	■	■	■	■													
set new leak rates																													■	■	

WEDNESDAY September 15		6:00 AM	6:30 AM	7:00 AM	7:30 AM	8:00 AM	8:30 AM	9:00 AM	9:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM	5:30 PM	6:00 PM	6:30 PM	7:00 PM	7:30 PM	8:00 PM	8:30 PM
Ophir flights	none																														
LaSen flights			■	■																					■	■					
ITT flights					■	■																	■	■							
LLNL UAV flight											■	■	■																		
LLNLTwin Otter flight											■	■	■																		
PSI drives						■	■	■																	■	■	■				
En'Urga drives										■	■	■								■	■	■									
start leaks		■																													
coordination meeting																■															
individual meetings																	■														
monitor leaks													■	■	■	■	■	■													
set new leak rates																													■	■	

THURSDAY September 16		6:00 AM	6:30 AM	7:00 AM	7:30 AM	8:00 AM	8:30 AM	9:00 AM	9:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM	5:30 PM	6:00 PM	6:30 PM	7:00 PM	7:30 PM	8:00 PM	8:30 PM
Ophir flights	none																														
LaSen flights																															
ITT flights																															
LLNL UAV flight																															
LLNLTwin Otter flight	none																														
PSI drives																															
En'Urga drives																															
start leaks																															
coordination meeting																															
individual meetings																															
monitor leaks																															
set new leak rates																															

FRIDAY September 17		6:00 AM	6:30 AM	7:00 AM	7:30 AM	8:00 AM	8:30 AM	9:00 AM	9:30 AM	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM	5:30 PM	6:00 PM	6:30 PM	7:00 PM	7:30 PM	8:00 PM	8:30 PM
Ophir flights	none																														
LaSen flights																															
ITT flights																															
LLNL UAV flight																															
LLNLTwin Otter flight	none																														
PSI drives																															
En'Urga drives																															
start leaks																															
coordination meeting																															
individual meetings																															
monitor leaks																															
stop all leaks																															

NOTES:

1. The time slots in the chart are set so that the time in the column is the beginning of the time slot. The "6:30 AM" column is meant to represent 6:30 AM to just before 7:00 AM.
2. As of Tuesday, September 14, 2004, the morning flight times were modified. The morning flight times (over the NPR-3 test site) were shifted to 15 minutes later than the original plan. That is, the morning flight times were changed to 6:45 AM to 7:35 AM, 7:45 AM to 8:35 AM, and 8:45 AM to 9:35 AM.
3. As of Tuesday, September 14, 2004, the evening flight times were modified. The evening flight times (over the NPR-3 test site) were shifted to 15 minutes earlier than the original plan. That is, the evening flight times were changed to 4:15 PM to 5:05 PM, 5:15 PM to 6:05 PM, and 6:15 PM to 7:05 PM.
4. In reality, the "one-hour" time slot for flights is only 50 minutes over the test site, assuming a 10-minute clear time.
5. The time slots were determined by a statistical technique for randomization called Latin Squares.

	Wind Condition		
Company	"Best"	"Average"	"Worst"
A	3	4	3
B	3	3	4
C	4	3	3

6. The companies were assigned to the time slots by the Random Number Generator in Excel.

Company Assignment	
C	ITT
B	LaSen
A	Ophir

7. Simultaneous flights for LLNL's UAV and Twin Otter are possible due to flight path elevations.
8. Since Ophir was not going to be able to participate, LaSen's morning time slots on Monday and Tuesday were modified to allow for the same number of "best" time slots as ITT.

Flight/Driving Schedule for Leak Detection Project – Tabular Form

	Flight/Driving Times on Each Date				
Company	**Wednesday, 8-Sep**	**Monday, 13-Sep**		**Tuesday, 14-Sep**	
Ophir	N/A	N/A	N/A	N/A	N/A
LaSen	N/A	6:30 to 7:20 AM	4:30 to 5:20 PM	7:45 to 8:35 AM	6:15 to 7:05 PM
ITT	N/A	8:30 to 9:20 AM	6:30 to 7:20 PM	6:45 to 7:35 AM	5:15 to 6:05 PM
LLNL UAV	N/A	10:30 AM to Noon		10:30 AM to Noon	
LLNL TwinOtter	10:30 AM to Noon	N/A		N/A	
PSI	N/A	9:20 to 10:50 AM	4:00 to 5:30 PM	10:30 to Noon	5:30 to 7:00 PM
En'Urga	N/A	10:00 to 11:30 AM	3:00 to 4:30 PM	10:00 to 11:30 AM	3:00 to 4:30 PM

	Flight/Driving Times on Each Date					
Company	**Wednesday, 15-Sep**		**Thursday, 16-Sep**		**Friday, 17-Sep**	
Ophir	N/A	N/A	N/A	N/A	N/A	N/A
LaSen	6:45 to 7:35 AM	5:15 to 6:05 PM	7:45 to 8:35 AM	4:15 to 5:05 PM	8:45 to 9:35 AM	6:15 to 7:05 PM
ITT	7:45 to 8:35 AM	4:15 to 5:05 PM	8:45 to 9:35 AM	6:15 to 7:05 PM	6:45 to 7:35 AM	5:15 to 6:05 PM
LLNL UAV	10:30 AM to Noon		N/A		N/A	
LLNL TwinOtter	10:30 AM to Noon		Noon to 1:00 PM		N/A	
PSI	8:00 to 9:30 AM	5:30 to 7:00 PM	7:30 to 9:00 AM	4:00 to 5:30 PM	7:00 to 7:30 AM	N/A
En'Urga	10:00 to 11:30 AM	N/A	N/A	N/A	N/A	N/A

Section 2

Daily Leak Rates for Each Leak Site

Detailed Daily Leak Rate Plan for Each Leak Site - Final Plan

			Leak Rates (scfh)																		
			Dates																		
Leak Site	**Gas Source**	**Leak Type**	**8/30/04**	**8/31/04**	**9/1/04**	**9/2/04**	**9/3/04**	**9/4/04**	**9/5/04**	**9/6/04**	**9/7/04**	**9/8/04**	**9/9/04**	**9/10/04**	**9/11/04**	**9/12/04**	**9/13/04**	**9/14/04**	**9/15/04**	**9/16/04**	**9/17/04**
1	RMOTC gas	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5,000	1,000	500	100	15 & 5,000
2A	cylinder	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
2B	cylinder	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0
2C	cylinder	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0
3	RMOTC gas	aboveground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,000	2,000	100	2,000	500
4	RMOTC gas	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	500	2,000	1,000	2,000
2D	cylinder	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0
5	RMOTC gas	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,500	5,000	5,000	0	5,000
P1	RMOTC gas	side-drilled	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
P2	RMOTC gas	side-drilled	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
6	RMOTC gas	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500	100	1,000	500	1,000
2E	cylinder	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0
P3	RMOTC gas	side-drilled	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
P4	RMOTC gas	side-drilled	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
P5	cylinder	side-drilled	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
"Phantom" Methane Leak																					
1F	cylinder	below ground	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	15

NOTES:

On Friday, September 17, the leak rate at Leak Site 1 (the calibration leak site) was set at 15 scfh for the morning and 5,000 scfh for the afternoon.

On Monday, September 13, the leak rate at Leak Site 5 was changed from 2,000 scfh to 2,500 scfh because the correct orifice plate was not available.

On Thursday, September 16, the leak rate at Leak Site 5 was changed from 5,000 scfh to OFF since this large leak site was fairly easy for the equipment providers to locate.

APPENDIX H

Field Measurements

Section 1 - Actual Leak Rates
Section 2 - Local Weather Data and Local Hydrocarbon Measurements
Section 3 - Wind Speed Data
Section 4 - Analyses of RMOTC Dry Gas

Section 1

Actual Leak Rates

Actual Leak Rates - August 30, 2004 to September 12, 2004

			Leak Rates (scfh)																				
			Dates																				
Leak Site	Gas Source	Leak Type	8/30/04			8/31/04			9/1/04			9/2/04			9/3/04			9/4/04			9/5/04		
			Time	Rate		Time	Rate		Time	Rate		Time	Rate		Time	Rate		Time	Rate		Time	Rate	
				As Found	Reset		As Found	Reset		As Found	Reset		As Found	Reset		As Found	Reset		As Found	Reset		As Found	Reset
P1	RMOTC gas	side-drilled	10:00 AM	0	1000	7:35 AM	960	1000	8:00 AM	990	1000	10:05 AM	980	1000	8:40 AM	990	1000	9:33 AM	940	1000	9:00 AM	960	1000
P2	RMOTC gas	side-drilled	10:45 AM	0	100	7:35 AM	120	100	8:11 AM	110	100	11:10 AM	99	100	8:45 AM	100	100	12:50 PM	86	99	9:10 AM	100	100
P3	RMOTC gas	side-drilled	11:15 AM	0	10	8:10 AM	23+	10	8:21 AM	16	10	11:35 AM	8	10	9:00 AM	23+	10	1:11 AM	7	10	9:18 AM	7	10
P4	RMOTC gas	side-drilled	12:50 PM	0	500	8:50 AM	680	500	9:10 AM	520	500	11:40 AM	450	500	9:10 AM	520	500	1:20 AM	490	500	9:30 AM	680	500
P5	cylinder	side-drilled	9:20 AM	0	0.9	9:25 AM	0.9	0.9	9:40 AM	0.6	0.9	11:50 AM	0.9	0.9	9:15 AM	0.9	0.9	1:23 PM	0.9	0.9	9:40 AM	0.9	0.9

			Leak Rates (scfh)																				
			Dates																				
Leak Site	Gas Source	Leak Type	9/6/04			9/7/04			9/8/04			9/9/04			9/10/04			9/11/04			9/12/04		
			Time	Rate		Time	Rate		Time	Rate		Time	Rate		Time	Rate		Time	Rate		Time	Rate	
				As Found	Reset		As Found	Reset		As Found	Reset		As Found	Reset		As Found	Reset		As Found	Reset		As Found	Reset
P1	RMOTC gas	side-drilled	10:00 AM	1000	1000	9:50 AM	1000	1000	9:15 AM	950	1000	8:40 AM	980	1000	10:40 AM	1000	1000	9:00 AM	1000	1000	10:00 AM	1000	1000
P2	RMOTC gas	side-drilled	10:05 AM	93	100	10:02 AM	120	100	9:25 AM	99	99	7:45 AM	110	100	10:50 AM	85	100	9:10 AM	110	100	10:05 AM	110	100
P3	RMOTC gas	side-drilled	10:20 AM	8	10	10:08 AM	14	10	9:32 AM	12	10	8:55 AM	23+	10	11:50 AM	0	10	10:15 AM	14	10	10:10 AM	7	10
P4	RMOTC gas	side-drilled	10:30 AM	440	500	10:15 AM	600	500	9:36 AM	510	500	8:00 AM	540	500	12:00 AM	420	500	10:30 AM	530	500	10:15 AM	480	500
P5	cylinder	side-drilled	10:35 AM	0.9	0.9	10:20 AM	0.9	0.9	9:40 AM	0.9	0.9	8:05 AM	0.9	0.9	12:15 PM	0.8	0.9	10:35 AM	0.9	0.9	10:20 AM	0.9	0.9
									4:10 PM [1]	0.8	0.9												

Notes:

1 Leak Site P2, 9/8/04, 4:10 PM - The leak site gas source was changed from cylinder #1 to cylinder #2

Actual Leak - Rates September 13-17, 2004

Leak Site	Gas Source	Leak Type	Leak Rates (scfh) — Dates: 9/13/04 Time	9/13/04 Rate As Found	9/13/04 Rate Reset	9/14/04 Time	9/14/04 Rate As Found	9/14/04 Rate Reset	9/15/04 Time	9/15/04 Rate As Found	9/15/04 Rate Reset	9/16/04 Time	9/16/04 Rate As Found	9/16/04 Rate Reset	9/17/04 Time	9/17/04 Rate As Found	9/17/04 Rate Reset
1	RMOTC gas	below ground	6:00 AM	0	5000	5:30 AM	0	1000	5:55 AM	0	500	6:45 AM	0	100	5:40 AM	0	15
			2:00 PM	4200	5000	6:40 AM	950	1000	8:15 AM	430	500	8:25 AM	46	100	2:50 PM	3.5	0
			7:20 PM	5000	0	10:15 AM	740	1000	12:25 PM	<230	500	1:45 PM	0	100	4:20 PM	0	4900
						1:40 PM	1000	1000	4:10 PM	530	500	3:30 PM	120	100	7:00 PM	4500	0
						3:45 PM	1000	1000	7:00 PM	650	0	7:20 PM	180	0			
						7:30 PM	1100	0									
2A	cylinder	below ground	N/A	0	0	N/A	0	0	N/A	0	0	N/A	0	0	5:35 AM	0	14
															3:45 PM	16	14
															7:05 PM	15	0
2B	cylinder	below ground	5:30 AM	0	15	N/A	0	0	N/A	0	0	N/A	0	0	N/A	0	0
			1:55 PM	17	15												
			4:45 PM	15	15												
			6:15 PM	15	15												
			7:20 PM	15	0												
2C	cylinder	below ground	N/A	0	0	N/A	0	0	5:50 AM	0	14	N/A	0	0	N/A	0	0
									8:30 AM	15	15						
									12:20 PM	15	15						
									6:53 PM	17	0						
3	RMOTC gas	above ground	5:25 AM	0	990	5:25 AM	0	2000	6:10 AM	0	98	6:40 AM	0	2000	5:30 AM	0	500
			1:50 PM	1000	1000	1:15 PM	1900	1900	8:40 AM	77	100	8:40 AM	0 [2]	2000	4:00 PM	460	500
			7:30 PM	1000	0	4:10 PM	2000	2000	12:15 PM	63	100	1:40 PM	2000	2000	7:10 PM	500	0
						7:15 PM	2000	0	6:45 PM	0 [1]	0	7:10 PM	2000	0			
4	RMOTC gas	below ground	5:15 AM	0	100	5:20 AM	0	500	5:40 AM	0	2000	6:40 AM	0	1000	5:25 AM	0	2000
			1:45 PM	86	100	1:10 PM	550	500	8:45 AM	1900	2000	8:45 AM	1000	1000	4:05 PM	1800	2000
			7:35 PM	120	0	4:05 PM	530	500	12:10 PM	1900	1900	1:35 PM	1000	1000	7:10 PM	2000	0
						7:10 PM	530	0	6:35 PM	2000	0	7:05 PM	1000	0			
2D	cylinder	below ground	N/A	0	0	5:45 AM	0	14	N/A	0	0	N/A	0	0	N/A	0	0
						6:45 AM	14	14									
						9:45 AM	15	15									
						1:05 PM	15	15									
						4:15 PM	15	15									
						7:05 PM	16	0									
5	RMOTC gas	below ground	5:15 AM	0	2500	5:15 AM	0	4900	5:25 AM	0	4800	N/A	0	0	6:00 AM	0	4800
			1:40 PM	2500	2500	12:55 PM	4800	4800	9:15 AM	4800	4800				8:10 AM	4800	4800
			7:20 PM	2500	0	7:30 PM	4800	0	12:50 PM	4800	4800				7:20 PM	4800	0
									7:30 PM	4800	0						
P1	RMOTC gas	side-drilled	1:10 PM	1000	1000	6:00 AM	1000	990	5:50 AM	1000	1000	7:05 AM	990	990	6:00 AM	990	990
						12:10 PM	1000	1000	9:20 AM	970	1000	10:30 AM	1000	1000	8:20 AM	950	990
									12:45 PM	1100	1000	1:40 PM	1000	1000	7:15 PM	1100	0
												7:10 PM	1000	1000			
P2	RMOTC gas	side-drilled	1:15 PM	100	100	5:50 AM	120	100	5:45 AM	86	100	7:00 AM	100	100	5:55 AM	100	100
						12:15 PM	98	98	9:30 AM	85	100	10:20 AM	100	100	8:35 AM	100	100
						7:30 PM	98	100	12:35 PM	110	100	1:40 PM	100	100	7:10 PM	100	0
												7:15 PM	120	120			
6	RMOTC gas	below ground	5:25 AM	0	500	5:25 AM	0	100	5:40 AM	0	1000	6:55 AM	0	500	5:50 AM	0	1000
			1:20 PM	500	500	12:20 PM	130	100	9:35 AM	1000	1000	10:10 AM	460	500	9:02 AM	1000	1000
			7:30 PM	500	0	7:10 PM	98	0	12:30 PM	1000	1000	1:45 PM	500	500	7:10 PM	1000	0
									7:19 PM	1010	0	7:10 PM	520	0			

Actual Leak - Rates September 13-17, 2004 (continued)

			Leak Rates (scfh)																	
			Dates																	
Leak Site	Gas Source	Leak Type	9/13/04			9/14/04			9/15/04			9/16/04			9/17/04					
			Time	Rate		Time	Rate		Time	Rate		Time	Rate		Time	Rate				
				As Found	Reset		As Found	Reset		As Found	Reset		As Found	Reset		As Found	Reset			
2E	cylinder	below ground	N/A	0	0	N/A	0	0	N/A	0	0	6:50 AM	0	14	N/A	0	0			
												10:05 AM	14	15						
												1:50 PM	15	15						
												7:05 PM	17	0						
P3	RMOTC gas	side-drilled	5:35 AM	23+	10	5:40 AM	23+	10	5:40 AM	23+	18	6:45 AM	23+	18	5:45 AM	23+	17			
			1:30 PM	0	10	12:30 AM	0	10	7:40 AM	17	17	1:55 PM	0	10	9:15 AM	0	10			
						9:22 AM	13	10	9:40 AM	6	10	4:10 PM	12	10	7:05 PM	10	0			
									12:25 AM	6	10	7:00 PM	22	10						
									3:55 PM	9	10									
P4	RMOTC gas	side-drilled	1:30 PM	480	500	5:35 AM	500	500	5:35 AM	500	500	6:40 AM	540	540	5:40 AM	570	550			
						12:40 PM	500	500	9:45 AM	500	500	9:15 AM	520	520	9:40 AM	490	490			
									12:20 PM	500	500	1:55 PM	490	490	7:00 PM	500	0			
												6:55 PM	500	500						
P5	cylinder	side-drilled	5:30 AM	0.9	0.9	5:30 AM	0.9	0.9	5:30 AM	0.9	0.9	6:35 AM	0.9	0.9	5:35 AM	0.9	0.9			
			1:35 PM	0.8	0.9	12:45 PM	0.8	0.9	9:50 AM	0.8	0.9	9:05 AM	0.8	0.9	9:30 AM	0.8	0.9			
									12:15 PM	0.9	0.9	2:00 PM	0.9	0.9	7:00 PM	0.9	0.0			
												6:45 PM	0.9	0.9						
"Phantom" Methane Leak																				
1F	cylinder	below ground	N/A	0	0	N/A	0	0	5:35 AM	0	14	N/A	0	0	5:45 AM	0	15			
									9:05 AM	15	15				4:10 PM	16	15			
									12:30 PM	15	15				7:12 PM	17	0			
									7:07 PM	18	0									

Notes:

1 Leak Site 3, 9/15/04 - the leak was shut off at the gas source by a well workover crew at approximately 1:30 PM

2 Leak Site 3, 9/16/04, 8:40 AM - the leak was shut off at the gas source by a well workover crew not long before 8:40 AM. Some gas was heard to be flowing upon arrival at site, but had stopped before we reached the rotameter

Section 2

Local Weather Data and Local Hydrocarbon Measurements

Local Weather and Hydrocarbon Gas Measurements

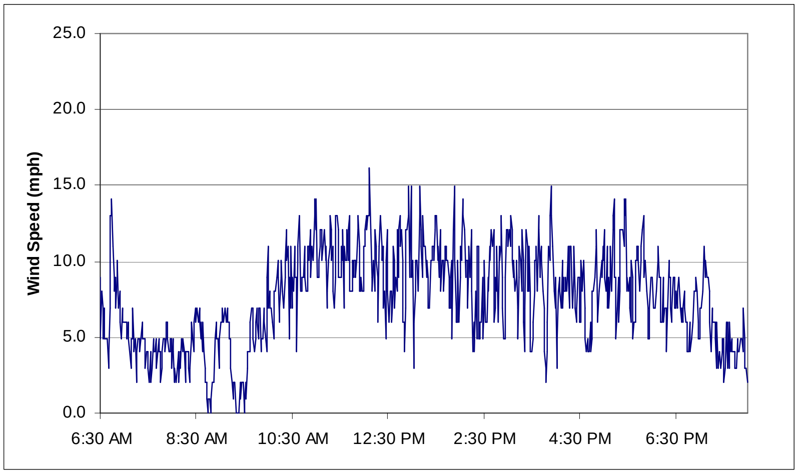
			Local Site Weather Conditions							Hydrocarbon Gas (FID) Measurements							
			Wind			Temp. (F)	Relative Humidity (%)	Baro. Pressure (in Hg)	Position 1 (approx 10 ft)				Position 2 (approx 30 ft)			
Date	Time	Site	Min Speed (mph)	Max Speed (mph)	Direction True N				N (Lat)	W (Long)	min (ppm)	max (ppm)	N (Lat)	W (Long)	min (ppm)	max (ppm)
9/13/04	7:42 AM	1	1.3	3.9	154	56.7	59.3	24.57	43 14 53.8	106 11 12.3	300	5000	43 14 54.1	106 11 12.1	20	6000
9/13/04	8:03 AM	3	3.5	4.8	188	54.8	67.9	24.62	43 15 15.8	106 12 19.2	2000	6000	43 15 16.2	106 12 19.1	500	1000
9/13/04	8:08 AM	4	2.0	4.6	187	55.0	65.2	24.60	43 16 20.4	106 12 24.3	500	900	43 16 20.6	106 12 24.3	0	80
9/13/04	8:21 AM	5	2.2	2.5	170	56.6	62.8	24.59	43 17 44.3	106 13 15.7	10	4500	43 17 44.5	106 13 15.8	500	2000
9/13/04	5:53 PM	6	2.0	7.9	272	75.1	19.4	24.70	43 18 56.2	106 13 30.7	100	5000	43 18 56.2	106 13 30.1	200	3000
9/13/04	7:54 AM	2B	2.8	5.8	218	54.1	64.0	24.50	43 15 26.5	106 11 59.7	2	300	43 15 26.7	106 11 59.6	5	15
9/13/04	8:28 AM	P1	5.1	6.9	186	54.9	66.5	24.66	43 18 13.3	106 13 6.2	10	6000	43 18 13.5	Not Avail	10	1000
9/13/04	6:06 PM	P2	8.4	11.3	272	72.4	18.8	24.68	43 18 36.9	106 13 18.0	50	800	43 18 36.7	106 13 17.2	5	10
9/13/04	5:45 PM	P3	2.6	5.2	276	74.7	22.4	24.81	43 19 44.4	106 13 52.0	10	20	43 19 44.3	106 13 51.6	0	0
9/13/04	5:29 PM	P4	9.1	11.8	280	72.2	19.8	24.82	43 20 13.0	106 13 37.9	500	700	43 20 12.9	106 13 37.3	0	2
9/13/04	5:37 PM	P5	5.6	8.1	32	68.6	24.2	24.85	43 20 27.5	106 13 36.5	0	2	N/A	N/A	N/A	N/A
9/14/04	3:50 PM	1	5.4	9.9	322	65.1	23.5	24.54	43 14 53.5	106 11 12.3	5000	10000	43 14 53.3	106 11 12.2	1000	2000
9/14/04	3:59 PM	3	3.5	7.0	312	64.5	25.5	24.60	43 15 15.4	106 12 19.3	2000	5000	43 15 15.2	106 12 19.1	1000	2000
9/14/04	4:04 PM	4	4.9	7.9	332	63.2	26.7	24.59	43 16 20.0	106 12 24.4	1000	200	43 16 19.9	106 12 24.0	500	1000
9/14/04	8:53 AM	5	3.6	6.6	187	59.1	39.4	24.62	43 17 44.0	106 13 15.7	N/A	10000	43 17 44.4	106 13 15.7	2000	6000
9/14/04	9:15 AM	6	4.2	4.6	312	53.8	51.0	24.71	43 18 56.5	106 13 30.5	400	1000	43 18 56.1	106 13 30.0	200	400
9/14/04	4:16 PM	2D	6.0	10.2	332	64.4	26.4	24.55	43 16 34.3	106 12 42.9	10	100	43 16 34.1	106 12 42.9	5	25
9/14/04	8:40 AM	ES&H	5.7	7.5	192	57.2	40.0	24.53	43 17 02.5	106 12 57.3	100	2000	N/A	N/A	N/A	N/A
9/14/04	8:58 AM	P1	5.0	5.6	332	56.2	47.9	24.69	43 18 13.0	106 13 6.1	200	800	43 18 12.6	106 13 6.1	1000	3500
9/14/04	9:04 AM	P2	6.0	6.9	312	52.6	54.4	24.69	43 18 36.6	106 13 17.4	200	400	43 18 36.4	106 13 17.0	40	60
9/14/04	9:22 AM	P3	5.3	8.2	312	58.0	47.0	24.83	43 19 44.5	106 13 51.5	2	5	43 19 44.5	106 13 51.4	1	3
9/14/04	9:29 AM	P4	3.2	3.9	328	60.6	44.6	24.84	43 20 12.6	106 13 37.7	100	300	43 20 12.2	106 13 37.5	100	200
9/14/04	9:35 AM	P5	2.3	5.2	308	61.5	43.8	24.87	43 20 27.3	106 13 36.1	1	2	43 20 27.1	106 13 36.0	1	1
9/15/04	8:14 AM	1	3.3	7.4	192	47.5	40.3	24.76	43 14 53.8	106 11 12.1	200	800	43 14 54.0	106 11 12.1	200	500
9/15/04	8:40 AM	3	4.6	6.5	222	50.2	41.3	24.82	43 15 15.8	106 12 19.3	100	400	43 15 15.9	106 12 19.0	5	10
9/15/04	8:46 AM	4	3.5	7.8	222	49.6	40.8	24.81	43 16 20.3	106 12 24.4	N/A	10000	43 16 20.5	106 12 24.1	1000	400
9/15/04	9:12 AM	5	7.8	14.3	242	50.8	34.5	24.80	43 17 44.2	106 13 15.6	5000	10000	43 17 44.3	106 13 15.2	2000	5000
9/15/04	9:36 AM	6	11.6	14.7	270	52.8	30.8	24.90	43 18 56.1	106 13 30.4	3000	6000	43 18 56.2	106 13 29.8	400	800
9/15/04	9:04 AM	1F	5.8	10.2	242	52.5	31.6	24.77	43 16 34.4	106 12 42.8	20	100	43 16 34.5	106 12 42.4	5	40
9/15/04	8:31 AM	2C	4.6	8.4	228	51.3	39.7	24.72	43 15 46.2	106 12 08.9	0	60	N/A	N/A	N/A	N/A
9/15/04	9:17 AM	P1	2.4	5.4	262	54.7	30.9	24.88	43 18 13.1	106 13 5.9	2000	4000	43 18 13.1	106 13 5.5	30	600

Local Weather and Hydrocarbon Gas Measurements

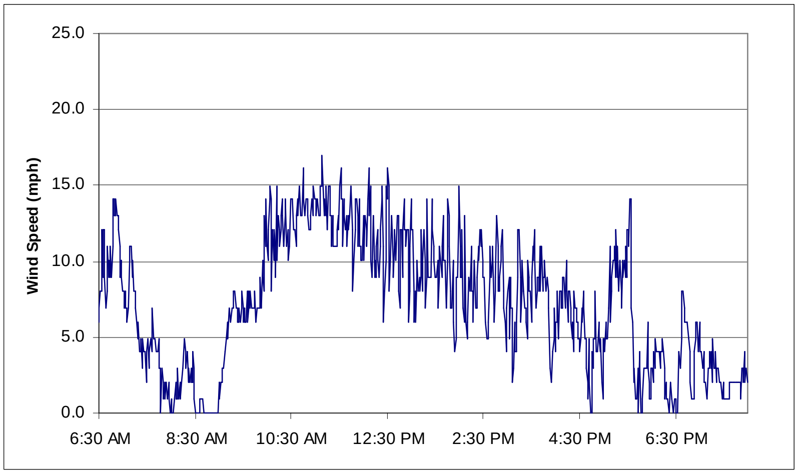
			Local Site Weather Conditions						Hydrocarbon Gas (FID) Measurements							
			Wind			Temp. (F)	Relative Humidity (%)	Baro. Pressure (in Hg)	Position 1 (approx 10 ft)				Position 2 (approx 30 ft)			
Date	Time	Site	Min Speed (mph)	Max Speed (mph)	Direction True N				N (Lat)	W (Long)	min (ppm)	max (ppm)	N (Lat)	W (Long)	min (ppm)	max (ppm)
9/15/04	9:30 AM	P2	5.4	10.8	272	54.4	31.4	24.87	43 18 37.0	106 13 17.6	20	80	43 18 36.9	106 13 16.9	30	80
9/15/04	3:52 PM	P3	Not Avail	Not Avail	292	Not Avail	Not Avail	Not Avail	43 19 44.7	106 13 51.9	0	10	N/A	N/A	N/A	N/A
9/15/04	9:47 AM	P4	7.2	11.1	272	55.5	28.2	25.02	43 20 12.9	106 13 37.6	200	300	43 20 12.7	106 13 37.3	30	60
9/15/04	9:52 AM	P5	7.9	12.4	242	56.7	30.1	25.04	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9/16/04	8:28 AM	1	2.7	3.7	207	60.5	23.3	24.66	43 14 53.8	106 11 12.2	30	100	43 14 54.1	106 11 12.0	20	80
9/16/04	8:43 AM	3	6.7	8.3	228	60.4	25.1	24.73	43 15 15.6	106 12 19.3	2000	6000	43 15 15.9	106 12 19.0	1000	2000
9/16/04	8:52 AM	4	7.4	12.5	224	60.1	25.0	24.71	43 16 20.2	106 12 24.4	2000	5000	43 16 20.3	106 12 24.1	200	800
9/16/04	10:12 AM	6	15.6	17.3	272	64.3	22.2	24.82	43 18 56.5	106 13 30.3	400	600	43 18 56.5	106 13 28.5	20	80
9/16/04	10:05 AM	2E	8.4	9.8	248	65.5	21.9	24.87	43 19 12.3	106 13 40.4	100	200	43 19 12.4	106 13 40.1	15	20
9/16/04	10:31 AM	P1	7.5	8.6	236	66.5	19.8	24.80	43 18 13.2	106 13 5.9	2000	4000	43 18 13.3	106 13 5.5	200	600
9/16/04	10:22 AM	P2	6.4	10.7	Not Avail	66.2	22.2	24.79	43 18 37.1	106 13 17.7	5	25	43 18 37.3	106 13 17.4	2	15
9/16/04	9:23 AM	P3	8.5	12.1	252	62.1	24.5	24.93	43 19 44.5	106 13 51.7	1	5	N/A	N/A	N/A	N/A
9/16/04	9:15 AM	P4	3.5	5.9	242	64.0	23.6	24.95	43 20 12.8	106 13 37.7	200	600	43 20 13.0	106 13 37.3	40	80
9/16/04	9:07 AM	P5	3.5	4.2	214	64.2	24.2	24.97	43 20 27.5	106 13 36.4	2	3	N/A	N/A	N/A	N/A
9/17/04	2:50 PM	1	6.3	8.6	234	86.7	11.0	24.64	43 14 53.7	106 11 12.2	10	100	43 14 53.8	106 11 11.8	10	20
9/17/04	4:00 PM	3	6.6	13.9	232	87.4	10.0	24.68	43 15 15.7	106 12 19.2	200	800	43 15 15.8	106 12 19.0	100	400
9/17/04	4:05 PM	4	9.4	14.1	242	86.1	8.8	24.66	43 16 20.1	106 12 24.4	1000	4000	43 16 20.5	106 12 24.0	200	600
9/17/04	8:10 AM	5	5.0	11.4	240	62.6	21.4	24.73	43 17 44.3	106 13 15.7	100	6000	43 17 44.5	106 13 15.4	500	6000
9/17/04	9:00 AM	6	9.8	11.0	240	64.5	20.6	24.83	43 18 56.5	106 13 30.4	2000	400	43 18 56.8	106 13 30.1	0	200
9/17/04	4:10 PM	1F	5.8	8.6	252	85.3	8.5	24.63	43 16 34.5	106 12 42.9	10	60	43 16 34.6	106 12 42.6	10	20
9/17/04	3:45 PM	2A	11.6	15.7	228	86.1	9.3	24.58	43 15 13.1	106 11 49.9	0	100	N/A	N/A	N/A	N/A
9/17/04	8:18 AM	P1	6.4	7.5	228	62.5	22.1	24.80	43 18 13.3	106 13 6.4	4000	6000	43 18 13.5	106 13 5.8	1000	3000
9/17/04	8:37 AM	P2	5.2	8.2	232	62.6	21.4	24.80	43 18 37.2	106 13 18.1	20	200	43 18 37.4	106 13 17.6	10	100
9/17/04	9:15 AM	P3	7.1	9.3	220	67.5	18.7	24.94	43 19 44.7	106 13 51.2	2	6	N/A	N/A	N/A	N/A
9/17/04	9:39 AM	P4	4.7	8.8	226	70.6	17.5	24.96	43 20 13.2	106 13 37.5	200	600	43 20 13.3	106 13 37.4	100	300
9/17/04	9:30 AM	P5	5.1	8.2	212	71.1	19.0	24.98	43 20 27.8	106 13 36.2	10	20	43 20 28.0	106 13 36.0	1	2

Section 3

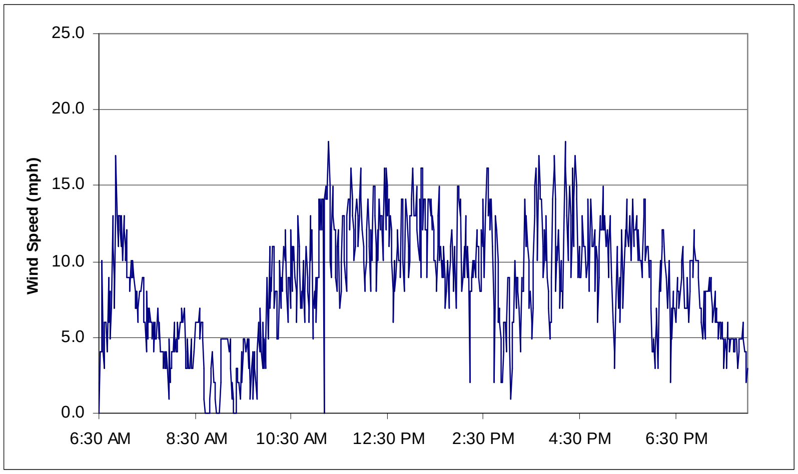
Wind Speed Data



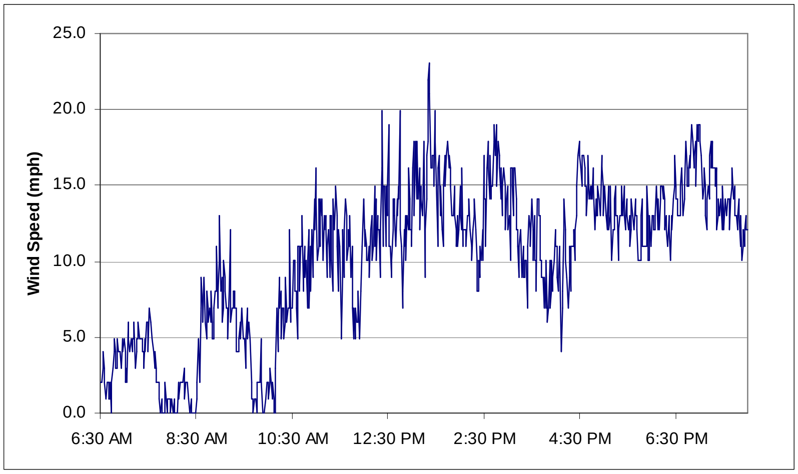
Wind Speed Data Collected on Monday, September 13
The plot represents data collected from Weather Station WS 1.



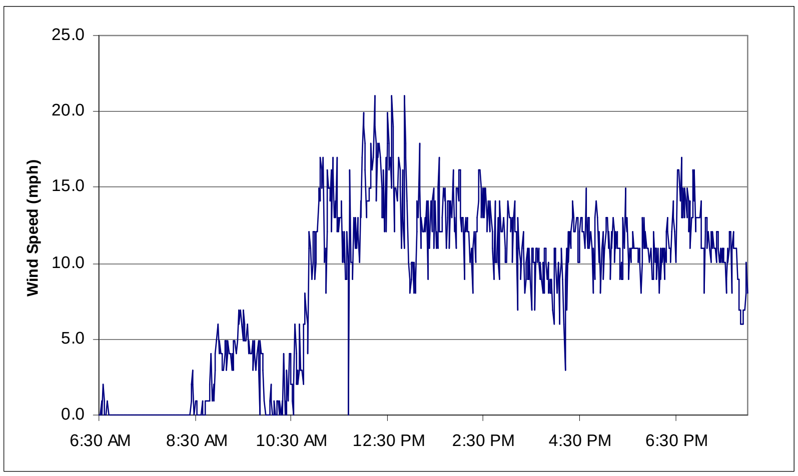
Wind Speed Data Collected on Monday, September 13
The plot represents data collected from Weather Station WS 2.



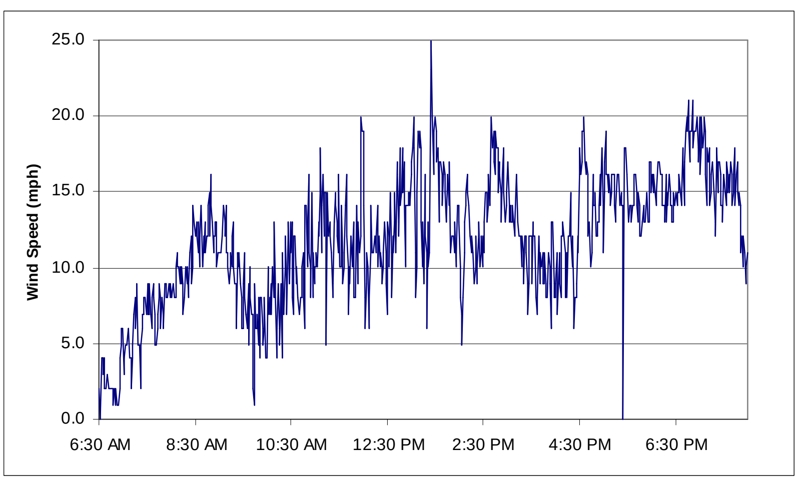
Wind Speed Data Collected on Monday, September 13
The plot represents data collected from Weather Station WS 3.



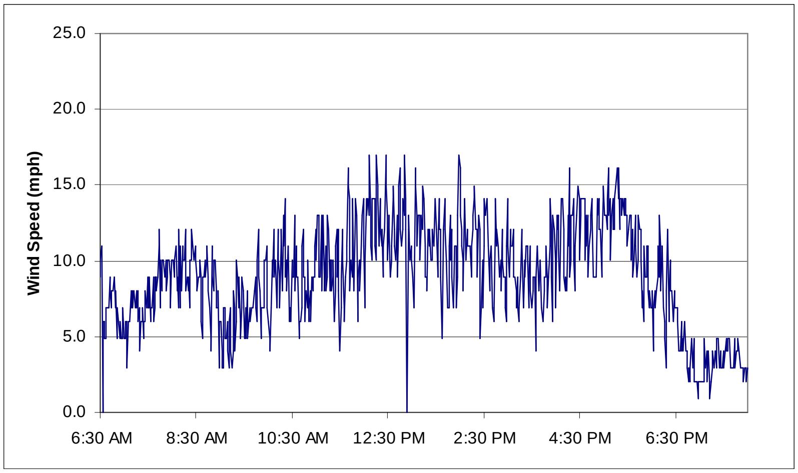
Wind Speed Data Collected on Tuesday, September 14
The plot represents data collected from Weather Station WS 1.



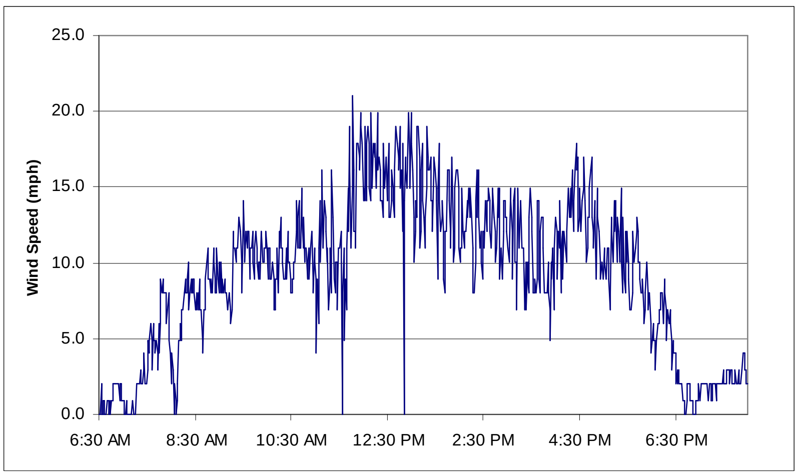
Wind Speed Data Collected on Tuesday, September 14
The plot represents data collected from Weather Station WS 2.



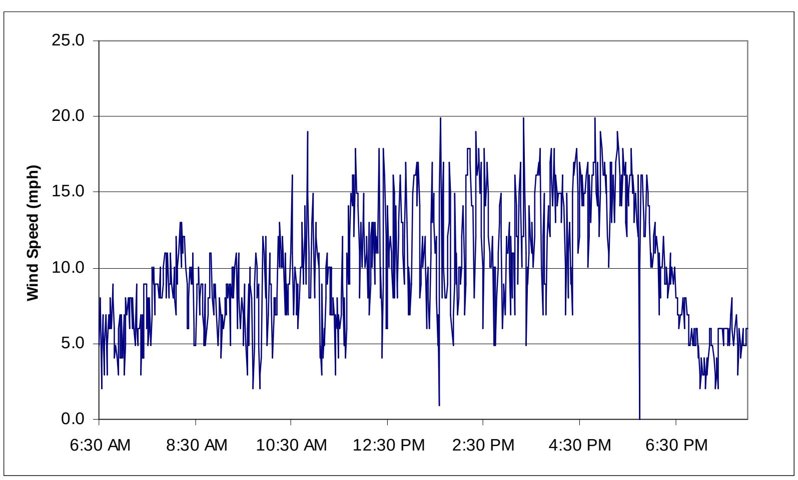
Wind Speed Data Collected on Tuesday, September 14
The plot represents data collected from Weather Station WS 3.



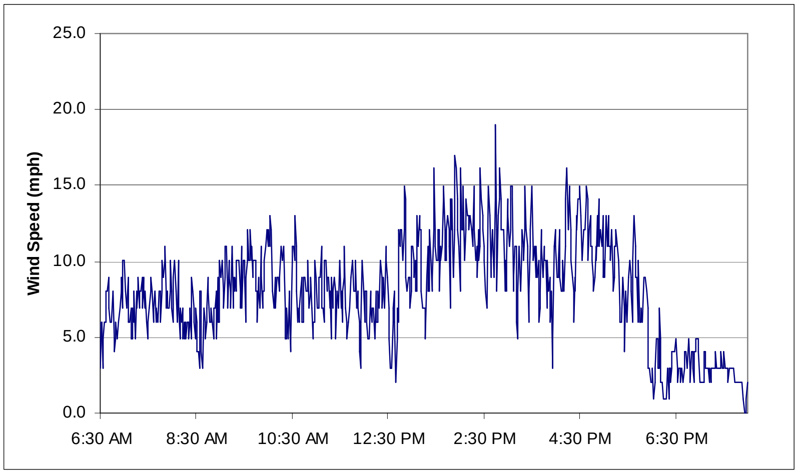
Wind Speed Data Collected on Wednesday, September 15
The plot represents data collected from Weather Station WS 1.



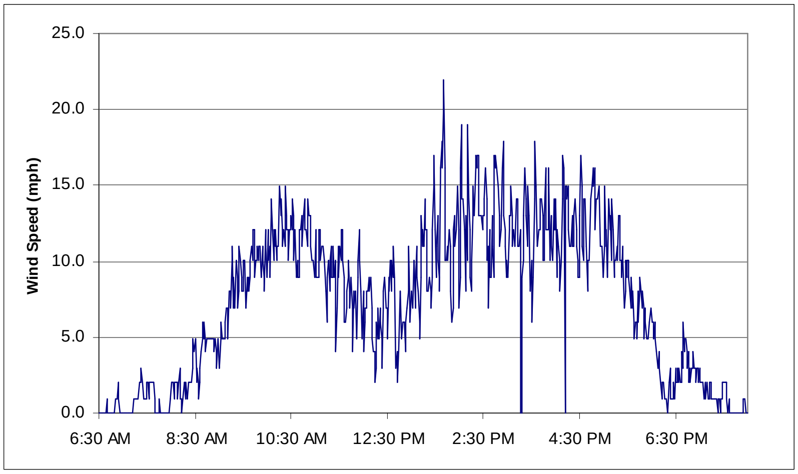
Wind Speed Data Collected on Wednesday, September 15
The plot represents data collected from Weather Station WS 2.



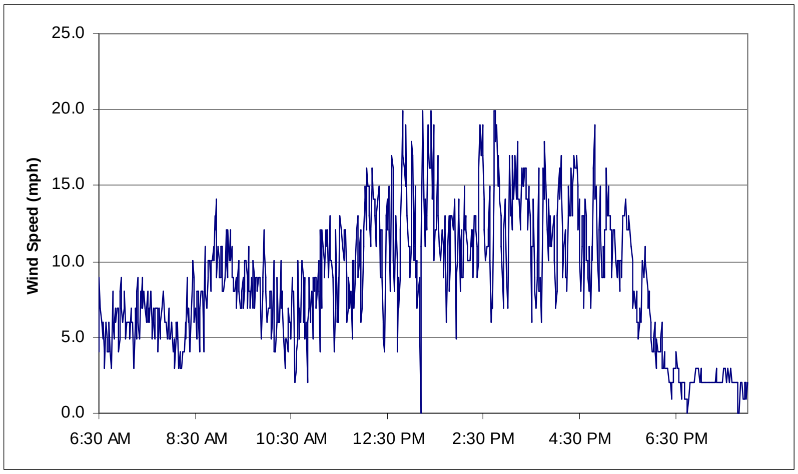
Wind Speed Data Collected on Wednesday, September 15
The plot represents data collected from Weather Station WS 3.



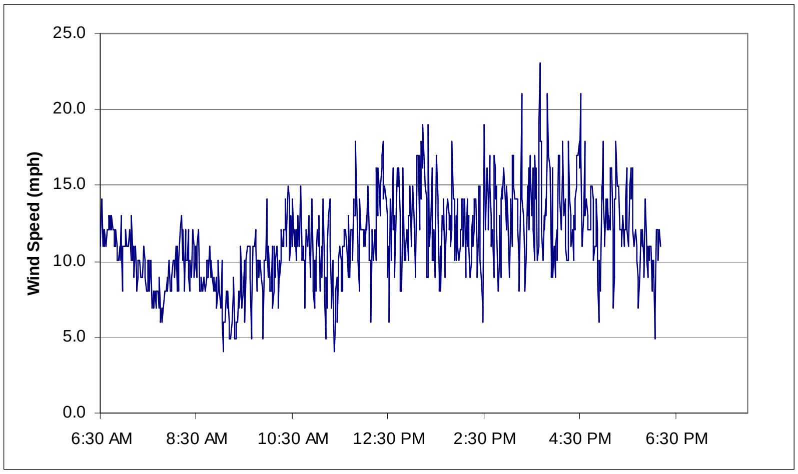
Wind Speed Data Collected on Thursday, September 16
The plot represents data collected from Weather Station WS 1.



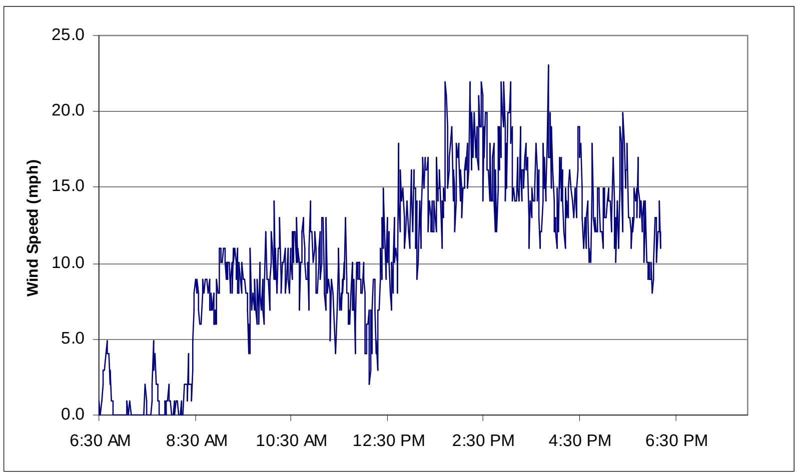
Wind Speed Data Collected on Thursday, September 16
The plot represents data collected from Weather Station WS 2.



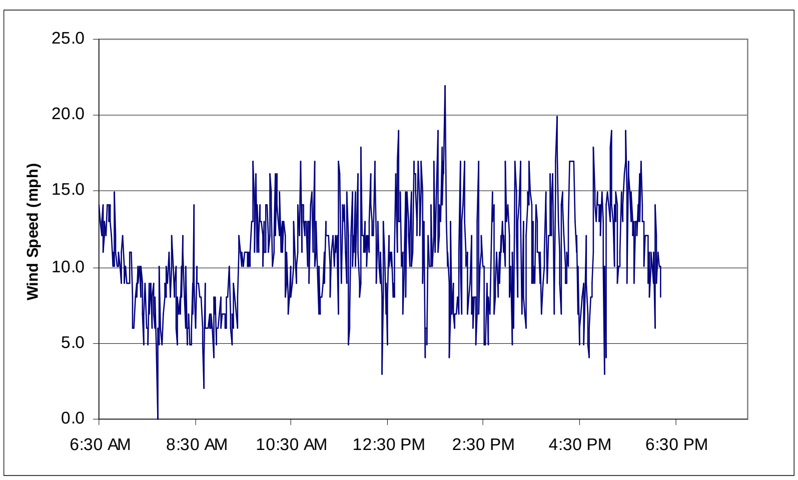
Wind Speed Data Collected on Thursday, September 16
The plot represents data collected from Weather Station WS 3.



Wind Speed Data Collected on Friday, September 17
The plot represents data collected from Weather Station WS 1.



Wind Speed Data Collected on Friday, September 17
The plot represents data collected from Weather Station WS 2.



Wind Speed Data Collected on Friday, September 17
The plot represents data collected from Weather Station WS 3.

Section 4

Analyses of RMOTC Dry Gas

ANALYSES OF RMOTC DRY GAS

SEP 13, 2004

Component	MOL%
N2 N202	1.788
Methane	87.921
CO2	3.034
Ethane	5.320
Propane	1.438
Iso-Butane	0.116
N-Butane	0.198
Iso-Pentane	0.042
N-Pentane	0.039
Hexane+	0.104

G.P.M. 0.5694
SPECIFIC GRAV. 0.6400
BTU/CU. FT. 1037.2600

SEP 14, 2004

Component	MOL%
N2 N202	1.813
Methane	88.243
CO2	3.003
Ethane	5.155
Propane	1.327
Iso-Butane	0.106
N-Butane	0.181
Iso-Pentane	0.039
N-Pentane	0.037
Hexane+	0.098

G.P.M. 0.5253
SPECIFIC GRAV. 0.6373
BTU/CU. FT. 1033.3200

SEP 15, 2004

Component	MOL%
N2 N202	1.801
Methane	87.997
CO2	3.022
Ethane	5.326
Propane	1.370
Iso-Butane	0.109
N-Butane	0.188
Iso-Pentane	0.043
N-Pentane	0.039
Hexane+	0.105

G.P.M. 0.5461
SPECIFIC GRAV. 0.6391
BTU/CU. FT. 1035.9700

SEP 16, 2004

Component	MOL%
N2 N202	1.802
Methane	88.106
CO2	3.019
Ethane	5.163
Propane	1.414
Iso-Butane	0.115
N-Butane	0.185
Iso-Pentane	0.042
N-Pentane	0.039
Hexane+	0.105

G.P.M. 0.5616
SPECIFIC GRAV. 0.6389
BTU/CU. FT. 1035.6500

SEP 17, 2004

Component	MOL%
N2 N202	1.790
Methane	87.830
CO2	3.037
Ethane	5.334
Propane	1.505
Iso-Butane	0.121
N-Butane	0.205
Iso-Pentane	0.044
N-Pentane	0.041
Hexane+	0.094

G.P.M. 0.5881
SPECIFIC GRAV. 0.6407
BTU/CU. FT. 1038.2300

APPENDIX I

Equipment Provider Test Reports (SwRI Format)

Section 1 - En'Urga Inc.
Section 2 - ITT Industries, Inc.
Section 3 - LaSen, Inc.
Section 4 - Lawrence Livermore National Laboratories
Section 5 - PSI Corporation

Note: These reports were completed by the equipment providers prior to SwRI divulging the actual leak sites and leak rates. That is, they include "blind" test results. Any claims of leaks detected should be considered preliminary, and the analysis of the results is provided in Section 4.3. The claims and comments of the equipment providers do not reflect the opinions of the Department of Energy.

Section 1

En’Urga Inc.

Note: This reports was completed by the equipment provider prior to SwRI divulging the actual leak sites and leak rates. That is, it includes “blind” test results. Any claims of leaks detected should be considered preliminary, and the analysis of the results is provided in Section 4.3. The claims and comments of the equipment provider do not reflect the opinions of the Department of Energy.

EQUIPMENT PROVIDER TEST REPORT

for

En'Urga Inc.

Prepared by:

Yudaya Sivathanu

On:

September 27, 2004

1. DESCRIPTION OF LEAK DETECTION SYSTEM

1.1 Sensor System Description (with block diagram)

En'Urga Inc. utilizes a low cost multi-spectral imager for detecting leaks. A schematic diagram of the optical design for the scanner is shown in Fig. 1.

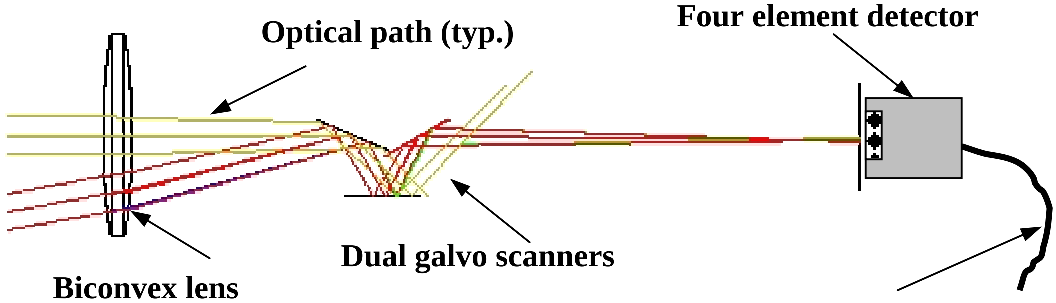


Figure 1. Schematic diagram of the optical design for the multi-spectral scanner.

The system determines the background emission at four mid infrared wavelengths. The emission intensities at these wavelengths are used to detect the presence of methane in the path. The sensor is meant to be mounted on a non-moving platform for continuous monitoring of the surrounding areas. Currently, the signals from the four detectors are sampled using a data acquisition system controlled by a laboratory computer. The data is collected for a fixed interval of time, and analyzed to determine the presence of natural gas.

A photograph of the multi-spectral scanner, mounted on a tripod is shown in Fig. 2. The front end of the system houses a two dimensional scanner. The four element detector, the drive circuit and power supply PCBs are housed in a cast aluminum enclosure. The system is designed to look at a 50 feet wide path across the pipeline.

Figure 2. Photograph of the multi-spectral scanner mounted on a tripod.

1.2 Platform Description

For the leak tests performed at RMOTC, the system was mounted on a tripod inside a mini-van. The computer and data acquisition system was also placed within the mini-van. Data was collected continuously during the drive through and analyzed later to provide the leak locations. The high speed required to scan a long pipeline from a moving platform, as opposed to a stationary platform, required data collection in one step and subsequent analysis off-line. Therefore, it was not possible to stop at suspected leak sites and obtain more definite data.

1.3 Pre-Test Checks

The pre-test checks conducted were to ensure that the system was obtaining sufficient signals from the background radiation.

2. DATA COLLECTION AND REDUCTION SCHEME

The data acquisition system collected the voltages on the four channels at a frequency of 10 Hz. Due to the difficulty in changing the orientation of the scanner, only one side of the road was scanned during each run. One continuous file of data was collected for each segment of the road, marked by the road crossing symbols, RC1, RC2, etc. Each file was named RCx-Rcy_date.scn, where x and y are the two neighboring road crossings. The data files were analyzed off-line to determine the absence/presence of natural gas leaks. The location of the leak was approximated by interpolating between the GPS readings of the two road crossing locations, with the ratio being determined by the position of the leak indication in the data file. This was necessary since the current system was not capable of simultaneously obtaining and displaying the leak at sufficiently high speeds required by the specific RMOTC test conditions.

3. TEST DATA

The system was tested on five separate passes. Only a portion of the pipeline was covered during each pass, as described in the following. The GPS data for the leaks were obtained based on interpolation of the road crossing markers since the system could not display leak data at sufficiently fast rate to enable scanning of nine miles.

3.1 Day 1

3.1.1 Data Collection Routes

During the first run, we discovered that changing the scanner from viewing the right side of the road to the left side of the road resulted required 10 minutes. In addition, the morning pass was started about 45 minutes late. Therefore, only the following road segments were scanned in the morning pass.

1. Calibration leak site (M1 to RC1)
2. RC3 to RC4
3. RC5 to RC6
4. RC6a to RC6b
5. RC10 to RC11

During the afternoon pass, the entire right side of the road was scanned.

3.1.2 Table of Gas Concentration Measurements for Each Pass (include in Attachment A)

The leaks detected in some of the above road segments are included in Attachment A.

3.1.3 Description of System/Software Modifications Made Throughout Testing

The detector used in the system failed near the end of the afternoon run due to excessive vibration. A second detector was placed in the system. In addition, the optics started getting very dusty requiring frequent clean up and degradation of the signal.

3.2 Day 2

3.2.1 Data Collection Routes (NOTE: include details regarding flight or driving paths for each data collection pass)

During the morning run, the right side of the road was scanned. During the afternoon run, the left side of the road was scanned.

3.2.2 Table of Gas Concentration Measurements for Each Pass (include in Attachment B)

The leaks detected in some of the above road segments are included in Attachment B.

3.2.3 Description of System/Software Modifications Made Throughout Testing

None

3.3 Day 3

3.3.1 Data Collection Routes (NOTE: include details regarding flight or driving paths for each data collection pass)

During the morning, the right side of the road segment was scanned. The system was getting very dirty and the signal was getting substantially degraded. Therefore, all tests were stopped after the morning of the third day.

3.3.2 Table of Gas Concentration Measurements for Each Pass (include in Attachment C)

The leaks detected in some of the above road segments are included in Attachment C.

3.3.3 Description of System/Software Modifications Made Throughout Testing

(start typing here)

3.4 Day 4

Did not test the system on Day 4.

3.5 Day 5

Did not test the system on Day 5.

4. SUMMARY OF RESULTS

(NOTE: quantitative and/or qualitative information regarding leak locations and system performance)

The two major problems with the system was that it was not able to operate reliably under the excessive vibration. In addition, the system was too slow to scan the entire road during the allotted time. Finally, the system performance degraded during the tests due to the dust particles being accumulated on the optics.

A further point of interest is that with the current system, there is not much control of the exact location being scanned. The road itself is very uneven and pointing the scanner towards the right and starting a 50 feet scan from the edge of the road till the pipeline is not easy to do from a moving van. It is essential that for future tests, the system is hoisted on a boom to extend directly over the pipe line. Alternatively, an ATV can be used to drive directly over the pipeline, with the scanner pointing directly on top of the pipeline. This will eliminate many of the problems associated with lack of proper aiming of the system.

The system was able to detect methane in 17 of the files collected. It is not known for certain if the methane was from the leak site or was transported to that location by the wind.

5. CONCLUSIONS

The major conclusion of the leak tests conducted is that further work is required to perfect the scanner. Only the feasibility of the multi-spectral scanning system was proven during the tests. Given the current developmental stage of the system, it was not possible to conduct a rigorous evaluation of its performance.

ATTACHMENTS

ATTACHMENT A– DAILY TEST DATA (DAY 1)

NAD 27 GPS Data (DD MM SS.S) Latitude	Longitude	Leak Detection (large, medium, small leak)	Date	Time	Pass Number	Comments
43 14 53.6	106 11 12.1	Big leak at calibration site	9/13/04	10.40	Morning pass 1	Drive by at 6 m/hr
43.16.53	106.12.54	Small leak	9/13/04	11.09	Morning pass 1	Drive by at 6 m/hr
43.19.05	106 13.33	Small leak	9/13/04	11.16	Morning pass 1	Drive by at 6 m/hr
43 14 53.6	106 11 12.1	Big leak at calibration site	9/13/04	3.02	Afternoon pass 1	Drive by at 6 m/hr
43.15.02	106.11.42	Medium leak	9/13/04	3.09	Afternoon pass 1	Drive by at 6 m/hr
43.18.26	106.13.12	Big leak	9/13/04	3.43	Afternoon pass 1	Drive by at 6 m/hr

ATTACHMENT B– DAILY TEST DATA (DAY 2)

NAD 27 GPS Data (DD MM SS.S) Latitude	Longitude	Leak Detection (large, medium, small leak)	Date	Time	Pass Number	Comments
43 14 53.6	106 11 12.1	Medium leak at calibration site	9/14/04	10.00	Morning pass 1	Stationary detection/high wind
43.15.50	106.12.47	Medium leak	9/14/04	10.30	Morning pass 1	Drive by at 6 m/hr
43.17.30	106.13.17	Small leak	9/14/04	10.38	Morning pass 1	Drive by at 6 m/hr
43.19.14	106.13.40	Medium leak	9/14/04	10.52	Morning pass 1	Drive by at 6 m/hr
43 14 53.6	106 11 12.1	Did not detect calibration leak	9/14/04	3.00	Afternoon pass 1	Drive by at 6 m/hr/Very high winds
43.15.35	106.12.01	Medium	9/14/04	3.20	Afternoon pass 1	Drive by at 6 m/hr
43.17.49	106.13.16	Big	9/14/04	3.40	Afternoon pass 1	Drive by at 6 m/hr

ATTACHMENT C– DAILY TEST DATA (DAY 3)

NAD 27 GPS Data (DD MM SS.S) Latitude	Longitude	Leak Detection (large, medium, small leak)	Date	Time	Pass Number	Comments
43 14 53.6	106 11 12.1	Medium leak at calibration site	9/15/04	10.26	Morning pass 1	Drive by at 6 m/hr
43.15.09	106.11.47	Small leak	9/15/04	10.35	Morning pass 1	Drive by at 6 m/hr
43.15.43	106.12.10	Medium leak	9/15/04	10.52	Morning pass 1	Drive by at 6 m/hr
43.19.59	106.13.44	Small leak	9/15/04	11.30	Morning pass 1	Drive by at 6 m/hr

Section 2

ITT Industries, Inc.

Note: This reports was completed by the equipment provider prior to SwRI divulging the actual leak sites and leak rates. That is, it includes “blind” test results. Any claims of leaks detected should be considered preliminary, and the analysis of the results is provided in Section 4.3. The claims and comments of the equipment provider do not reflect the opinions of the Department of Energy.

EQUIPMENT PROVIDER TEST REPORT

Prepared by ITT Industries

October 8, 2004

1. DESCRIPTION OF LEAK DETECTION SYSTEM

1.1 Sensor System Description (with block diagram)

The ITT Industries Natural Gas Emission Lidar (ANGEL) system is designed to provide users with quantitative information on the emission of natural gas from transmission pipelines. The information includes the geolocation of emissions. The system will provide both standardized and customized reports to customers on the emissions identified by the ANGEL system. The system includes pre-flight mission planning, airborne survey for emissions, and post-flight data processing to prepare the reports for customers.

The airborne portion of the ANGEL System consists of an aircraft and an integrated payload. The ground portion consists of a set of networked computer workstations that provide the required mission planning data to perform an airborne operation. These workstations are then used to process, analyze, archive, display and distribute the results of ANGEL survey work to customers.

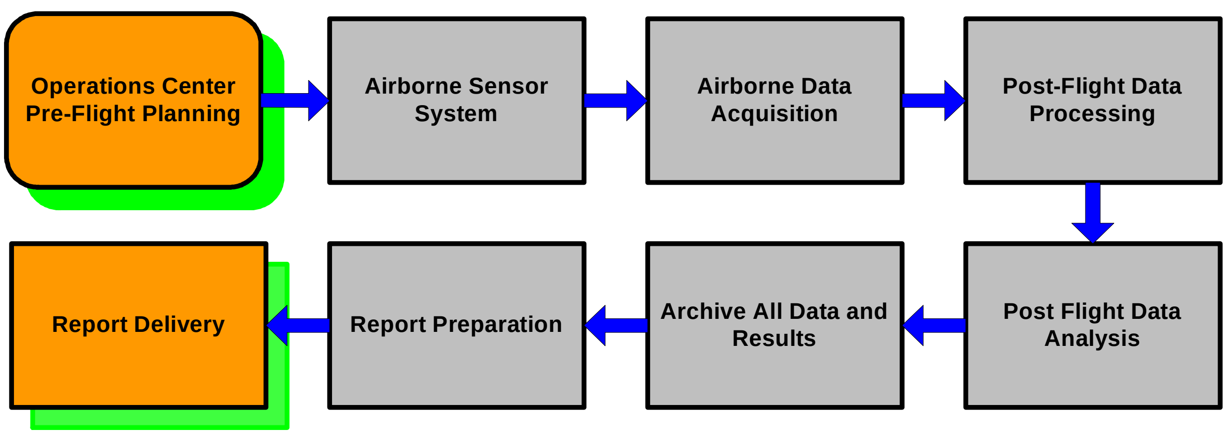


Figure 1.1.1 ANGEL System Block Diagram

1.1.1 System Function

The airborne portion of the system is based on Differential Lidar Absorption (DIAL) technology and is used to survey the pipeline corridor for natural gas emissions. The airborne platform flies over the pipeline corridor to collect the raw data. Figure 1.1.2 gives an artist conceptual drawing of the in-flight survey of a plume created by natural gas emission.

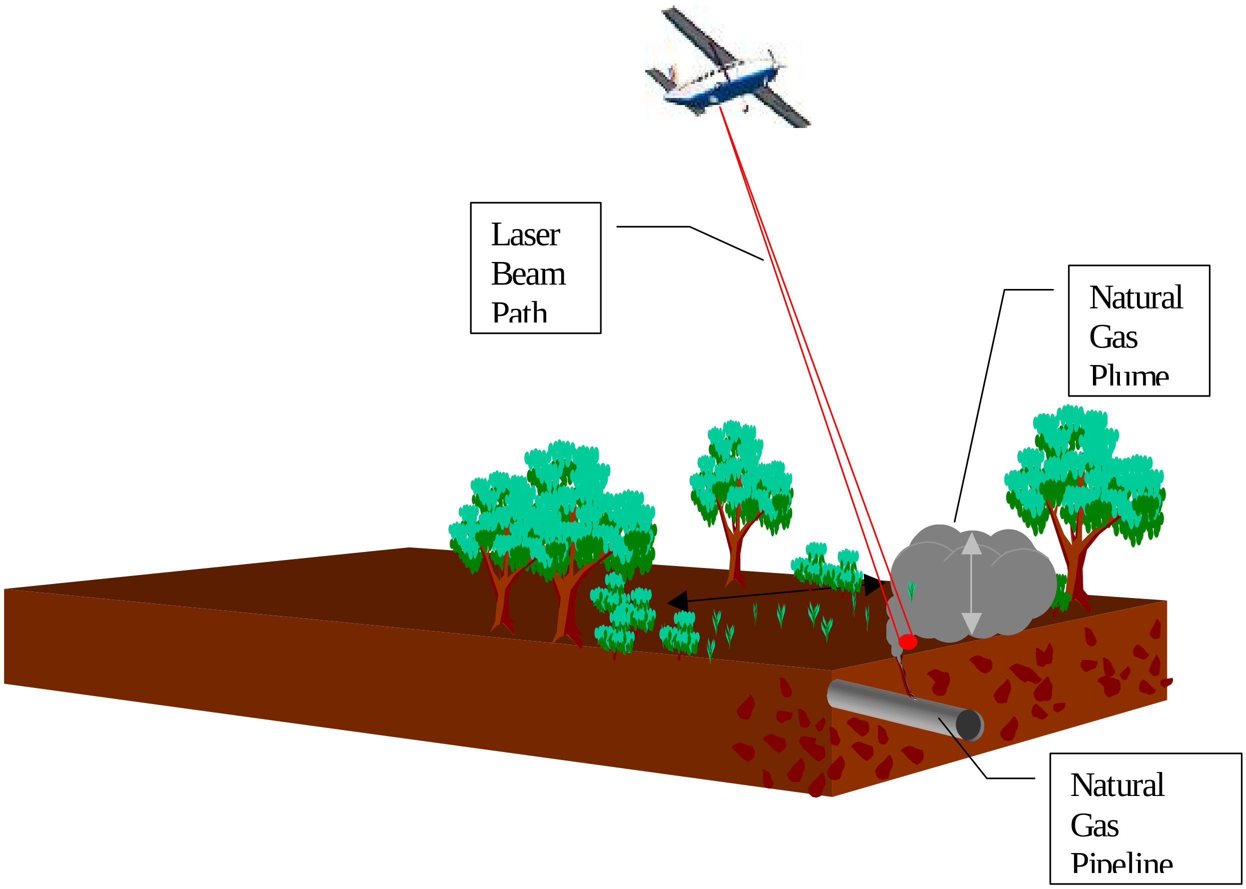


Figure 1.1.2 ANGEL System In-Flight Conceptual Drawing

The aircraft with the remote sensing payload flies along a selected pipeline route. The Payload uses a pointing and scanning subsystem to survey the area near the pipeline. The Payload also provides the laser sources and receivers to perform the DIAL remote sensing detection of the natural gas near the pipelines. The system also includes a navigation aid for the pilot in order to assure that the aircraft is located in the correct position to allow the pointing and scanning subsystem to acquire the pipeline.

For a typical flight operation, the Operations Center provides mission planning data for a selected pipeline to the flight crew. This data is loaded into the airborne system. The crew then proceeds to the starting point for a pipeline survey and flies the pre-selected natural gas pipeline route. During the flight, the Payload ingests real-time position and attitude data produced by an

Applanix POSAVTM system that is then used in conjunction with the targeting data from the Operations Center to assure the continuous collection of raw sensor data along the route.

While the Aircraft and Payload are working together to target the pipeline, the Payload uses a Differential Absorption Lidar (DIAL) technique to collect spectroscopic measurements along the pipeline corridor. An individual sample consists of three approximately 3400 nm laser pulses (Pulse Triplet Sets) that are transmitted to the ground and then reflected back to the Payload, where they are detected. At RMOTC these Pulse Triplet Sets were generated at a rate of 1000 Hz. This is referred to as the Pulse Repetition Frequency (PRF). The PRF of the sensor has been designed to be adjustable between 1000 to 2000 Hz. By combining the PRF with the linear motion of the aircraft, the targeting of the pipelines by the pointing mechanism and the conical scanning of the laser beams, the desired information is collected along the pipeline corridor.

In addition to the DIAL data, aircraft positional data (yaw, pitch, roll) is also collected for each DIAL data sample, along with other meta-data such as atmospheric pressure and temperature. This data is stored on board the aircraft, and is available for post-flight processing.

There is also an on-board high resolution video camera that captures imagery in real time while the aircraft is flying and collecting DIAL data. This imagery is also stored on a hard drive for later copying to a writable DVD.

After the flight is completed, the DIAL, Imagery, and other data is removed from the airborne system and delivered to the Operations Center.

The Operations Center provides the major input and output data processing and handling for the overall system.

- The ANGEL Service provides contract data to the Operations Center to establish tasking for flight operations
- The Operations Center provides a mission plan for each of the flight operations for the Aircraft and Payload
- The integrated Aircraft and Payload targets the pipeline using the mission plan.
- The Payload collects and stores raw data from the sensor system on-board the Aircraft.
- The data is transferred from the Payload to the Operations Center, following the flight operation
- The Operations Center processes, exploits, archives, and distributes the information derived from the survey, for the ANGEL Service

Once a flight operation is complete, the Operations Center takes the raw data captured during the flight operation and processes it into a concentration path length for each sample. If natural gas emission is present, the resulting mapping of concentration path lengths may create a visual graphic similar to that which is displayed in Figure 1.1.3. This data can then be interpreted visually or through more algorithms to signify the presence and quantification of a natural gas leak.

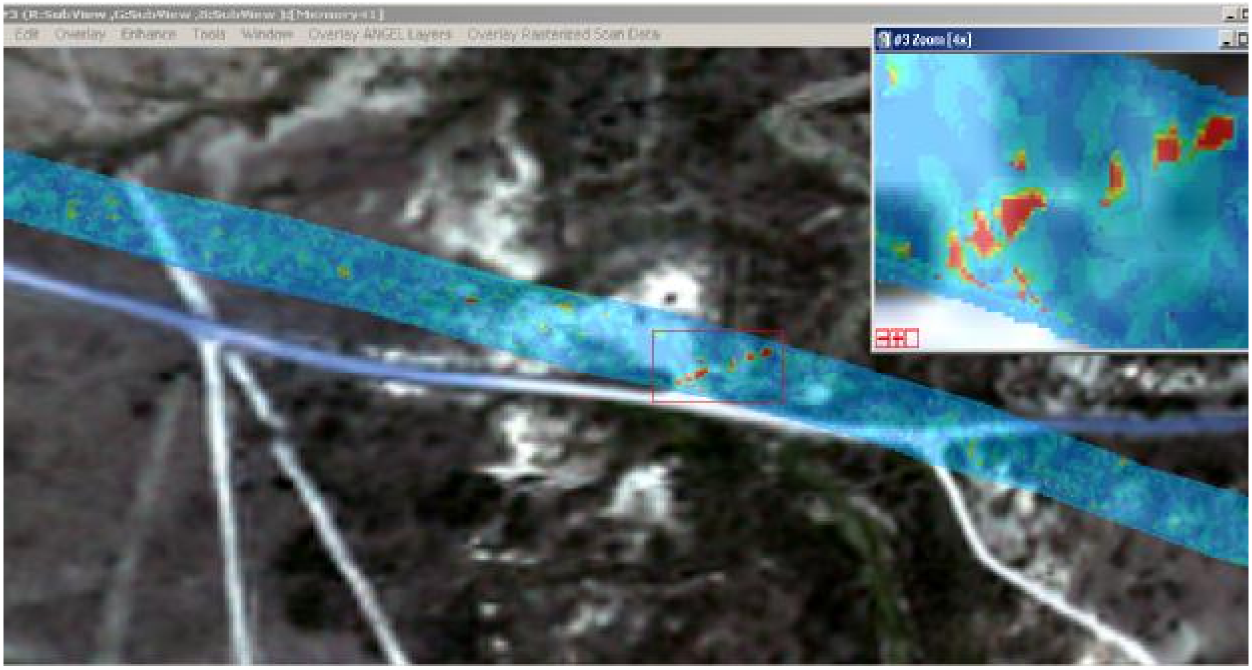


Figure 1.1.3 Visual Display of Natural Gas Emissions Detected By the ANGEL System on the Afternoon of September 17th, 2004 (Calibration Leak)

1.2 Platform Description

For the initial Flight Test Phase, the airborne portion of the ANGEL System consists of a Test Aircraft and an integrated Payload. The Operations Center is a beta site that functionally supports the engineering debug and optimization of the system during test flights. The Test Aircraft used is a modified Air Force owned Convair 580 (NC-131H) Turboprop known as the Total In-Flight Simulator (TIFS), operated by General Dynamics, and illustrated in Figure 1.2.1.

Figure 1.2.1 ANGEL test aircraft – General Dynamics Convair 580 (NC-131H) turboprop in flight at Natrona County International Airport, Casper, Wyoming

The Payload used in this Test Phase is the same basic hardware and software design that will be used in the Operations Phase. Generally, the Payload consists of a Transceiver Assembly, a Rack #1 Assembly, a Rack #2 Assembly, cables, and other miscellaneous hardware and software. The integration of the Payload within the Test aircraft is illustrated in Figure 1.2.2.

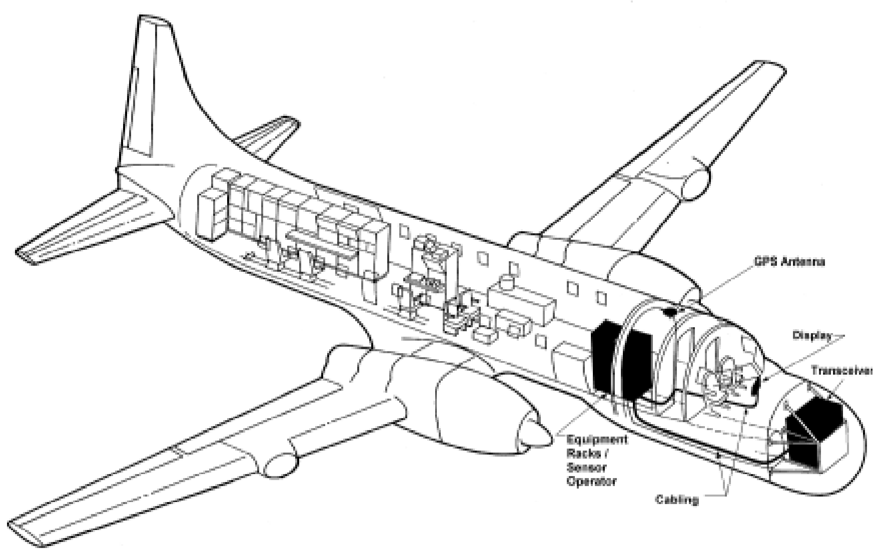


Figure 1.2.2 ANGEL Test Aircraft with Payload Installed

Figure 1.2.3 ANGEL Transceiver in Test Aircraft

Figure 1.2.4 Airborne System Operator's Station in Test Aircraft

2. DATA COLLECTION AND REDUCTION SCHEME

The following material describes the scheme used for data collection and reduction during the DOE sponsored tests conducted at RMOTC September 13th through September 18th-

2.1 Mission Plan

Each flight begins with the creation of a mission plan. GIS data defining the pipeline route is used to create a target file consisting of a set of GIS points to define the position of the pipeline in x, y, z space. Because the target file is used to guide the pilot and to point the sensor from a relatively high altitude (>1000 ft), the ANGEL system requires accurate GIS data to accurately fly the pipe. Pipeline position data with unknown or insufficient accuracy must be field verified/corrected by ITT or customer teams using GPS equipment.

2.2 Pre-flight Briefing

Each flight begins with a pre-flight briefing in which the pilots, sensor operators, and mission planning personnel meet prior to the flight and discuss the following:

- Aircraft Status
- Discussion of the route to and from RMOTC, including any obstacles that may be encountered during flight. Review of sectional aviation charts as required.
- Weather
- What targets will be flown (e.g. the RMOTC test range, calibration targets, etc.)
- Number of desired runs for each target
- Direction of each target run
- Payload status.
- Configurable system parameters (scan rate, cone angle, etc.)

2.3 Pre take-off

Once in the aircraft, the flight crew prepares the aircraft and the sensor system for the flight. Activities at this time include:

- Pilots perform pre-flight checklist – enable master power for sensor and control systems
- Sensor Operators execute their pre-flight checklist:

- Sensor Operator(s) power up the sensor and control systems
- Verify the target files are correct for both the Pilot Navigation system and the Sensor Pointing system
- Laser warm-up
- Scanner warm-up
- Verify all sensor control systems are operational
- Verify GPS receiver is locked before the aircraft moves

2.4 For each pipeline run

Once in the air the aircraft flies to the pipeline and collects data over the pipeline. At this time the sensor operator(s) will:

- Load the appropriate target file into the Pilot Navigation Aid and the Sensor Pointing system
- Verify correct operation of the sensor and start sensor data collection

2.5 After completion of data collect

- Transfer auxiliary data (aircraft positional data, telemetry, etc.) to a common removable hard drive in the aircraft flight equipment. Hard drive contains all data for ground based data processing and emission analysis. This drive is then removed from the aircraft.
- Visual camera images are saved to a writable DVD, and removed from the aircraft.

2.6 Post-Flight Processing and Algorithms

Data is transferred from the flight disk to ground storage disks. The data is processed using software based on ITT Industries' advanced, proprietary DIAL/Lidar algorithms where each data point is geo-located and assessed for the presence of the objective gas. The level of gas detected is computed as a "concentration path length" (CPL).

The output of the processing step includes 1) ESRI shapefiles that will be used to create graphical reports and 2) data that represents the performance of the sensor and related subsystems. ITT Industries engineers use this latter information to ensure that proper criteria are applied to correct and select data to compensate for various environmental, surface and operational variables that can obscure data interpretation.

2.7 Reports

Shapefiles are used to create geo-located graphical and tabular reports using ITT Industries ANGEL Pipeline Visual Inspection and Analysis Software – APVIAS (based on Research Systems Inc. IDL/ENVI software). The reports can also employ a geo-referenced image or DEM as a backdrop.

2.8 Weather Data

During the field demonstration at RMOTC, data on temperatures, precipitation, pressures, humidity, wind direction and speed were collected at three different ground locations throughout the week.

Figure 2.0.1 is a block diagram of the data collection and reduction scheme as used for the tests at RMOTC.

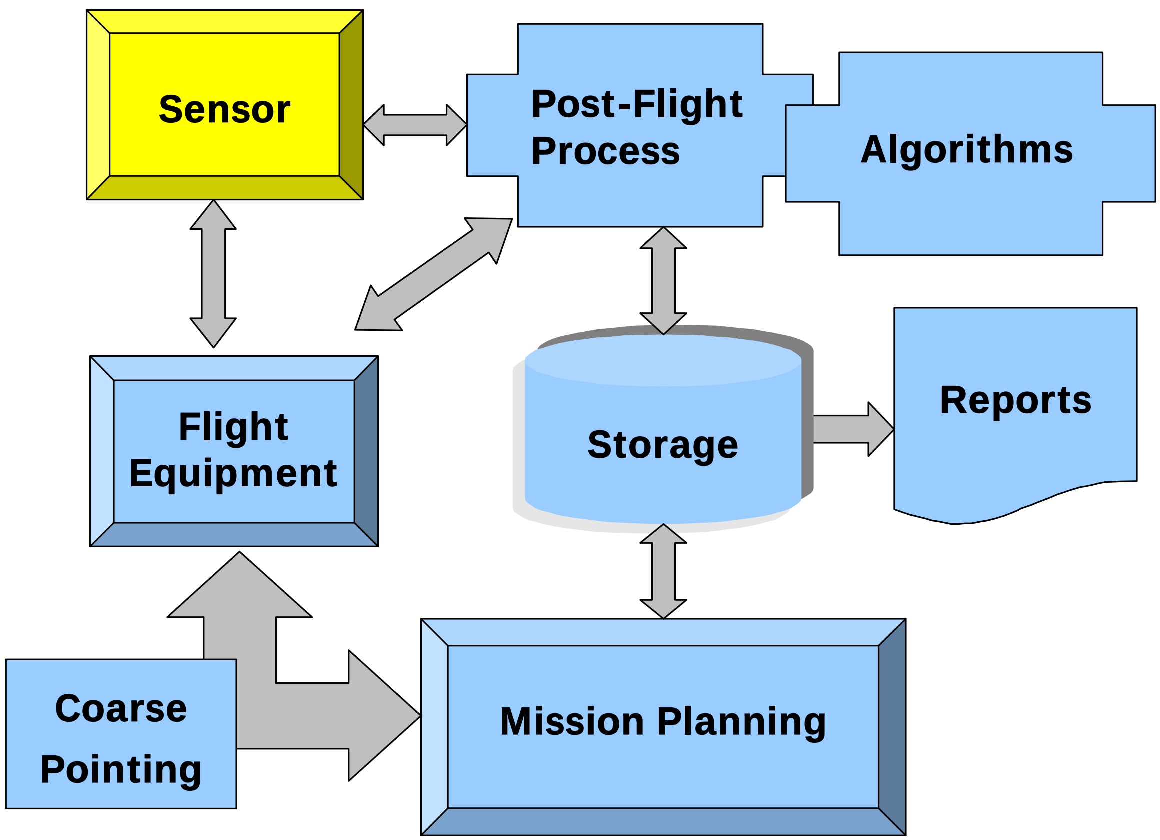


Figure 2.0.1 Data Collection and Reduction Scheme

3. TEST DATA

Over the course of the week the test aircraft flew and collected data during every available time slot. A total of 11 flight from Sunday the 9/12/2004 to Friday 9/17/2004 and 54 passes over the course. The RMOTC Virtual Pipeline is 7.5 miles in length and the test aircraft was able to inspect the entire Virtual Pipeline route in approximately 5.5 minutes. In the 50 minute window allotted, the ANGEL aircraft was able to collect 6 - 7 complete passes over the pipeline route. Although the RMOTC Virtual Pipeline contains a number of relatively sharp turns, the ANGEL sensor intelligent pointing and scanning system and pilot guidance system allowed coverage of 100% of the pipeline route in a single pass.

At RMOTC the ANGEL sensor collected approximately 3 gigabytes of data for each complete pass. During every pass the sensor measured the abundance of methane more than 250,000 times, allowing the creation of a methane map the entire length of the pipeline. By the end of the week in Casper the ITT Ground Data Processing team filled a 500 gigabyte server hard drive with raw and processed ANGEL data. The data in the following tables is a condensation of what was detected during the course of the week. For each day ITT has a table of the locations of the areas where we are most confident that there are leaks. For each location, the table displays when each leak was detected (what pass in the AM or PM). In addition, there are a number of locations where the ANGEL system detected elevated amounts of methane at a lower level of confidence. Some of the locations listed in the second table are a very small distance from to the higher confidence locations listed in the first table and likely represent the edges of large plumes. In addition, it is likely that the positions of a number of smaller leaks are listed in the second table.

3.1 Day 1

3.1.1 Data Collection Routes (NOTE: include details regarding flight or driving paths for each data collection pass)

Flight	Pass	Local Start Time	Local End Time	Pass Duration	Pass Direction			Weather	Data		
						SOUTH L5L6-Wind Speed (mph)	SOUTH L5L6-Wind Direction	MIDDLE L1L2-Wind Speed (mph)	MIDDLE L1L2-Wind Direction	NORTH L3L4-Wind Speed (mph)	NORTH L3L4-Wind Direction
20040913_1000	1	7:33:09	7:37:20	0:05:00	N to S	6.2	N	3.6	NNW	4.7	W
20040913_1000	2	7:50:23	7:55:23	0:05:00	N to S	3.3	NW	5.2	NNW	1.8	SW
20040913_1000	3	8:05:30	8:09:55	0:04:25	N to S	4.7	WNW	2.8	WSW	1.4	SSW
20040913_2000	1	17:32:59	17:37:44	0:04:45	N to S	12.1	WNW	7.7	NNW	10.1	N
20040913_2000	2	18:05:07	18:11:27	0:06:20	N to S	7.0	W	7.7	NNW	4.0	NNW
20040913_2000	3	18:13:12	18:19:58	0:06:46	S to N	10.4	WNW	6.7	WNW	2.8	NNE
Total passes:	6	TOTAL RUN TIME IN		0:32:16							
					mean:	7.3	mph	5.6	mph	4.1	mph
						covers M1-M4		covers M5-M9		covers M10-M14	

3.1.2 Table of Gas Concentration Measurements for Each Pass (include in Attachment A)

No usable gas measurements were collected on Day 1

3.1.3 Description of System/Software Modifications Made Throughout Testing

Low laser output power measured during the morning run was caused by an optical component (mirror) with a damaged coating. This was replaced during the day on Monday, resulting in greatly improved sensor performance.

3.2 Day 2

3.2.1 Data Collection Routes (NOTE: include details regarding flight or driving paths for each data collection pass)

Date	Day	Flight	Pass	Local Start Time	Local End Time	Pass Duration	Pass Direction			Weather	Data		
								SOUTH L5L6-Wind Speed (mph)	SOUTH L5L6-Wind Dir	MIDDLE L1L2-Wind Speed (mph)	MIDDLE L1L2-Wind Dir	NORTH L3L4-Wind Speed (mph)	NORTH L3L4-Wind Dir
14-Sep-04	**Tuesday**	20040914_0815	1	13:08:06	13:14:03	0:05:57	S to N	0.0	CALM	1.6	S	0.0	CALM
14-Sep-04		20040914_0815	2	13:14:22	13:20:09	0:05:47	N to S	0.8	S	1.5	S	0.1	NNW
14-Sep-04		20040914_0815	3	13:21:42	13:26:08	0:04:26	S to N	2.9	S	1.0	S	0.0	CALM
14-Sep-04		20040914_0815	4	13:28:13	13:34:30	0:06:17	N to S	4.05	N	2.79	S	6.525	S
14-Sep-04		20040914_1840	1	23:18:54	23:23:54	0:05:00	N to S	11.6	N	10.5	N	12.2	NNW
14-Sep-04		20040914_1840	2	23:26:05	23:31:05	0:05:00	S to N	12.4	NNE	15.5	N	11.9	NNW
14-Sep-04		20040914_1840	6	23:33:15	23:38:40	0:32:27	N to S	18.1	N	15.9	N	12.7	NNW
14-Sep-04		20040914_1840	4	23:39:43	23:44:41	0:04:58	19	14.0	N	15.2	N	12.3	N
14-Sep-04		20040914_1840	5	23:47:16	23:48:54	0:01:38		12.51	N	14.9	N	10.1	NNW
14-Sep-04		20040914_1840	6	23:51:56	23:56:53	0:04:57		13.5	N	13.8	N	12.1	N
14-Sep-04		20040914_1840	7	23:57:58	0:03:06	0:05:08	S to N	15.8	NNE	14.5	N	11.2	N
14-Sep-04		20040914_1840	8	0:05:05	0:06:04	0:00:59	N to S	17.4	NNE	13.7	N	N	N
		Total passes:	**13**	TOTAL RUN TIME IN		1:22:34							
								10.3	mph	10.1	mph	8.1	mph
								covers M1-M4		covers M5-M9		covers M10-M14	

3.2.2 Table of Gas Concentration Measurements for Each Pass (include in Attachment B)

See Attachment B

3.2.3 Description of System/Software Modifications Made Throughout Testing

Sensor GPS lost lock on Monday morning run and scan position data was improperly recorded on Monday afternoon. Beginning Tuesday, increased time for pre-takeoff locking of the GPS system on the runway allowed sensor operators to complete sensor startup checklist and fully enable the GPS/IMU and scanning system before takeoff. Adjusted the speed of the scanning mechanisms throughout the day to optimize power draw. Adjustments to Ground Data Processing (GDP) software filters were made after initial analysis of morning data.

3.3 Day 3

3.3.1 Data Collection Routes (NOTE: include details regarding flight or driving paths for each data collection pass)

Date	Day	Flight	Pass	Local Start Time	Local End Time	Pass Duration	Pass Direction			Weather	Data		
								SOUTH L5L6-Wind Speed (mph)	SOUTH L5L6-Wind Dir	MIDDLE L1L2-Wind Speed (mph)	MIDDLE L1L2-Wind Dir	NORTH L3L4-Wind Speed (mph)	NORTH L3L4-Wind Dir
15-Sep-04	**Wednesday**	20040915_0910	1	13:54:29	13:59:12	0:04:43	N to S	5.2	W	5.6	WSW	1.9	WSW
15-Sep-04		20040915_0910	2	14:00:04	14:06:18	0:06:14	S to N	6.1	WSW	5.5	WSW	0.4	S
15-Sep-04		20040915_0910	3	14:06:18	14:11:30	0:05:12	N to S	7.1	WSW	6.8	WSW	0.2	ESE
15-Sep-04		20040915_0910	4	14:14:07	14:19:17	0:05:10	S to N	6.2	WSW	7.3	SW	1.0	SSE
15-Sep-04		20040915_0910	5	14:21:22	14:26:08	0:04:46	N to S	5.2	SW	6.2	SW	2.1	SSW
15-Sep-04		20040915_0910	6	14:28:15	14:32:58	0:04:43	S to N	7.0	WSW	7.3	SW	2.7	SW
15-Sep-04		20040915_0910	6	14:33:46	14:36:22	0:30:48	N to S	7.0	WSW	7.6	WSW	4.2	SW
15-Sep-04		20040915_1755	1	22:25:12	22:30:09	0:04:57	19	11.3	W	9.0	WNW	10.8	WNW
15-Sep-04		20040915_1755	2	22:31:19	22:35:41	0:04:22		11.6	NW	7.9	WSW	10.4	WNW
15-Sep-04		20040915_1755	3	22:37:29	22:42:16	0:04:47		16.8	WNW	8.9	W	11.0	WNW
15-Sep-04		20040915_1755	4	22:44:46	22:49:24	0:04:38	N to S	9.9	WNW	8.7	WNW	9.6	W
15-Sep-04		20040915_1755	5	22:51:34	22:56:36	0:05:02	S to N	15.1	WNW	10.0	WNW	8.4	WNW
15-Sep-04		20040915_1755	6	22:58:13	23:03:08	0:04:55	N to S	15.6	NW	11.1	WNW	10.5	WNW
15-Sep-04		20040915_1755	7	23:04:23	23:05:56	0:01:33	S to N	15.1	NW	11.5	WNW	11.5	WNW
		Total passes:	**15**	TOTAL RUN TIME IN		1:31:50							
								9.9	mph	8.1	mph	6.1	mph
								covers M1-M4		covers M5-M9		covers M10-M14	

3.3.2 Table of Gas Concentration Measurements for Each Pass (include in Attachment C)

See Attachment C

3.3.3 Description of System/Software Modifications Made Throughout Testing

Adjustments to Ground Data Processing "pulse finding" algorithms result in a great improvement in data processing.

3.4 Day 4

3.4.1 Data Collection Routes (NOTE: include details regarding flight or driving paths for each data collection pass)

Date	Day	Flight	Pass	Local Start Time	Local End Time	Pass Duration	Pass Direction			Weather	Data		
								SOUTH L5L6-Wind Speed (mph)	SOUTH L5L6-Wind Dir	MIDDLE L1L2-Wind Speed (mph)	MIDDLE L1L2-Wind Dir	NORTH L3L4-Wind Speed (mph)	NORTH L3L4 Wind Dir
16-Sep-04	**Thursday**	20040916_0955	1	14:45:55	14:51:08	0:05:13	N to S	6.9	SSW	8.9	SSW	0.1	SW
16-Sep-04		20040916_0955	2	14:53:00	14:57:52	0:04:52	S to N	6.2	S	8.1	SSW	0.0	CALM
16-Sep-04		20040916_0955	3	15:00:05	15:04:44	0:04:39	N to S	5.2	SSE	8.4	SW	1.3	SW
16-Sep-04		20040916_0955	4	15:07:35	15:12:31	0:04:56	S to N	4.5	SSW	6.8	SW	1.8	SW
16-Sep-04		20040916_0955	5	15:15:32	15:19:56	0:04:24	N to S	5.4	SSW	5.7	SW	1.2	SW
16-Sep-04		20040916_0955	6	15:23:08	15:27:48	0:04:40	S to N	6.7	SSW	6.7	SSW	2.0	SSW
16-Sep-04		20040916_0955	6	15:29:23	15:34:03	0:28:44	N to S	7.2	SW	6.0	SSW	3.2	SW
16-Sep-04		20040916_1940	1	0:29:45	0:34:39	0:04:54	19	12.1	WNW	6.9	WNW	9.1	WNW
16-Sep-04		20040916_1940	2	0:37:31	0:41:40	0:04:09		8.1	NW	9.5	WNW	6.8	WNW
16-Sep-04		20040916_1940	3	0:47:36	0:55:54	0:08:18		9.4	NW	8.0	WNW	6.1	WNW
16-Sep-04		20040916_1940	4	0:58:36	1:02:50	0:04:14	N to S	5.7	NW	3.1	NNW	6.3	WNW
17-Sep-04		20040917_1830	4	23:56:54	0:00:58	0:04:04	N to S	12.9	SW	13.9	SW	12.5	WSW
		Total passes:	**13**	TOTAL RUN TIME IN		289:23:07							
								7.5	mph	7.7	mph	4.2	mph
								covers M1-M4		covers M5-M9		covers M10-M14	

3.4.2 Table of Gas Concentration Measurements for Each Pass (include in Attachment D)

See Attachment D

3.4.3 Description of System/Software Modifications Made Throughout Testing

Warm conditions on Thursday and parking the sensor in the sun for the VIP event resulted in thermal stress and reduced laser output power. Sensor operator began close monitoring of the in-flight sensor temperatures. Further improvements to Ground Data Processing data filtering resulted in greatly improved signal-to-noise and plume discrimination.

3.5 Day 5

3.5.1 Data Collection Routes (NOTE: include details regarding flight or driving paths for each data collection pass)

Date	Day	Flight	Pass	Local Start Time	Local End Time	Pass Duration	Pass Direction			Weather	Data		
								SOUTH L5L6-Wind Speed (mph)	SOUTH L5L6-Wind Dir	MIDDLE L1L2-Wind Speed (mph)	MIDDLE L1L2-Wind Dir	NORTH L3L4-Wind Speed (mph)	NORTH L3L4-Wind Dir
17-Sep-04	**Friday**	20040917_0810	1	12:45:55	12:50:31	0:04:36	N to S	12.1	SSW	11.0	SSW	0.0	CALM
17-Sep-04		20040917_0810	2	12:53:32	12:58:10	0:04:38	S to N	12.1	SSW	13.0	SSW	0.0	SW
17-Sep-04		20040917_0810	3	13:01:53	13:06:22	0:04:29	N to S	11.8	SSW	13.7	SW	0.0	SW
17-Sep-04		20040917_0810	4	13:08:32	13:12:58	0:04:26	S to N	11.6	SSW	14.0	SSW	0.1	S
17-Sep-04		20040917_0810	5	13:16:04	13:20:58	0:04:54	N to S	10.6	SSW	13.4	SSW	0.0	CALM
17-Sep-04		20040917_0810	6	13:23:00	13:27:53	0:04:53	S to N	13.3	SSW	13.0	SW	0.4	WSW
17-Sep-04		20040917_0810	6	13:29:28	13:33:50	0:27:56	N to S	13.3	SSW	12.1	SSW	0.3	SW
17-Sep-04		20040917_1830	1	23:15:54	23:20:41	0:04:47	19	14.9	SW	14.1	W	14.9	SW
17-Sep-04		20040917_1830	2	23:23:05	23:27:57	0:04:52		14.1	SW	14.3	SW	13.9	WSW
17-Sep-04		20040917_1830	3	23:50:32	23:54:44	0:04:12		14.1	SW	10.5	SW	13.5	WSW
17-Sep-04		20040917_1830	4	23:56:54	0:00:58	0:04:04	N to S	12.9	SW	13.9	SW	12.5	WSW
		Total passes:	**12**	TOTAL RUN TIME IN		73:13:47							
								12.8	mph	13.0	mph	5.1	mph
								covers M1-M4		covers M5-M9		covers M10-M14	

3.5.2 Table of Gas Concentration Measurements for Each Pass (include in Attachment E)

See Attachment E

3.5.3 Description of System/Software Modifications Made Throughout Testing

No modifications to the sensor or software were performed.

4. SUMMARY OF RESULTS

During the DOE RMOTC field trials, the ITT ANGEL System verified the functionality of all major systems including gas detection, gas quantification, sensor targeting, laser scanning, data logging, data analysis, mission planning and flight operations. The system was flown at every opportunity from Sunday afternoon through Friday evening for a total of 11 flights and 58 field passes. Data was collected during every flight comprising approximately 80 gigabytes of data per day. Sensor pointing and laser scanning systems successfully provided 100% pipeline corridor coverage. Given that much of the system's total performance was untested prior to these trials, the event provided an opportunity to test, learn and improve the system.

Emissions were detected at a number of locations along the virtual pipeline on Tuesday, Wednesday, Thursday and Friday. Results were reported as high confidence when signals indicating high concentration path length (CPL) were detected on multiple passes of both morning and afternoon flights. The degree of confidence is proportional to the number of detections.

We also observed evidence of emissions near the calibration leak location on Tuesday (morning and afternoon), Wednesday (morning and afternoon), and Friday (afternoon). While some signals were detected on Thursday near the calibration site, the evidence was less conclusive than on the earlier days.

Tuesday - Eleven distinct methane concentration areas were detected with sufficient quantity and frequency (5 or 6 passes) that they have high confidence. Several signals were detected in the vicinity or slightly south of site M2 and were near enough to each other that they may well represent a single emission. Twenty-one lesser emissions were also detected along the virtual pipeline on 4 or fewer passes. (See ITT Industries @MF DK Customer Report for September 14, 2004.)

Wednesday - Six distinct methane concentration areas were detected with sufficient quantity and frequency (7 or 8 passes) that they have high confidence. A number of signals were detected along the route north of site M12 and imply the presence of extensive or multiple emissions in this area. Forty lesser emissions were also detected along the virtual pipeline on 6 or fewer passes. (See ITT Industries @MF DK Customer Report for September 15, 2004.)

Thursday - Nine distinct methane concentration areas were detected with sufficient quantity and frequency (6 to 9 passes) that they have high confidence. Multiple signals were detected once again to the south of site M2 and indicate the presence of extensive or multiple emissions in this area. Twenty-six lesser emissions were also detected along the virtual pipeline on 5 or fewer passes. (See ITT Industries @MF DK Customer Report for September 16, 2004.)

Friday - Six distinct methane concentration areas were detected with sufficient quantity and frequency (7 to 9 passes) that they have high confidence. Several signals were again detected south of site M2, a very strong signal was again detected near the gas plant (M8) and the afternoon calibration emission near M1 showed a well pronounced plume. Sixteen lesser emissions were also detected along the virtual pipeline on 6 or fewer passes. (See ITT Industries @MF DK Customer Report for September 17, 2004.)

5. CONCLUSIONS

The tests conducted at RMOTC from 13 September to 17 September 2004 provided a unique opportunity to demonstrate the capabilities and value, as well as the challenges, of an air-borne natural gas detection system. In spite of known performance limitations (all of which will be addressed in the coming weeks), the ITT ANGEL System has successfully demonstrated its ability to fly, point, scan, detect, quantify, geo-locate and ultimately provide comprehensive visualization of pipeline gas emissions in a rugged natural environment.

During each flight (which included several passes), the ANGEL System successfully in-gested GPS/GIS data, accurately pointed at the virtual pipeline route, fully scanned the ROW (100% coverage), and collected all necessary differential GPS information to precisely locate leak locations. The Ground Data Processing systems accurately processed all the raw data to "image" gas emissions and precisely position the data to the earth.

The ANGEL system was constrained during this field test due to three system level limi-tations. These constraints led to reduced performance and capabilities throughout the week and were not addressable until the system was returned to the lab. Three primary limitations of the system included:

1. Reduced laser output power. Overall the system was producing less than 50% of the normal operating power. Laser power is directly linked to low-end gas detect ability. Traceability to various internal components, principally coated optics, was completed on-sight and is currently being addressed in the lab.

2. Disabled ethane detection laser bench. The system is designed for detection of both methane and ethane via companion laser benches tuned to different absorp-tion frequencies. Prior to leaving for RMOTC, the ethane laser bench was not functioning properly and was taken "off-line" for the event. The detection of eth-ane with methane is a telltale sign of natural gas and significantly reduces the po-tential of false alarm due to various and abundant natural sources of methane.

3. Signal degradation with the scanner optics. The computer controlled scanner moves the lasers across the right-of-way as the plane flies its route. Throughout the week the scanner was able to consistently and accurately scan the lasers above the pipeline, yet performance issues within the scanner significantly contributed to overall system "noise" and degraded signal detectability.

ATTACHMENTS

ATTACHMENT A– DAILY TEST DATA (DAY 1)

No usable DIAL data was collected on 9/13/2004.

ATTACHMENT B– DAILY TEST DATA (DAY 2)

Latitude NAD 27 Data (DMS)	Longitude	Leak Detection	Date	AM Passes	PM Passes	Comments
43 14 57.966	-106 11 27.3228	6	09/14/04	3	1,2,3,4,6	south of M2
43 14 58.992	-106 11 31.6464	5	09/14/04	3	2,3,4,7	M1-M2
43 15 0.0216	-106 11 35.0844	5	09/14/04	3	2,3,4,7	south of M2
43 15 1.0188	-106 11 37.7412	5	09/14/04	3	2,3,4,7	vicinity of M2
43 16 39.8244	-106 12 50.6232	5	09/14/04	3,4	1,2,7	vicinity of M5
43 17 45.3624	-106 13 15.4164	6	09/14/04	3	1,2,4,6,7	already have M8 (gas plant)
43 18 6.048	-106 13 4.1844	5	09/14/04	3,4	1,2,7	vicinity of M9
43 18 57.0096	-106 13 30.9792	5	09/14/04		2,3,4,6,7	south of M11
43 19 37.128	-106 13 53.7888	5	09/14/04	3,4	1,3,7	many discrete points just south of
43 19 40.0908	-106 13 53.7852	6	09/14/04	3,4	1,2,3,4	just north of M12
43 19 51.2508	-106 13 48.5724	5	09/14/04	3	2,4,6,7	single small area M12-M13

Table of Large and Medium emissions. The methane emissions with the highest confidence were captured on a relatively large number of passes as indicated in this table. The geographic coordinates provide the location of the aggregated multiple detections.

NAD 27 Data (DMS)			
Latitude	Longitude	Date	Comments
43 19 54.7284	-106 13 47.3628	14-Sep-04	M12-M13
43 15 25.2	-106 11 58.9632	14-Sep-04	M2-M3
43 16 14.304	-106 12 17.406	14-Sep-04	M4-M5
43 17 28.8132	-106 13 12.5976	14-Sep-04	M8 - south of gas plant
43 17 45.7188	-106 13 15.3012	14-Sep-04	M8 (gas plant)
43 19 40.08	-106 13 53.778	14-Sep-04	just north of M12
43 14 57.9336	-106 11 27.3732	14-Sep-04	north of M1
43 18 56.826	-106 13 30.6768	14-Sep-04	south of M11
43 14 59.964	-106 11 35.2896	14-Sep-04	south of M2
43 15 1.0728	-106 11 38.3712	14-Sep-04	vicinity of M2
43 15 5.5764	-106 11 45.0348	14-Sep-04	just north of M2
43 16 23.0772	-106 12 29.3076	14-Sep-04	north of M4-M5
43 14 59.0316	-106 11 31.704	14-Sep-04	north of M1
43 19 51.0384	-106 13 48.5292	14-Sep-04	single small area M12-M13
43 19 37.2	-106 13 53.7888	14-Sep-04	just south of M12
43 19 31.6884	-106 13 50.8584	14-Sep-04	many discrete points south of M12
43 20 8.0916	-106 13 40.4868	14-Sep-04	south of M13
43 16 49.8504	-106 12 51.5232	14-Sep-04	south of M6
43 14 53.9196	-106 11 14.2692	14-Sep-04	vicinity of M1
43 16 39.954	-106 12 50.5296	14-Sep-04	vicinity of M5
43 18 6.246	-106 13 4.044	14-Sep-04	vicinity of M9

Table of relatively small emissions. Methane emissions detected with lesser, but still significant confidence are listed in the table above. In all cases these were detected on multiple passes, but not as consistently as the detections of large and medium emissions.

ATTACHMENT C– DAILY TEST DATA (DAY 3)

NAD 27 Data (DMS)					
Latitude	**Longitude**	**Date**	**AM Passes**	**PM Passes**	**Comments**
43 14 58.91	-106 11 31.31	15-Sep-04	1,2,3,4,5,6	1,5,6	area between M1 & M2
43 15 7.23	-106 11 46.72	15-Sep-04	4,5,6	1,2,4,5	area northwest of M2
43 17 58.9236	-106 13 8.9328	15-Sep-04	1,2,4,5,6	1,3,4,5,6	Big leak north of gas plant (high confider
43 20 9.312	-106 13 39.972	15-Sep-04	2,3,4,6	1,4,5	area #1 between M12 & M13
43 20 15.0252	-106 13 36.498	15-Sep-04	2,3,4,5,6	1,6	area #2 between M12 & M13
43 20 23.68	-106 13 36.43	15-Sep-04	1,4,5,6	2,3,4,5,6	area between M13 & M14

Table of Large and Medium emissions. The methane emissions with the highest confidence were captured on a relatively large number of passes as indicated in this table. The geographic coordinates provide the location of the aggregated multiple detections.

NAD 27 Data (DMS)			
Latitude	Longitude	Date	Comments
43 14 57.948	-106 11 27.7332	15-Sep-04	M1-M2 middle
43 19 29.9784	-106 13 50.232	15-Sep-04	M11-M12
43 19 38.6472	-106 13 54.2496	15-Sep-04	M12 corner - large area extent
43 20 4.1208	-106 13 42.4884	15-Sep-04	M12-M13
43 15 1.98	-106 11 42.324	15-Sep-04	M2
43 17 8.7396	-106 12 58.0896	15-Sep-04	M6-M7
43 17 30.8184	-106 13 14.16	15-Sep-04	M7-M8
43 15 6.786	-106 11 46.5684	15-Sep-04	
43 14 59.316	-106 11 33.0324	15-Sep-04	M1-M2 - big leak
43 20 0.9492	-106 13 43.8204	15-Sep-04	M12-M13
43 17 44.5092	-106 13 15.8808	15-Sep-04	just north of M8
43 20 23.9784	-106 13 36.3252	15-Sep-04	just south of M14
43 19 54.714	-106 13 47.1072	15-Sep-04	north of M12
43 20 17.142	-106 13 36.966	15-Sep-04	just north of M13
43 15 3.6936	-106 11 43.62	15-Sep-04	just north of M2
43 16 20.046	-106 12 24.4044	15-Sep-04	just north of M4
43 15 1.1808	-106 11 38.8716	15-Sep-04	just south of M2 - many discrete areas
43 16 59.9124	-106 12 51.7608	15-Sep-04	just south of M6
43 20 13.3116	-106 13 37.6644	15-Sep-04	just south of M13
43 19 49.0008	-106 13 49.9116	15-Sep-04	north of M12
43 15 5.1228	-106 11 44.7972	15-Sep-04	north of M2
43 17 47.1984	-106 13 14.5956	15-Sep-04	north of M8
43 19 57.9792	-106 13 45.0264	15-Sep-04	north of M12
43 16 22.3572	-106 12 27.3528	15-Sep-04	north of M4
43 19 51.8916	-106 13 48.0252	15-Sep-04	north of M12
43 15 9.5652	-106 11 48.3612	15-Sep-04	north of M2
43 20 31.2504	-106 13 36.5376	15-Sep-04	on M14
43 15 18.63	-106 11 55.0932	15-Sep-04	single M2-M3
43 18 45.8568	-106 13 22.3068	15-Sep-04	single north of M10
43 15 29.7684	-106 12 1.8612	15-Sep-04	single south of M3
43 16 38.9388	-106 12 49.554	15-Sep-04	small areas just south of M5
43 16 7.2192	-106 12 11.3256	15-Sep-04	small area just south of M4
43 20 28.6656	-106 13 36.2064	15-Sep-04	small areas just south of M14
43 16 5.502	-106 12 11.2752	15-Sep-04	south of M4
43 20 8.9772	-106 13 40.2024	15-Sep-04	tiny area south of M13
43 16 41.1564	-106 12 51.678	15-Sep-04	tiny area at M5
43 17 38.5584	-106 13 17.076	15-Sep-04	tiny area just south of M8
43 18 5.2884	-106 13 4.278	15-Sep-04	tiny areas just south of M9
43 19 22.0044	-106 13 45.6276	15-Sep-04	tiny area north of M11
43 14 54.7188	-106 11 15.9504	15-Sep-04	vicinity of calibration leak

Table of relatively small emissions. Methane emissions detected with lesser, but still significant confidence are listed in the table above. In all cases these were detected on multiple passes, but not as consistently as the detections of large and medium emissions.

ATTACHMENT D– DAILY TEST DATA (DAY 4)

NAD 27 Data (DMS)					
Latitude	**Longitude**	**Date**	**AM Passes**	**PM Passes**	**Comments**
43 14 55.2408	-106 11 17.322	16-Sep-04	1,2,3,4,6	5,6	area #1 between M1 & M2
43 14 58.1352	-106 11 27.726	16-Sep-04	1,2,3,4,5,6,7	5,6	area #2 between M1 & M2
43 14 59.6544	-106 11 32.8236	16-Sep-04	1,2,3,4,6,7	5,6	area #3 between M1 & M2
43 15 0.7272	-106 11 36.8484	16-Sep-04	1,2,3,4,6,7	5,6	area #4 between M1 & M2
43 16 39.0504	-106 12 50.0508	16-Sep-04	2,3,4,5,7	5,6	area southeast of M5
43 18 11.2464	-106 13 5.2284	16-Sep-04	1,2,3,4,7	5,6	area northwest of M9
43 19 40.9188	-106 13 53.9472	16-Sep-04	1,2,3,4,6,7	5,6	area #1 between M12 & M13
43 20 0.24	-106 13 44.04	16-Sep-04	1,2,5,6,7	6	area #2 between M12 & M13
43 20 3.2892	-106 13 42.6108	16-Sep-04	1,2,3,6,7	5,6	area #3 between M12 & M13

Table of Large and Medium emissions. The methane emissions with the highest confidence were captured on a relatively large number of passes as indicated in this table. The geographic coordinates provide the location of the aggregated multiple detections.

NAD 27 Data (DMS)			
Latitude	Longitude	Date	Comments
43 14 59.4276	-106 11 32.4816	16-Sep-04	M1-M2
43 14 53.2212	-106 11 10.8924	16-Sep-04	M1
43 20 14.5392	-106 13 37.6788	16-Sep-04	M13
43 16 24.8268	-106 12 30.69	16-Sep-04	M4-M5
43 16 39.6264	-106 12 50.6016	16-Sep-04	M5
43 17 8.6028	-106 12 58.428	16-Sep-04	M6-M7
43 18 7.4916	-106 13 4.2852	16-Sep-04	M9
43 19 40.8972	-106 13 53.9652	16-Sep-04	just north of M12
43 16 15.8808	-106 12 19.728	16-Sep-04	just north of M4
43 16 19.1316	-106 12 24.8364	16-Sep-04	just north of M4
43 19 35.76	-106 13 52.8996	16-Sep-04	just south of M12
43 19 54.8292	-106 13 47.0424	16-Sep-04	large area M12-M13
43 20 0.4416	-106 13 44.4	16-Sep-04	medium area M12-M13
43 14 54.3012	-106 11 15.4608	16-Sep-04	north of M1
43 18 46.7712	-106 13 23.0952	16-Sep-04	north of M10
43 20 23.7336	-106 13 36.2496	16-Sep-04	north of M13
43 15 6.3324	-106 11 45.6072	16-Sep-04	north of M2
43 17 48.5916	-106 13 13.7388	16-Sep-04	north of M8
43 18 11.1312	-106 13 5.0448	16-Sep-04	north of M9
43 14 56.3856	-106 11 22.1028	16-Sep-04	north of north of M1
43 18 13.1616	-106 13 6.24	16-Sep-04	north of north of M9
43 20 6.8676	-106 13 40.8	16-Sep-04	northern M12-M13
43 20 3.1704	-106 13 42.5928	16-Sep-04	northern area M12-M13
43 15 27.7668	-106 12 0.3528	16-Sep-04	single poly
43 19 31.2276	-106 13 50.862	16-Sep-04	south of M12
43 18 3.4668	-106 13 5.9772	16-Sep-04	south of M9

Table of relatively small emissions. Methane emissions detected with lesser, but still significant confidence are listed in the table above. In all cases these were detected on multiple passes, but not as consistently as the detections of large and medium emissions.

ATTACHMENT E– DAILY TEST DATA (DAY 5)

NAD 27 Data (DMS)					
Latitude	**Longitude**	**Date**	**AM Passes**	**PM Passes**	**Comments**
43 14 57.8148	-106 11 27.4776	17-Sep-04	2,3,4,5,6	2,3	area #1 between M1 & M2
43 14 58.7472	-106 11 31.8408	17-Sep-04	1,2,3,4,6	2,3	area #2 between M1 & M2
43 15 1.1592	-106 11 37.8132	17-Sep-04	1,2,3,6,7	1,3	area #3 between M1 & M2
43 17 44.8908	-106 13 15.8556	17-Sep-04	1,2,4,5,6,7	1,2,3	north of gas plant (high confidence)
43 18 56.9124	-106 13 31.0548	17-Sep-04	2,3,4,5,6,7	2	area between M10 & M11
43 19 40.0116	-106 13 53.8824	17-Sep-04	1,2,3,4,5	3,4	area northeast of M12

Table of Large and Medium emissions. The methane emissions with the highest confidence were captured on a relatively large number of passes as indicated in this table. The geographic coordinates provide the location of the aggregated multiple detections.

NAD 27 Data (DMS)			
Latitude	**Longitude**	**Date**	**Comments**
43 16 14.322	-106 12 17.3376	17-Sep-04	
43 15 27.0432	-106 12 0.3456	17-Sep-04	M2-M3
43 17 45.726	-106 13 15.2076	17-Sep-04	already have M8 (gas plant)
43 19 40.08	-106 13 53.8104	17-Sep-04	already have just north of M12
43 14 57.912	-106 11 27.348	17-Sep-04	already have north of M1
43 18 56.6784	-106 13 30.3636	17-Sep-04	already have south of M11
43 15 0.1368	-106 11 34.7856	17-Sep-04	already have south of M2
43 15 1.0908	-106 11 38.4576	17-Sep-04	already have vic M2
43 15 5.5692	-106 11 45.0132	17-Sep-04	just north of M2
43 14 59.0244	-106 11 31.7436	17-Sep-04	north of already have north of M1
43 19 51.2508	-106 13 48.5724	17-Sep-04	single sliver M12-M13
43 19 36.1452	-106 13 52.554	17-Sep-04	sliverama just south of M12
43 19 30.7308	-106 13 50.07	17-Sep-04	sliverama south of M12
43 14 53.7108	-106 11 13.5456	17-Sep-04	vic M1
43 16 40.3032	-106 12 51.1956	17-Sep-04	vic M5
43 18 6.246	-106 13 4.044	17-Sep-04	vic M9

Table of relatively small emissions. Methane emissions detected with lesser, but still significant confidence are listed in the table above. In all cases these were detected on multiple passes, but not as consistently as the detections of large and medium emissions.

NAD 27 Data (DMS)					
Latitude	**Longitude**	**Date**	**AM Passes**	**PM Passes**	**Comments**
43 14 53.7036	-106 11 13.434	17-Sep-04	N/A	1,2,3	Calibration leak

Methane emissions detected at the location of the 5,000 scfh calibration leak were analyzed separately. A GIS analysis of just the Friday PM passes indicate that the leak was detected on 3 passes. The position of that leak is shown in this table.

Section 3

LaSen, Inc.

Note: This reports was completed by the equipment provider prior to SwRI divulging the actual leak sites and leak rates. That is, it includes “blind” test results. Any claims of leaks detected should be considered preliminary, and the analysis of the results is provided in Section 4.3. The claims and comments of the equipment provider do not reflect the opinions of the Department of Energy.

EQUIPMENT PROVIDER TEST REPORT

for LaSen, Inc.
Prepared by E. Degtiarev, D. Troutman and A. Karpov
on 10/04/04

1. DESCRIPTION OF LEAK DETECTION SYSTEM

1.1 Sensor System Description (with block diagram)

LaSen's Airborne Lidar Pipeline Inspection System (ALPIS) is based on a Differential Absorption Lidar (DIAL) chemical sensor operating in the mid-IR (3—5-µm) range. The laser beam is transmitted down from the aircraft to illuminate the area on the ground above the buried pipe. After reflection from the ground, the beam is collected by the sensor's receiver and the amount of received energy is measured. If the laser beam passes through a methane plume emanating from a pipeline leak, the received energy will be diminished due to the absorption of laser light in the plume. This absorption signature is used to located the leak and assess its magnitude.

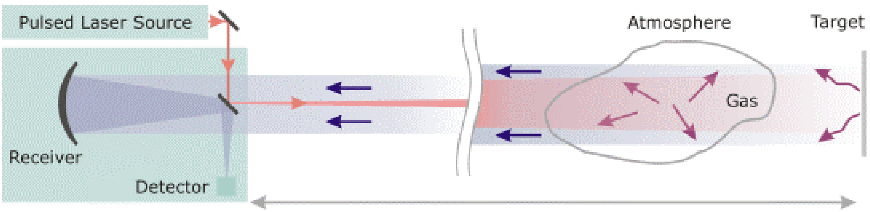


Figure 1. Remote detection of chemical using LIDAR

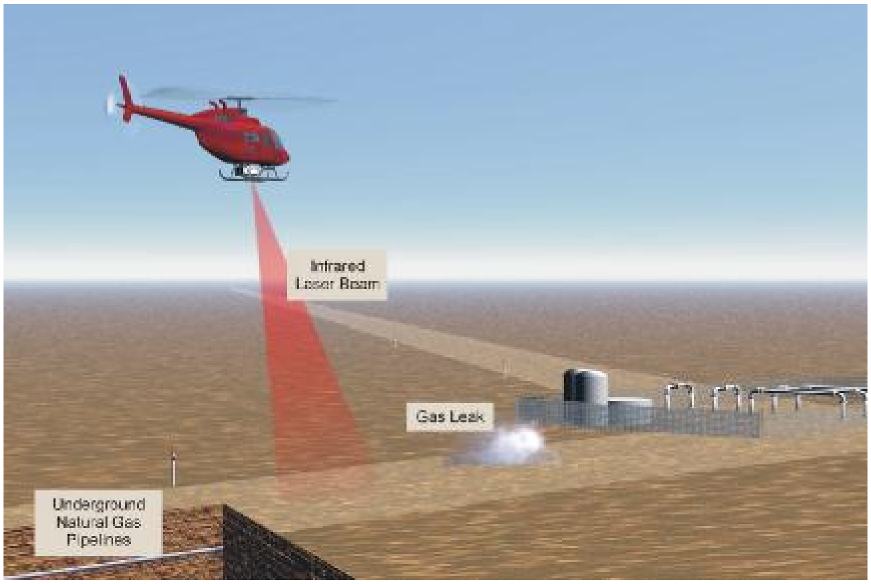


Figure 2. ALPIS operational principle

In addition to the Lidar chemical sensor, the ALPIS system also contains a suite of auxiliary sensors, including GPS, video camera and a rangefinder.

1.2 Platform Description

Bell 206B-III (Jet Ranger) helicopter

1.3 Pre-Test Checks

Laser output energy and wavelength calibration;

Visual monitors;

Power supplies;

Cryo-detector status;

All checks can be completed in less than 5 minutes

2. DATA COLLECTION AND REDUCTION SCHEME

The system implements a classic Differential Absorption Lidar (DIAL) approach. After a mission is started, data acquisition occurs continuously along the track of the aircraft. The laser is fired first at the "on" frequency, corresponding to an absorption line of methane. Within 10 ms the laser is fired again, this time at the "off" frequency which is detuned from the methane absorption line. Each on/off frequency pair is repeated 10 to 20 times a second. For each laser firing, transmitted and received energy values are measured and recorded. The ratio of the normalized received energy for the on and off pulses is directly related to methane concentration. Thus, less energy received in the "on" pulse (ratio less than 1) indicates a potential leak site. Each ratio measurement (corresponding to a pair of laser pulses) is recorded with a unique number in the mission data file. Data from the rangefinder, GPS and video camera are also recorded and referenced to the pulse number.

In processing of the recorded data, each potential leak location is analyzed based on a certain set of both quantitative and qualitative criteria to distinguish it from random noise and ground clutter.

3. TEST DATA

3.1 Day 1

3.1.1 Data Collection Routes (NOTE: include details regarding flight or driving paths for each data collection pass)

The morning flight was aborted due to a power supply failure.

Data was collected during the afternoon flight, but a malfunction in the GPS unit prevented location information from being recorded. (The GPS was not "seeing" any satellites.) As a result, locations of detected leaks could not be established.

3.1.2 Table of Gas Concentration Measurements for Each Pass (include in Attachment A)

No reported data.

3.1.3 Description of System/Software Modifications Made Throughout Testing

The damaged power conditioning unit was eliminated from the system.

3.2 Day 2

3.2.1 Data Collection Routes (NOTE: include details regarding flight or driving paths for each data collection pass)

The GPS unit was still malfunctioning during the morning flight. The problem was traced to electromagnetic interference from the pilot's monitor. Relocating the GPS unit restored the reception for the afternoon flight.

Afternoon: two passes, first— South to North, second—South to North

3.2.2 Table of Gas Concentration Measurements for Each Pass (include in Attachment B)

Data is reported for the afternoon flight only. See Attachment B.

3.2.3 Description of System/Software Modifications Made Throughout Testing

The GPS unit was relocated and an external antenna was added.

3.3 Day 3

3.3.1 Data Collection Routes (NOTE: include details regarding flight or driving paths for each data collection pass)

Morning: two passes, first—South to North, second—North to South

Afternoon: two passes, first—South to North, second—South to North

3.3.2 Table of Gas Concentration Measurements for Each Pass (include in Attachment C)

See attachment C

3.3.3 Description of System/Software Modifications Made Throughout Testing

An additional thermal shield was installed to protect the sensor package from cold temperatures experienced during the early morning and late afternoon flights.

3.4 Day 4

3.4.1 Data Collection Routes (NOTE: include details regarding flight or driving paths for each data collection pass)

Morning: two passes, first—South to North, second—North to South

Afternoon: two passes, first—North to South, second—South to North

3.4.2 Table of Gas Concentration Measurements for Each Pass (include in Attachment D)

See attachment D

3.4.3 Description of System/Software Modifications Made Throughout Testing

None

3.5 Day 5

3.5.1 Data Collection Routes (NOTE: include details regarding flight or driving paths for each data collection pass)

Morning: two passes, first—South to North, second—South to North

Afternoon: two passes, first—South to North, second—North to South (incomplete pass, aborted around marker 5)

3.5.2 Table of Gas Concentration Measurements for Each Pass (include in Attachment E)

See Attachment E

3.5.3 Description of System/Software Modifications Made Throughout Testing

None

4. SUMMARY OF RESULTS

Several general comments apply to the results presented in this report.

1. In the current configuration, GPS information is updated every two (2) seconds. At the average helicopter speed of 30 mph, this corresponds to position uncertainty of up to 100 ft (30 m).

2. Leak locations are reported "as detected", i.e., no attempt has been made to bring closely correlated data points to a single location. This is believed to be consistent with SwRI reporting requirements. In actual reporting to the pipeline customer, every leak would be represented by a single most probable location.

3. Plume migration due to wind further increases the uncertainty of reported leak locations. For very large leaks, such as the leak near the gas plant on Friday, the plume extended over an area of at least 200 ft.

4. There is no direct correlation between the true magnitude of a leak (i.e., flow rate expressed in scfh) and its expression (the signature the leak produces in the data). The same leak can appear as large, medium or small depending primarily on how well the laser beam overlaps with the plume for a given pass. The latter overlap factor is determined by the spatial relation between the gas plume and the aircraft track. Therefore, the estimates of leak sizes reported in the Attachments are only qualitative.

5. Lack of sufficient visual indicators along the simulated pipeline made following the route difficult and increased the possibility of tracking errors and, consequently, missed leaks. The 14 plywood markers were spread too far apart to provide reliable navigational guidance. Following the pipeline via GPS coordinates proved to be impractical, at least with commercially available navigational units. Thus, the pilot had to rely on his assessment of recognizable topographic features to follow the "invisible" route. In real world application, the pipeline's right of way always provides a reliable tracking reference.

6. The noise level in the data is significantly higher in areas of high ground clutter (particularly in the northern part of the route due to heavy vegetation and "rough" terrain). Consequently, the probability of detecting leaks, especially small, in those areas is lower. Whether or not this amount of vegetation and terrain features is representative for a typical pipeline right of way remains a point of contention.

7. Wind conditions affect both flying accuracy and plume dispersion. The relatively larger number of leaks reported for Wednesday is due to the generally calmer conditions on that day.

8. Instrumented leaks are indistinguishable from fugitive VOC emissions in the survey path.

5. CONCLUSIONS

Final conclusions regarding the system performance can be drawn only after the test matrix (leak locations and rates) is made available to the equipment providers. At this point we are fairly confident in saying that the ALPIS system performed as expected under the given set of test conditions. Detection of various calibration leaks confirmed previous estimates of the system's sensitivity.

The level of performance demonstrated in the RMOTC test does not set the limit on the system's ultimate capability. LaSen is continuously improving the leak detection technology. By the end of 2004, the next generation of ALPIS will become available, allowing for higher survey speed and increased accuracy of leak detection.

ATTACHMENTS

ATTACHMENT A– DAILY TEST DATA (DAY 1)

NAD 27 GPS Data (DD MM SS.S) Latitude	Longitude	Leak Detection (large, medium, small leak)	Date	Time	Pass Number	Comments

ATTACHMENT B– DAILY TEST DATA (DAY 2)

NAD 27 GPS Data (DD MM SS.S) Latitude	Longitude	Leak Detection (large, medium, small leak)	Date	Time	Pass Number	Comments
43 14 53.6	-106 11 12.4	LARGE	9/14/2004	Afternoon	1	Calibration leak @ 1000 scfh
43 14 53.5	-106 11 12.0	LARGE	9/14/2004	Afternoon	2	Calibration leak @ 1000 scfh
43 16 19.3	-106 12 24.1	MEDIUM	9/14/2004	Afternoon	1	
43 16 19.4	-106 12 24.3	MEDIUM	9/14/2004	Afternoon	2	
43 17 3.0	-106 12 52.7	SMALL	9/14/2004	Afternoon	1	
43 17 3.1	-106 12 52.5	SMALL	9/14/2004	Afternoon	2	
43 17 15.4	-106 13 6.1	SMALL	9/14/2004	Afternoon	1	
43 17 13.2	-106 13 4.3	MEDIUM	9/14/2004	Afternoon	2	
43 17 43.8	-106 13 16.0	VERY LARGE	9/14/2004	Afternoon	1	
43 17 43.6	-106 13 16.2	LARGE	9/14/2004	Afternoon	2	

ATTACHMENT C– DAILY TEST DATA (DAY 3)

NAD 27 GPS Data (DD MM SS.S) Latitude	Longitude	Leak Detection (large, medium, small leak)	Date	Time	Pass Number	Comments
43 14 53.7	-106 11 12.2	LARGE	9/15/2004	Morning	1	Calibration leak @ 500 scfh
43 14 54.0	-106 11 11.9	LARGE	9/15/2004	Morning	2	Calibration leak @ 500 scfh
43 14 53.5	-106 11 11.5	MEDIUM	9/15/2004	Afternoon	1	Calibration leak @ 500 scfh
43 14 53.5	-106 11 11.8	LARGE	9/15/2004	Afternoon	2	Calibration leak @ 500 scfh
43 15 7.3	-106 11 45.3	SMALL	9/15/2004	Morning	1	Potential small leak in the area of a ravine
43 15 7.0	-106 11 45.0	MEDIUM	9/15/2004	Afternoon	1	Potential small leak in the area of a ravine
43 15 6.8	-106 11 44.8	MEDIUM	9/15/2004	Afternoon	2	Potential small leak in the area of a ravine
43 16 19.5	-106 12 24.4	MEDIUM	9/15/2004	Morning	1	
43 16 20.6	-106 12 25.1	LARGE	9/15/2004	Morning	2	
43 16 19.6	-106 12 24.3	MEDIUM	9/15/2004	Afternoon	1	
43 16 19.6	-106 12 24.3	MEDIUM	9/15/2004	Afternoon	2	
43 17 2.3	-106 12 52.5	SMALL	9/15/2004	Morning	1	
43 17 2.4	-106 12 52.4	MEDIUM	9/15/2004	Morning	2	
43 17 2.4	-106 12 52.4	SMALL	9/15/2004	Afternoon	1	
43 17 13.4	-106 13 4.9	MEDIUM	9/15/2004	Morning	1	
43 17 12.5	-106 13 3.4	MEDIUM	9/15/2004	Afternoon	1	
43 17 44.4	-106 13 15.8	VERY LARGE	9/15/2004	Morning	1	
43 17 43.8	-106 13 16.0	LARGE	9/15/2004	Morning	2	
43 17 44.0	-106 13 16.1	SMALL	9/15/2004	Afternoon	1	
43 17 43.7	-106 13 16.1	VERY LARGE	9/15/2004	Afternoon	2	
43 18 13.2	-106 13 5.4	LARGE	9/15/2004	Morning	1	
43 18 13.4	-106 13 5.4	LARGE	9/15/2004	Morning	2	
43 18 12.5	-106 13 5.7	LARGE	9/15/2004	Afternoon	1	
43 18 12.4	-106 13 6.1	VERY LARGE	9/15/2004	Afternoon	2	
43 18 51.4	-106 13 26.9	MEDIUM / LARGE	9/15/2004	Morning	1	
43 18 52.7	-106 13 26.3	SMALL / MEDIUM ,	9/15/2004	Morning	2	
43 18 51.9	-106 13 27.1	MEDIUM / LARGE	9/15/2004	Afternoon	1	
43 18 52.2	-106 13 27.4	LARGE	9/15/2004	Afternoon	2	
43 18 56.9	-106 13 30.4	VERY LARGE	9/15/2004	Morning	1	
43 18 55.4	-106 13 30.0	LARGE	9/15/2004	Morning	2	
43 18 55.9	-106 13 29.9	VERY LARGE	9/15/2004	Afternoon	1	
43 18 55.9	-106 13 30.0	VERY LARGE	9/15/2004	Afternoon	2	
43 20 12.7	-106 13 37.9	MEDIUM	9/15/2004	Morning	1	
43 20 13.1	-106 13 37.9	VERY LARGE	9/15/2004	Morning	2	
43 20 12.6	-106 13 37.9	MEDIUM / LARGE	9/15/2004	Afternoon	1	
43 20 12.2	-106 13 38.2	VERY LARGE	9/15/2004	Afternoon	2	

ATTACHMENT D– DAILY TEST DATA (DAY 4)

NAD 27 GPS Data (DD MM SS.S) Latitude	Longitude	Leak Detection (large, medium, small leak)	Date	Time	Pass Number	Comments
43 14 54.6	-106 11 13.2	SMALL	9/16/2004	Morning	1	Calibration leak @ 100 scfh
43 14 53.2	-106 11 13.1	LARGE	9/16/2004	Morning	2	Calibration leak @ 100 scfh
43 14 54.0	-106 11 13.5	MEDIUM / LARGE	9/16/2004	Afternoon	1	Calibration leak @ 100 scfh
43 14 53.7	-106 11 13.1	MEDIUM	9/16/2004	Afternoon	2	Calibration leak @ 100 scfh
43 16 15.6	-106 12 18.4	VERY LARGE	9/16/2004	Morning	1	
43 16 16.2	-106 12 19.3	VERY LARGE	9/16/2004	Morning	2	
43 16 15.7	-106 12 19.0	VERY LARGE	9/16/2004	Afternoon	1	
43 16 15.6	-106 12 18.5	VERY LARGE	9/16/2004	Afternoon	2	
43 16 20.4	-106 12 24.9	LARGE	9/16/2004	Morning	1	
43 16 20.7	-106 12 24.7	VERY LARGE	9/16/2004	Morning	2	
43 16 20.5	-106 12 25.3	SMALL / MEDIUM	9/16/2004	Afternoon	1	
43 16 19.5	-106 12 23.6	VERY LARGE	9/16/2004	Afternoon	2	
43 17 12.5	-106 13 3.4	MEDIUM	9/16/2004	Morning	1	
43 18 9.9	-106 13 4.6	SMALL	9/16/2004	Morning	2	
43 18 11.0	-106 13 5.6	SMALL	9/16/2004	Afternoon	1	
43 18 12.5	-106 13 6.1	MEDIUM	9/16/2004	Afternoon	2	
43 18 56.3	-106 13 30.6	MEDIUM	9/16/2004	Morning	1	
43 18 57.5	-106 13 29.3	MEDIUM / LARGE	9/16/2004	Morning	2	
43 18 56.7	-106 13 29.4	SMALL	9/16/2004	Afternoon	1	
43 18 56.0	-106 13 29.9	MEDIUM	9/16/2004	Afternoon	2	
43 20 11.3	-106 13 38.4	LARGE	9/16/2004	Morning	1	
43 20 11.5	-106 13 38.5	LARGE	9/16/2004	Morning	2	
43 20 12.1	-106 13 38.1	MEDIUM	9/16/2004	Afternoon	1	
43 20 12.5	-106 13 38.0	MEDIUM	9/16/2004	Afternoon	2	

ATTACHMENT E– DAILY TEST DATA (DAY 5)

NAD 27 GPS Data (DD MM SS.S) Latitude	Longitude	Leak Detection (large, medium, small leak)	Date	Time	Pass Number	Comments
43 14 54.1	-106 11 13.6	SMALL	9/17/2004	Morning	F - M - 2	Calibration leak @ 15 scfh
43 14 53.7	-106 11 11.8	VERY LARGE	9/17/2004	Afternoon	F - A - 1	Calibration leak @ 5000 scfh
43 16 19.7	-106 12 23.9	VERY LARGE	9/17/2004	Morning	F - M - 1	
43 16 19.0	-106 12 23.7	MEDIUM	9/17/2004	Morning	F - M - 2	
43 16 20.0	-106 12 24.5	MEDIUM	9/17/2004	Afternoon	F - A - 1	
43 17 12.3	-106 13 3.1	SMALL	9/17/2004	Morning	F - M -2	
43 17 14.5	-106 13 6.1	SMALL	9/17/2004	Afternoon	F - A - 2	
43 17 45.5	-106 13 15.1	VERY LARGE	9/17/2004	Morning	F - M - 1	
43 17 45.3	-106 13 14.8	VERY LARGE	9/17/2004	Morning	F - M -2	
43 17 44.9	-106 13 15.4	VERY LARGE	9/17/2004	Afternoon	F - A - 1	
43 17 47.3	-106 13 14.1	VERY LARGE	9/17/2004	Afternoon	F - A - 2	
43 18 12.6	-106 13 6.3	VERY LARGE	9/17/2004	Morning	F - M - 1	
43 18 12.6	-106 13 6.1	VERY LARGE	9/17/2004	Morning	F - M - 2	
43 18 12.4	-106 13 6.2	MEDIUM	9/17/2004	Afternoon	F - A - 1	
43 18 12.5	-106 13 6.1	LARGE	9/17/2004	Afternoon	F - A - 2	
43 18 56.6	-106 13 29.8	VERY LARGE	9/17/2004	Morning	F - M - 1	
43 18 56.3	-106 13 30.1	VERY LARGE	9/17/2004	Morning	F - M - 2	
43 18 56.9	-106 13 30.2	LARGE	9/17/2004	Afternoon	F - A - 1	
43 18 56.9	-106 13 30.3	VERY LARGE	9/17/2004	Afternoon	F - A - 2	
43 20 11.2	-106 13 38.7	MEDIUM	9/17/2004	Morning	F - M - 1	
43 20 11.4	-106 13 38.8	MEDIUM	9/17/2004	Morning	F - M - 2	
43 20 10.9	-106 13 39.0	MEDIUM	9/17/2004	Afternoon	F - A - 1	
43 20 11.0	-106 13 38.8	MEDIUM	9/17/2004	Afternoon	F - A - 2	

Section 4

Lawrence Livermore National Laboratories

Note: This reports was completed by the equipment provider prior to SwRI divulging the actual leak sites and leak rates. That is, it includes "blind" test results. Any claims of leaks detected should be considered preliminary, and the analysis of the results is provided in Section 4.3. The claims and comments of the equipment provider do not reflect the opinions of the Department of Energy.

Note: Subsequent to submission of the attached report, LLNL submitted the following text that was inadvertently omitted from Section 1.1 of the attached report.

> *"The HyMap sensor system is probably the most advanced hyperspectral imaging spectrometer in the world today. The sensor system has evolved over the past eight years partially because of the LLNL/UCSC collaboration with HyVista. The complete description of the HyMap sensor system is found at http://www.hyvista.com/main.html*
>
> *HyVista Corporation operates a HyMap™ hyperspectral scanner manufactured by Integrated Spectronics Pty Ltd. The design of the HyMap series of airborne hyperspectral sensors features an opto-mechanically scanned fore-optics combined with modular, high efficiency spectrographs and optimized detector arrays..*
>
> *The HyMap provides 126 bands across the reflective solar wavelength region of 0.45 – 2.5 nm with contiguous spectral coverage (except in the atmospheric water vapor bands) and bandwidths between 15 – 20 nm.*
>
> *The sensor operates in a 3-axis gyro stabilized platform to minimize image distortion due to aircraft motion. The system can be rapidly adapted into any aircraft with a standard aerial camera port and is transported between international survey sites by airfreight. The HyMap provides a signal to noise ratio (>500:1 usually over 1000 to 1) and image quality that sets the industry standard. Laboratory calibration and operational system monitoring ensures the calibrated imagery required for demanding spectral mapping tasks. Geolocation and image encoding achieved with DGPS and an integrated IMU (inertial monitoring unit).*
>
> *A typical spatial configuration of the HyMap sensor is shown below.*
>
> - *IFOV - 2.5 mr along track, 2.0 mr across track*
> - *FOV - 61.3 degrees (512 pixels)*
> - *GIFOV - 3 – 10 m (typical operational range)"*

EQUIPMENT PROVIDER TEST REPORT
for Lawrence Livermore National Laboratories
Prepared by William L. Pickles
On October 1, 2004

1. DESCRIPTION OF LEAK DETECTION SYSTEM

1.1 Sensor System Description (with block diagram)

The sensor system is a

1.2 Platform Description

The hyperspectral imaging spectrometer is mounted in a Twin Otter aircraft, which has ca view hole cut in the bottom of the plane. The sensor is mounted on a stabilizing platform, which contains an inertial measuring unit (IMU). The stabilizing platform maintains the sensor axis angle with respect to the earth below in spite of the motions of the aircraft. The stabilizing platform and sensor combination are mounted over the hole in the bottom of the aircraft. The sensor and the stabilizing platform are controlled be a computer which is rack mounted in the plane near the sensor stabilizing platform combination. The photo in Figure 1 below shows the sensor as white labeled HyMap and the stabilizing platform, which is yellow inside the Twin Otter. The HyVista sensor operator, Mike Hornibrook, is standing at the open hatch doors.

Figure 1 The HyMap sensor is white sitting on the stabilizing platform that is yellow inside the Twin Otter manned aircraft. Mike Hornibrook who is the HyVista operator is shown standing outside side the hatch doors.

The computer that controls the sensor and stores the imaging spectrometer data and the stabilizing platform orientation information can be seen in the second figure.


HYMAP

1.3 Pre-Test Checks

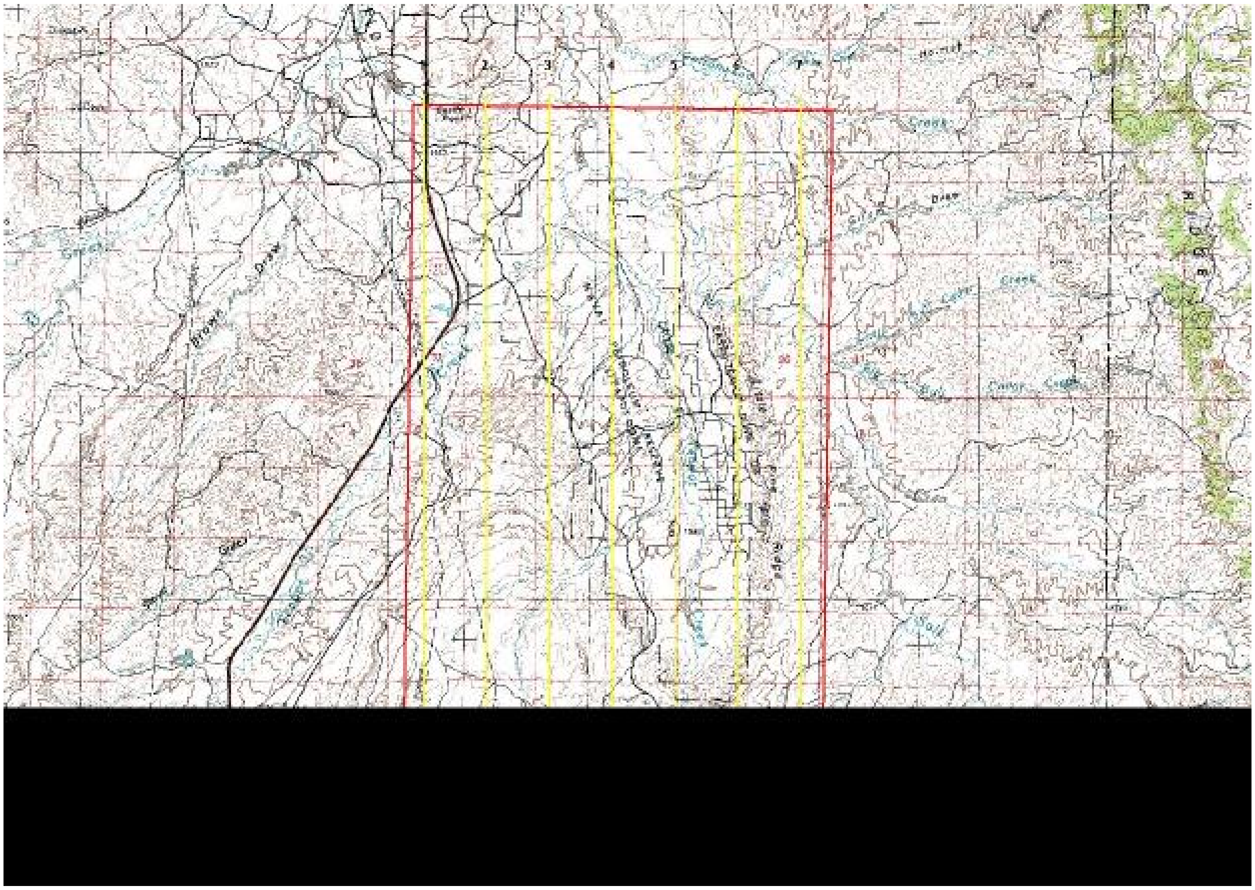
The preflight checks include sensor calibration, which was done in Las Vegas before arriving at Casper, filling the liquid nitrogen reservoirs that cool the detectors and loading the DGPS flight line plan.

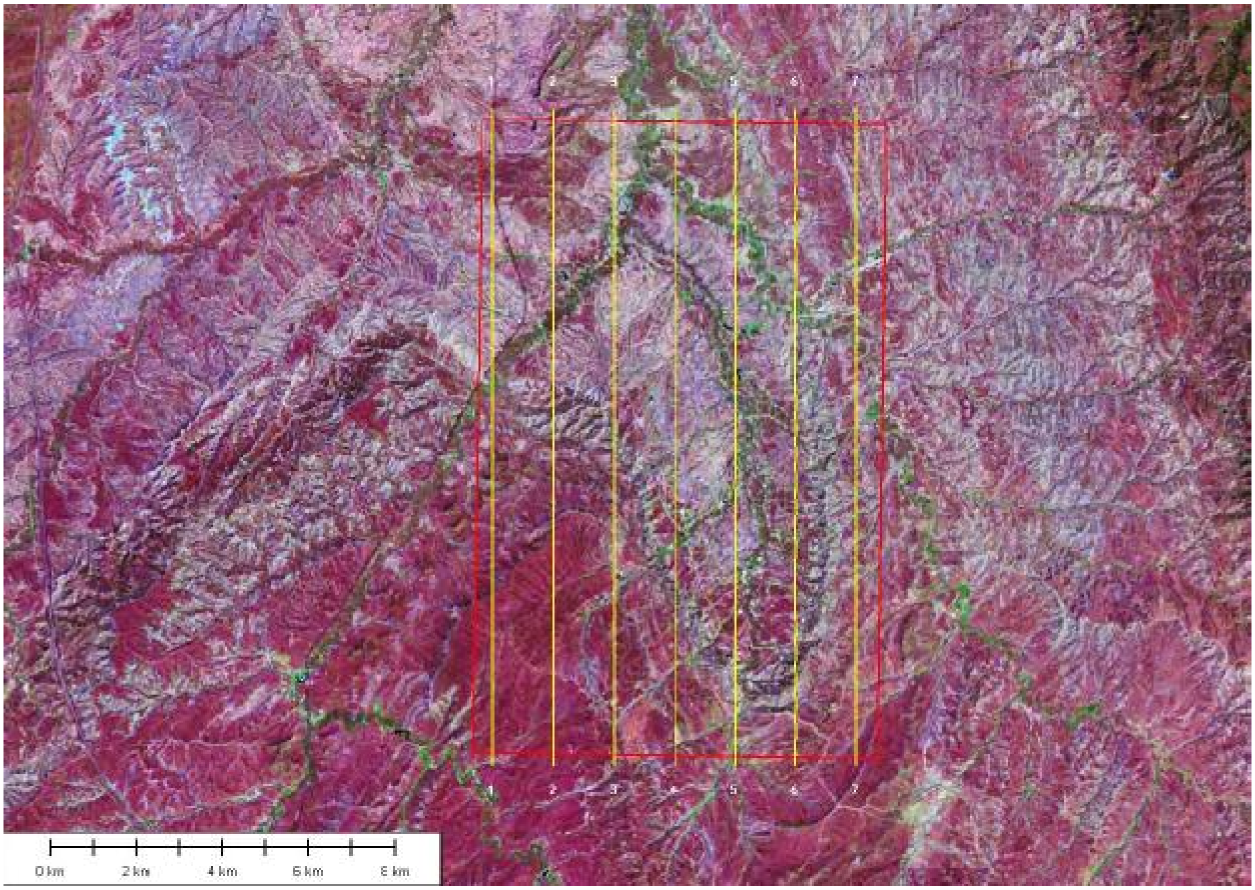
2. DATA COLLECTION AND REDUCTION SCHEME

(NOTE: Discuss general data collection scheme, including sample identification numbering, etc.)

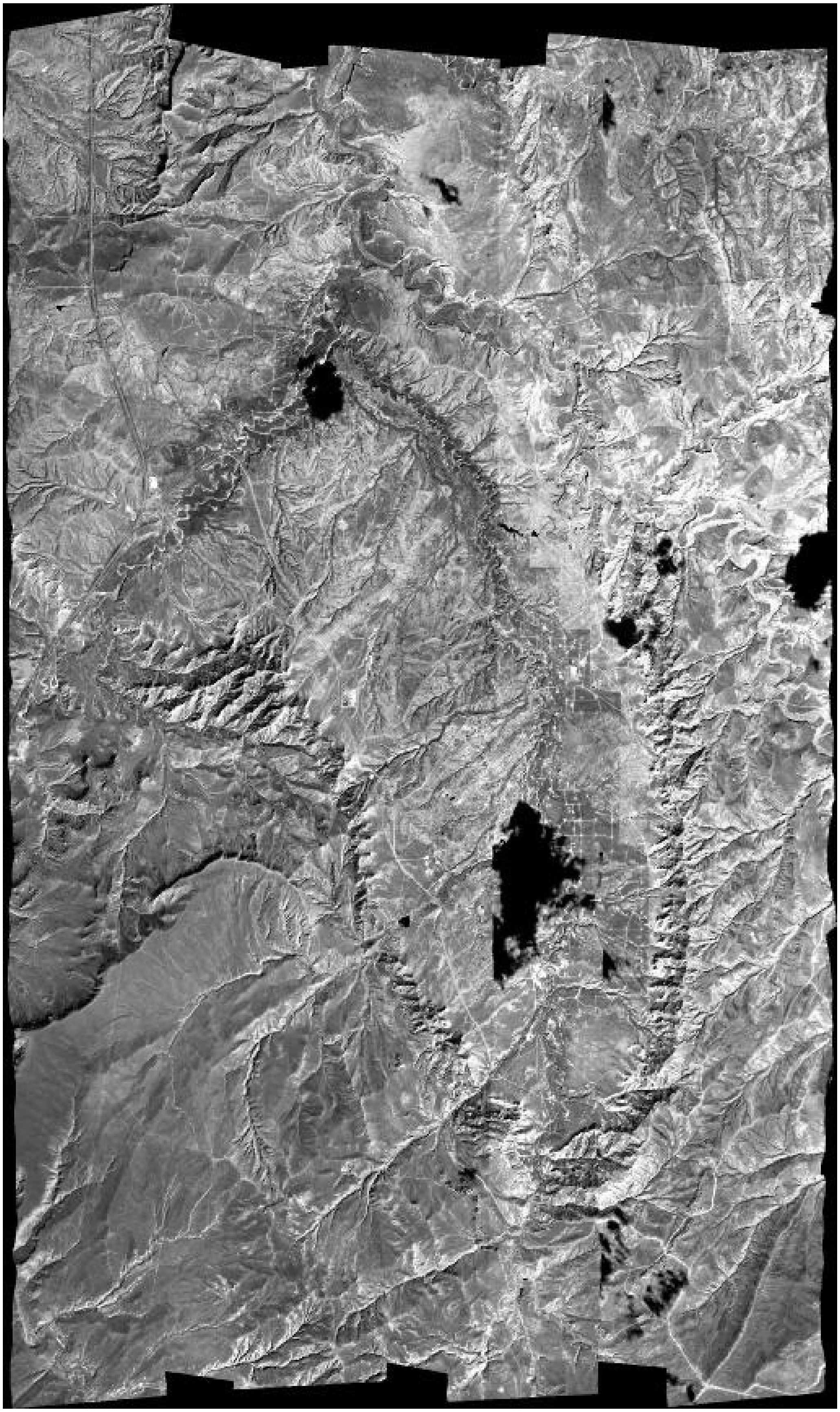
The plane flies south to north along the predetermined flight line DGPS coordinates. The sensor scans across the direction of the planes motion. The sensor images and the DGPS position of every image pixel are moved to the computer in real time. HyVista developed this very advanced and powerful capability during our collaborations with them over the past eight years. The data is stored on magnetic tape. After all the data is taken for the day and the plane is landed, the tape is read on to an external Firewire/USB2 hard drive. The data is reduced by algorithms that HyVista has created and that they now can run in a laptop in the plane or in the motel room. The fully reduced and dynamically georectified imagery is saved as radiance, and reflectance. This imagery product is handed to us in the motel room. We then use the commercial hyperspectral analysis program "ENVI" to measure plant distributions and plant stress patterns. ENVI is a commercially available analysis program that we have helped develop over the years. We did use ENVI to locate several plant stress patches in the imagery immediately after getting the data from Mike Hornibrook on the portable external hard drive. The Firewire/USB2 external hard drive holds 200 Giga Bytes and is very fast. In our manned airborne hyperspectral, imaging technique the individual flight lines and the DGPS data are about two Giga Bytes in size. The image analysis using ENVI in the laptops requires less than an hour.

To image the entire NPR3-RMOTC site required seven flight lines as shown in the next two figures.





The seven flight lines that were required to image the entire NPR3_RMOTC site are shown mosaiced together in the Figure 4 below. The images are shown in grayscale using one of the bands in the visible wavelengths.



3. TEST DATA

The manned hyperspectral Imaging took place on two days. Wed Sept 9 and Wed Sept 15. The underground “Pickles Leaks” were started on August 30. This was done to allow time for the methane from the leaks to saturate the soils and produce pant stress be excluding oxygen from the plant root systems. On both days, the entire NPR3-RMOTC site was successfully imaged. At this time of year, the vegetation at NPR3-RMOTC is largely in hibernation. The exception is in the gullies where there is some moisture. Therefore, we were able to look for unusually stressed plant “patches” in the gullies as possible leak points. We found X location that were along the “virtual pipeline leak. We used the September 15 images to spot the patches. We do not need “before and after images to detect plant stress. We use the spectral signatures of the plants reflected sunlight to determine their relative health. The “Pickles Leaks” were only between M9 and M14. The leak locations and relative size can be determined from the images in one day of flying.

3.1 Day 2

3.1.1 Data Collection Routes (NOTE: include details regarding flight or driving paths for each data collection pass)

The entire site was imaged in seven flight lines

3.1.2 Table of Plant Stress Indicators for Each Pass (include in Attachment A)

Only the measured spectral shape in each image pixel is needed to assign plant stress level.

3.1.3 Description of System/Software Modifications Made Throughout Testing

None

4. SUMMARY OF RESULTS

(NOTE: quantitative and/or qualitative information regarding leak locations and system performance)

We have found pixels in the hyperspectral imagery that have the spectral signature typical of sick vegetation that that were several pixels in diameter in Y locations in the gullies or ravines along the virtual pipeline route. We found several patches of stressed vegetation in gullies that were somewhat away from the virtual pipeline. The locations of the center of the patches in Latitude and Longitude in WGS 84 and the approximate dimensions are given below. A pixel is 3 meters in size. In this report, we are only listing locations and approximate sizes of sick vegetation patches. In the year-end report, we will be converting these patches to polygons in a GIS layer. We have only used flight line 3 taken on Wed Sept 15 because it does include the entire virtual pipeline. We have not had time to analyze the rest of flight lines or look at the imagery taken on Wed Sept 9

Stressed vegetation patches in gullies along the virtual pipeline route:

1. The most northerly patch of sick vegetation is centered at

43 20 28.52 N 106 13 37.69 W

The patch is approximately ellipsoidal +- 9 meters east and west and +- 5 meters north and south. This is a large leak.

2. The second patch of vegetation showing sick vegetation spectral signatures moving south alone the virtual pipeline route is centered on

43 20 13.57 106 13 44.85

The patch is about 2.5 pixels in diameter so it would be a small leak

3. There is a stressed patch near the virtual pipeline route between M12 and M11 near M12

43 19 35.22 106 13 47.54

The patch is an ellipse. It is about 15 meters long and 6 meters wide. The long direction runs NE SW

4. There is a small stressed vegetation patch next to the road north of the Gas Plant.

43 17 51.75 106 13 11.76

It is only about 6 meters in diameter so it would be a very small leak.

Stressed vegetation patches in gullies away from the virtual pipeline route:

1. There is a big patch of stressed vegetation on the return route south of M14.

From 43 20 10.94 N 106 11.71 W to 43 20 10.63 106 14 13.96

This would be a very large leak. The vegetation west of the road crossing is very stressed while the vegetation east of the road crossing is very healthy.

2. There is another suspicious stressed vegetation patch at a road crossing west of the virtual pipeline near RC 16 south of M 13.

43 20 5.72 106 14 0.41

It is about 9 meters NS and 24 meters EW Making it a very large leak.

5. CONCLUSIONS

We do see several patches of stressed vegetation that is adjacent to healthy vegetation, which is a signature of a possible underground gas leak. We have seen small and very large patches of stressed vegetation. However, we see vegetation only in the gullies, which is very restrictive. We will be analyzing the whole site images later.

Section 5

Physical Sciences Inc.

Note: This reports was completed by the equipment provider prior to SwRI divulging the actual leak sites and leak rates. That is, it includes "blind" test results. Any claims of leaks detected should be considered preliminary, and the analysis of the results is provided in Section 4.3. The claims and comments of the equipment provider do not reflect the opinions of the Department of Energy.

Remote Methane Leak Detector Testing at Rocky Mountain Oil Test Center

September 13-17, 2004

Equipment Provider Test Report

Prepared by:

Mickey B. Frish, Matthew C. Laderer, and B. David Green
Physical Sciences Inc.
and
Graham Midgley
Heath Consultants Incorporated

Prepared for:

DoE NETL
and
Chris Buckingham
Southwest Research Institute

September 2004

EQUIPMENT PROVIDER TEST REPORT

for Physical Sciences Inc.
Prepared by Mickey B. Frish, Matthew C. Laderer, and B. David Green
Physical Sciences Inc.
and
Graham Midgley
Heath Consultants Incorporated
on September 13-17, 2004

1. DESCRIPTION OF LEAK DETECTION SYSTEM

Physical Sciences Inc. (PSI) and our partner Heath Consultants Incorporated participated in the tests conducted under DoE National Energy Technology Laboratory sponsorship at the Rocky Mountain Oilfield Testing Center (RMOTC) during the week of September 13, 2004.

1.1 Sensor System Description (with block diagram)

RMLD is a technology previously developed under sponsorship of the PSI and Heath internal funds, US EPA, NYGAS (now NGA), PSE&G, and SoCal for walking survey applications by Local Distribution Companies. The NETL recognized the potential to extend this technology to mobile detection so as to enable its application to transmission pipeline surveys. RMLD participated as a ground-based instrument during the tests at RMOTC. A photograph of the RMLD unit that participated in the RMOTC tests is shown in Figure 1. The control unit is connected to the optical transceiver via a single umbilical.

Figure 1. Remote methane leak detector alpha prototype unit.

In the RMLD, the light from a compact semiconductor laser is collimated and launched out from the transceiver. When the light falls upon any natural surface, a fraction is scattered back to the receiver. We rapidly tune the frequency of the laser across a methane vibrational absorption line. As the laser frequency is swept, the level of the return signal changes by an amount proportional to the absorption. We very sensitively detect this modulation, and transform it to a column methane concentration between the source and the reflecting surface. Different surfaces reflect different amounts of light and so the maximum range will depend on the viewed surface. We have found the effective range to be at least 100 feet (30 meters) for most natural terrain and even paved surfaces, although often detection to 150 feet (45 meters) is possible. For walking survey applications, the proven sensitivity is at 10 ppm-m level. If insufficient signal is returned – a not valid indicator prohibits a survey area to be missed by accident. The RMLD is self-contained, operates an entire day on a battery charge. It has had extensive testing by researchers and LDC surveyors.

1.2 Platform Description

Rear seat of car (Chevy Suburban) rented for occasion.

1.3 Pre-Test Checks

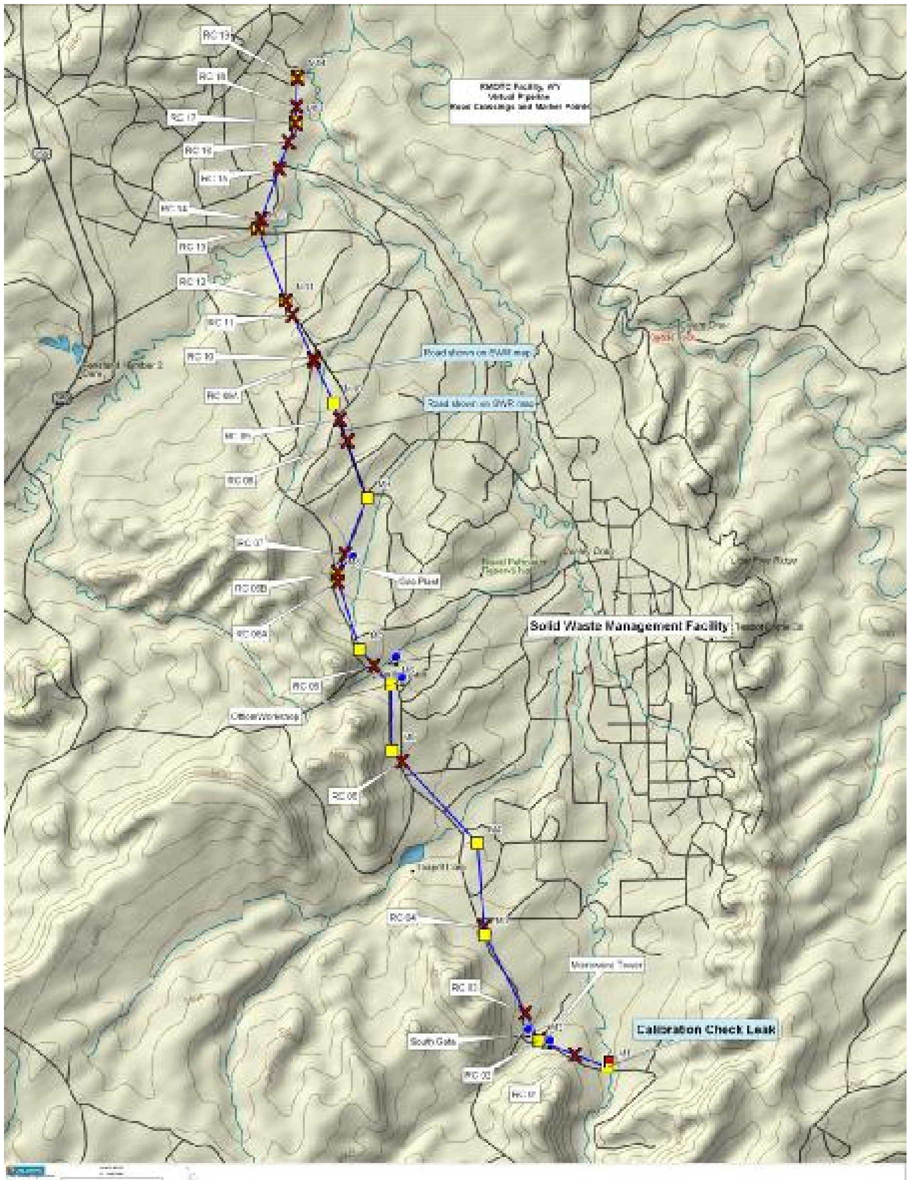
Turn on RMLD power, all self checks performed in 5 seconds. Ready to begin measurements.

2. DATA COLLECTION AND REDUCTION SCHEME

For the development of a unit for mobile testing we transformed the electronics to permit more rapid sample collection and improved the user interface to permit more rapid and sensitive leak detection. In particular, we made use of an audio tone as a column concentration indicator.

Our objective during the RMOTC tests was to determine the effectiveness of these changes in permitting detection at speeds far in excess of walking. However, because this was the first time we had participated in a testing of the mobile version of this unit, we chose to travel slowly in an attempt to optimize the detection of leaks, rather than test the maximum speed where the sensor would work. As a result we traveled at 8 to 10 miles per hour (13 to 16 kilometer per hour), and stopped to investigate and characterize each leak. For these tests we typically averaged 5 mph for the entire 7.4 mile course, but we believe that operating at 35 mph would produce the same level of detection.

We had hoped to investigate the effect of viewing height (on the roof of the vehicle vs. inside), but this was not permitted due to safety constraints. All data were acquired with the surveyor sitting in the rear set of the vehicle looking sideward, viewing the terrain at the limit of RMLD range (about 100 feet) through the open rear windows. We used the audio tone as a rapid indicator of methane cloud detection. We also recorded numerous instrument performance indicators, returned signal levels and the detected concentration on a laptop computer in the front seat of the vehicle. Also operational in the vehicle was a GPS unit (Garmin Etrex, WAAS enabled) connected to a second laptop running a DeLorme topographical mapping software program. The Virtual Pipeline route, markers and road crossings were inserted into this display prior to the RMOTC testing. An example of a map created for the RMOTC tests is shown in Figure 2. These tools permitted the survey vehicle location to be instantaneously displayed with respect to the pipeline and a track of the entire driven route to be shown. When a leak was detected, a compact laser rangefinder (Bushnell Yardage Pro Sport Rangefinder) was used to estimate the range to the leak. The location of the survey vehicle when a leak was observed was entered onto the GPS map. We entered the detected leaks onto the test form provided each day, making note of the relative wind direction, magnitude of leak and other salient characteristics.



G-7948

Figure 2. Virtual pipeline course on topographic map with markers, crossings and roads indicated.

3. TEST DATA

3.0 Introduction

PSI participated in morning and afternoon tests Monday through Thursday, always traveling the same route shown in Figure 3. We measured the low-level calibration leak only on Friday. No modifications were made to the system or software any time. We have listed the leaks detected during each of these 8 test runs in Tables 3.1.1 through 3.5.1. Also given in Figures 4 through 7 are the topo maps with Virtual Pipeline and markers indicated along with the detected leaks. The leaks are indicated as on the road, but the notes would permit more accurate location. In Figure 8 an expanded view of an area where two leaks were detected is shown. These were easily resolved in our ground operations.

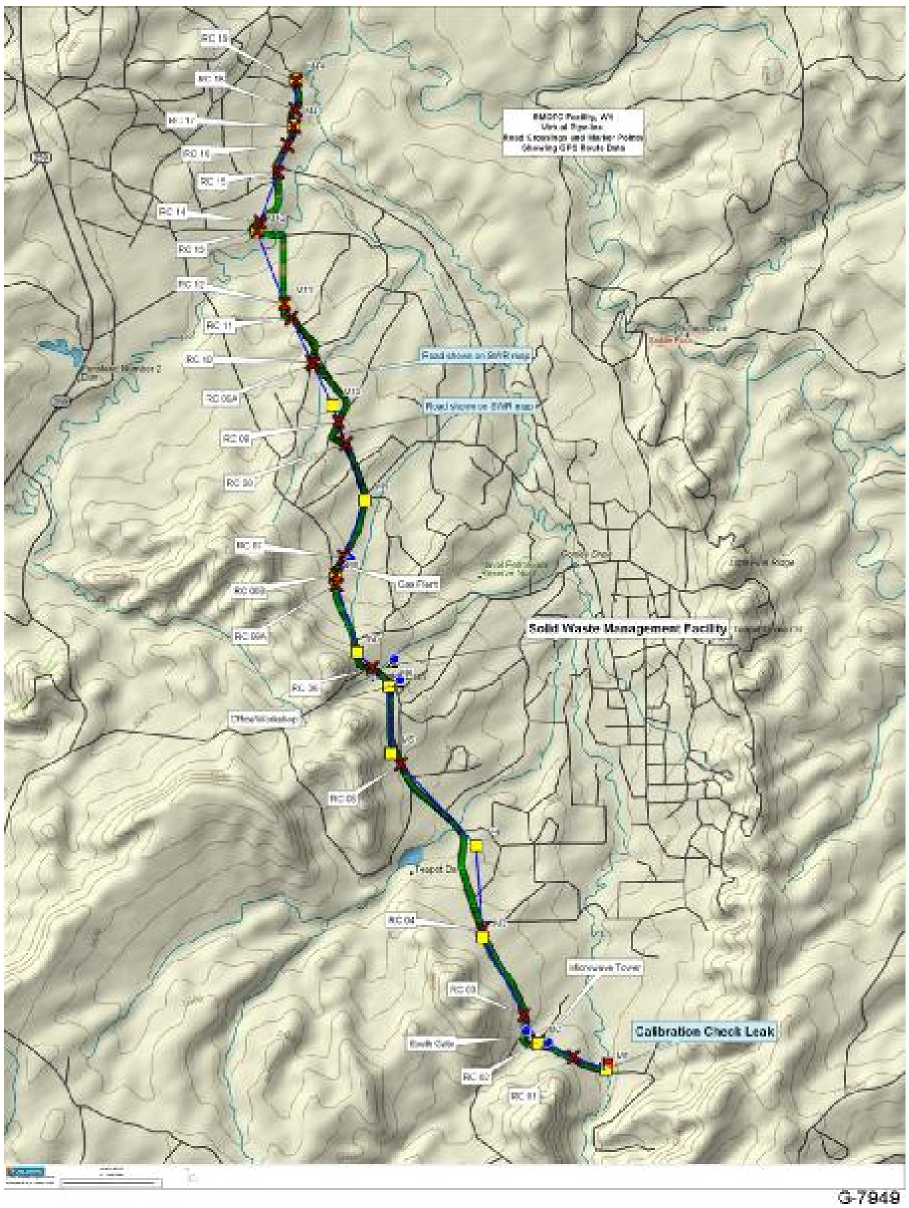


Figure 3. Topographical map as in Figure 2 with path traveled during testing shown in green.

3.1 Day 1

The positions with enhanced column concentrations of methane as detected by mobile survey of RMLD. Figure 4 shows the location of these leaks on the topo map.

Table 3.1.1. Enhanced Methane Positions Monday AM

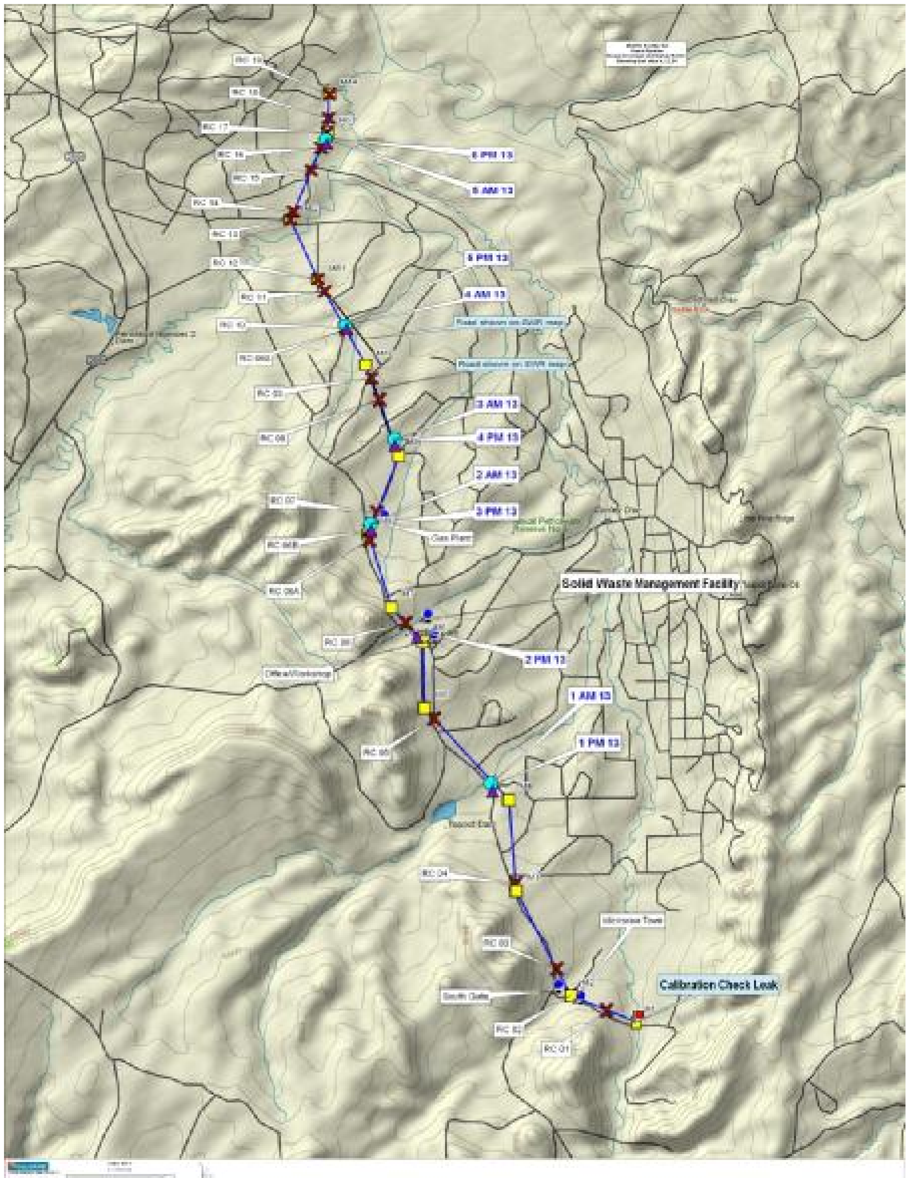
Equipment Provider: Physical Sciences Inc. Interviewer: Jim States Date: Sept. 13, 2004

Time	NAD 27 GPS Latitude (DD MM SS.S)	NAD 27 GPS Longitude (DD MM SS.S)	Assessment of Leak	Comments
9:47 a.m.	N 43 14 53.3	W 106 11 10.92		5,000' SCFH calibration leak test run
	N 43 16 14.88	W 106 12 19.57		
	N 43 17 7.67	W 106 12 55.23		
	N 43 17 44.2	W 106 13 16.7		
	N 43 18 13.8	W 106 13 5.5		
	N 43 18 56.41	W 106 13 28.19		
	N 43 20 12.29	W 106 13 37.47		
11:10 a.m.	Done			

Table 3.1.2. Enhanced Methane Positions Monday PM

Equipment Provider: Physical Sciences Inc. Interviewer: Jim States Date: Sept. 13, 2004

Time	NAD 27 GPS Latitude (DD MM SS.S)	NAD 27 GPS Longitude (DD MM SS.S)	Assessment of Leak	Comments
4:00 p.m.	N 43 14 53.18	W 106 11 12.24	Large	5,000' SCFH calibration leak Wind from NW
4:15 p.m.	N 43 16 15.26	W 106 12 20.04	Narrow	60' E. of road Wind from W.
4:33 p.m.	N 43 17 44.11	W 106 13 16.70	Relatively small leak	20' E. of road Gusty low wind from NW
4:43 p.m.	N 43 18 13.00	W 106 13 5.32	Large leak 1st seen 200' back south of leak	60' NW of road Gusty wind from NW
4:55 p.m.	N 43 18 55.70	W 106 13 28.55	Small leak Wind blowing leak downstream	90' NW of Road Gusty wind from NW
5:16 p.m.	N 43 20 12.12	W 106 13 37.64	Small leak Wind blowing leak downstream	60' NW of Road Mild gusty wind from NW
5:27 p.m.	Done			



G-7950

Figure 4. Positions of survey vehicle when enhanced methane was observed on Monday, September 13, ˜ AM, ▲ PM.

3.2 Day 2

The positions with enhanced column concentrations of methane as detected by mobile survey of RMLD. Figure 5 shows the location of these leaks on the topo map.

Table 3.2.1. Enhanced Methane Positions Tuesday AM

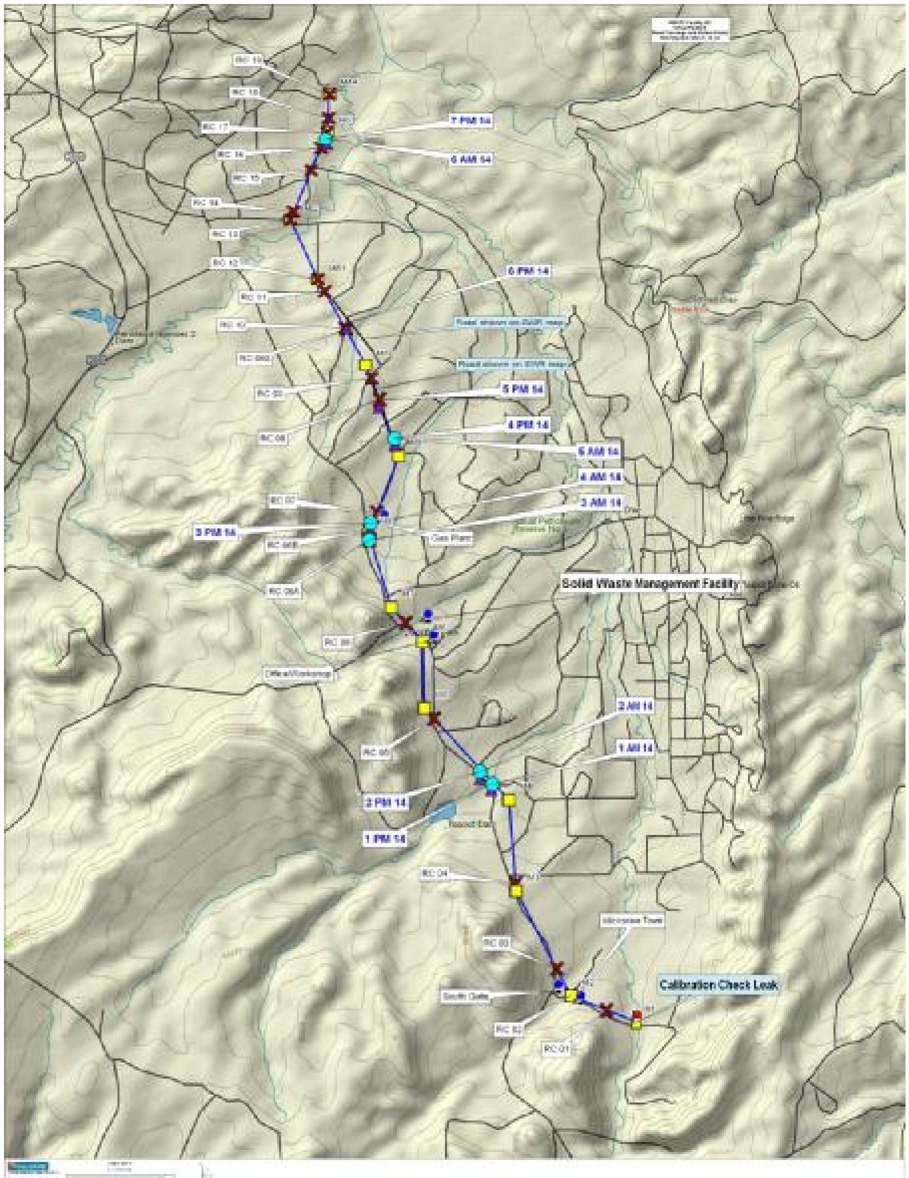
Equipment Provider: Physical Sciences Inc. Interviewer: Jim States Date: Sept. 14, 2004

Time	NAD 27 GPS Latitude (DD MM SS.S)	NAD 27 GPS Longitude (DD MM SS.S)	Assessment of Leak	Comments
10:40 a.m.	N 43 14 53.04	W 106 11 12.12	Large leak	1,000' SCFH Calibration leak
10:56 a.m.	N 43 16 15.38	W 106 12 20.13	15' wide leak	45' east of road 25 mph from SW
11:00 a.m.	N 43 16 19.37	W 106 12 25.34	Small, but at limit of test range Low vertical angle	60' NE of road 25 mph from SW
11:18 a.m.	N 43 17 44.26	W 106 13 16.81	More localized 200'+ downwind	50' NNE of road Gusts from SW
11:28 a.m.	N 43 18 13.52	W 106 13 5.45	Wide leak Wind carried?	30-75' probably dispersed by wind Gusty from SW
11:34 a.m.	N 43 18 26.39	W 106 13 12.91	Potential prior leak – see 11:28 entry	Gusty from SW
11:45 a.m.	N 43 18 56.10 (.56)	W 106 13 28.40 (.14)	Small Leak Intermittent also seen downwind 120 ppm at 300'	100' W from road 120' gusty from SW light rain
12:03	N 43 20 12.16	W 106 13 37.44	Narrow plume also downwind 300 ft.	60' NW of road Gusty from SW
12:08	Done			

Table 3.2.2. Enhanced Methane Positions Tuesday PM

Equipment Provider: Physical Sciences Inc. Interviewer: Jim States Date: Sept. 14, 2004

Time	NAD 27 GPS Latitude (DD MM SS.S)	NAD 27 GPS Longitude (DD MM SS.S)	Assessment of Leak	Comments
5:31 p.m.	N 43 14 53.15	W 106 11 12.44	Large leak	1,000' SCFH calibration leak
5:52 p.m.	N 43 16 14.96	W 106 12 19.56	Large leak	50' NE of road Wind from W.
5:56 p.m.	N 43 16 19.22	W 106 12 25.15	Large leak	80' NE of road off bushes - wind from W.
6:18 p.m.	N 43 17 38.42	W 106 13 17.39	Possible intermittent	70' E of road Near Gas Plant Wind N-NW
6:21 p.m.	N 43 17 44.29	W 106 13 16.66	Easy too see & constant	70' E of road Wind from N – NW
6:31 p.m.	N 43 18 13.20	W 106 13 5.35	Large leak Also seen 300' downwind	75' W of road Wind out of N
6:56 p.m.	N 43 20 12.13	W 106 13 37.67	Large + 75' downwind	55' NW of road Wind from N-NE
7:02 p.m.	Done			



G-7951

Figure 5. Positions of survey vehicle when enhanced methane was observed on Tuesday, September 14, ˜ AM, ▲ PM.

3.3 Day 3

The positions with enhanced column concentrations of methane as detected by mobile survey of RMLD. Figure 6 shows the location of these leaks on the topo map.

Table 3.3.1. Enhanced Methane Positions Wednesday AM

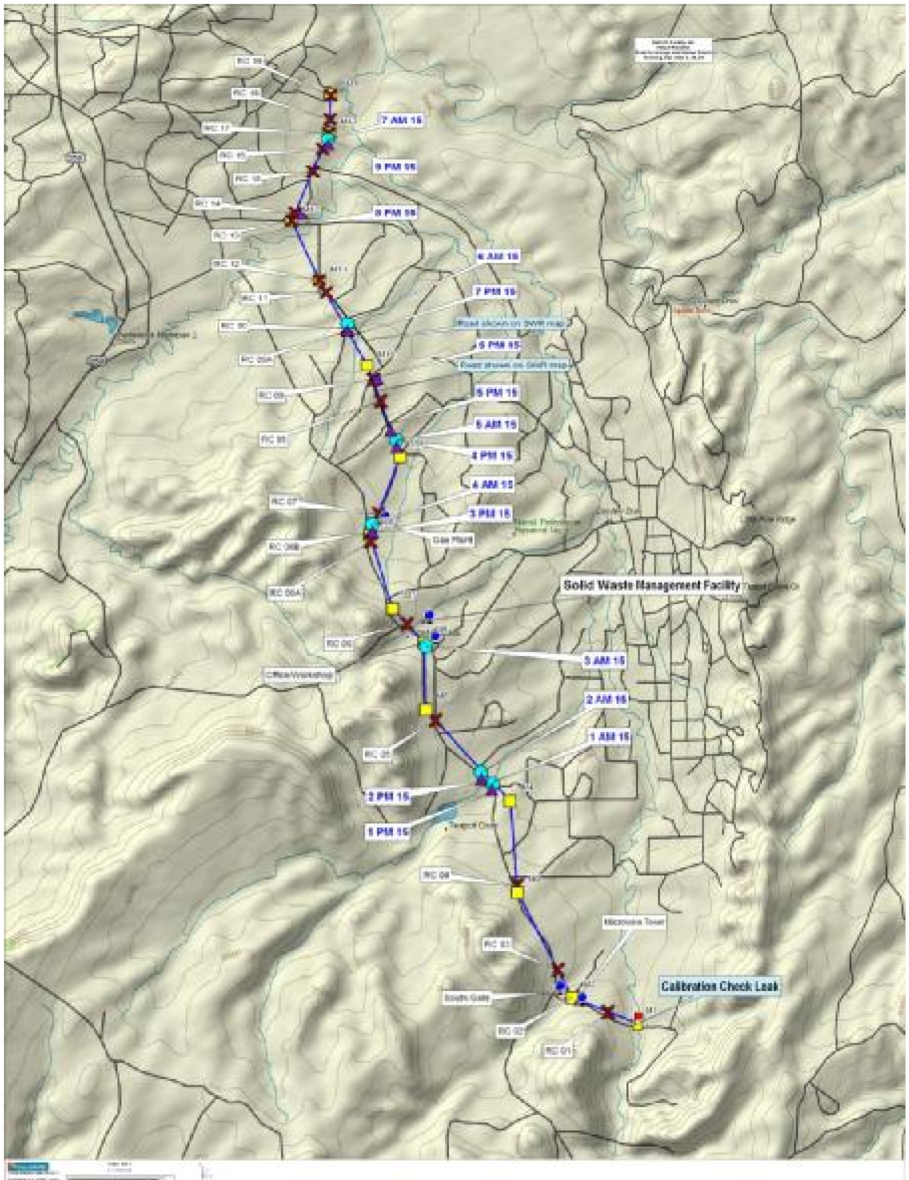
Equipment Provider: Physical Sciences Inc. Interviewer: Jim States Date: Sept. 15, 2004

Time	NAD 27 GPS Latitude (DD MM SS.S)	NAD 27 GPS Longitude (DD MM SS.S)	Assessment of Leak	Comments
7:59 a.m.	N 43 14 53.18	W 106 11 12.38	Smaller than prior days 4,000-8,000 ppm-m	500 SCFH calibration leak 50' N of road
8:17 a.m.	N 43 16 15.41	W 106 12 20.03	Smaller than prior 2,000-3,000 ppm-m	33' NE of road Gusty wind from SE
8:22 a.m.	N 43 16 19.48	W 106 12.25.54	Lower level 1,500 – 2,500 ppm-m disbursed over 100'	80' NNE of road Constant from SE
8:33 a.m.	N 43 17 2.59	W 106 12 51.49	Low level 100-300 ppm-m	60' W of Road Gusty from SE
8:45 a.m.	N 43 17 44.33	W 106 13 16.63	Large leak 7,000-9,500 900 ppm-m on downwind 80 yards from leak 300 ppm-m @ 112 yards from leak 0 @ RC 07	40' NE of road Gusty from SE
Just beyond M9 (100') low level just above noise possible wind carried from prior leak				
9:00 a.m.	N 43 18 13.11	W106 13 5.36	Large leak 7,000-9,500 ppm-m Dirt patch Blowing	60' SW of road Gusty from SE
9:13 a.m. to 9:20 a.m.	N 43 18 56.67	W106 13 28.21	Small Leak 200-1,500 ppm-m Close to range of instrument. consistent at 1,200 ppm-m then low again. Possibly intermittent or wind	60' – 120' W of road Gusty from SE
9:34 a.m.	N 43 20 12.49	W 106 13 37.47	Moderate localized 3,500 – 4,000 ppm-m Gas also seen downwind	60' NW of road Strong gusts from SE
9:40 a.m.	End			

Table 3.3.2. Enhanced Methane Positions Wednesday PM

Equipment Provider: Physical Sciences Inc. Interviewer: Jim States Date: Sept. 15, 2004

Time	NAD 27 GPS Latitude (DD MM SS.S)	NAD 27 GPS Longitude (DD MM SS.S)	Assessment of Leak	Comments
5:29 p.m.	N 43 14 53.15	W 106 11 12.22	4,000-5,000 ppm-m	500 SCFH calibration leak Gusty wind from N-NE
5:49 p.m.	N 43 16 15.83	W 106 12 20.62	Twice saw 180 ppm – m fleeting	Either residual or intermittent
5:54 p.m.	N 43 16 19.38	W 106 12 25.48	1,200-10,000 ppm-m	Gusty from W
6:16 p.m.	N 43 17 44.23	W 106 13 16.65	Large 5,000-18,000+ ppm-m	51’ NE of road Gusty from NW
6:25 p.m.	N 43 18 13.18	W 106 13 5.46	Narrow/localized 8,000-20,000 ppm-m	60’ W of road Mild from NW
6:30 p.m.	N 43 18 18.74	W 106 13 8.21	Small 100-300 ppm-m	100’ NW of Road Mild from NW
6:38 p.m.	N 43 18 36.58	W 106 13 14.62	Small 200-500 ppm-m (Orange) 150 consistent	120’ WNW of road Mild from NW
6:48 p.m.	N 43 18 56.17	W 106 13 28.51	Large HSL – good 6,000 ppm-m	100 to bushes NW of road No wind 126’ to bill for solid return
7:02 p.m.	N 43 19 44.29	W 106 13 50.01	Low Level 180 ppm – m	60’ NW of road No wind extended area
7:13 p.m.	N 43 20 12.44	W 106 13 37.50	Large 20,000 – 25,000 ppm-m 5,000 lower limit Local: middle of oilfield, plowed patch	61’ WNW NW of road No wind
7:20 p.m.	Done			



G-7952

Figure 6. Positions of survey vehicle when enhanced methane was observed on Wednesday, September 15, ˜ AM, ▲ PM.

3.4 Day 4

The positions with enhanced column concentrations of methane as detected by mobile survey of RMLD. Figure 7 shows the location of these leaks on the topo map.

Table 3.4.1. Enhanced Methane Positions Thursday AM

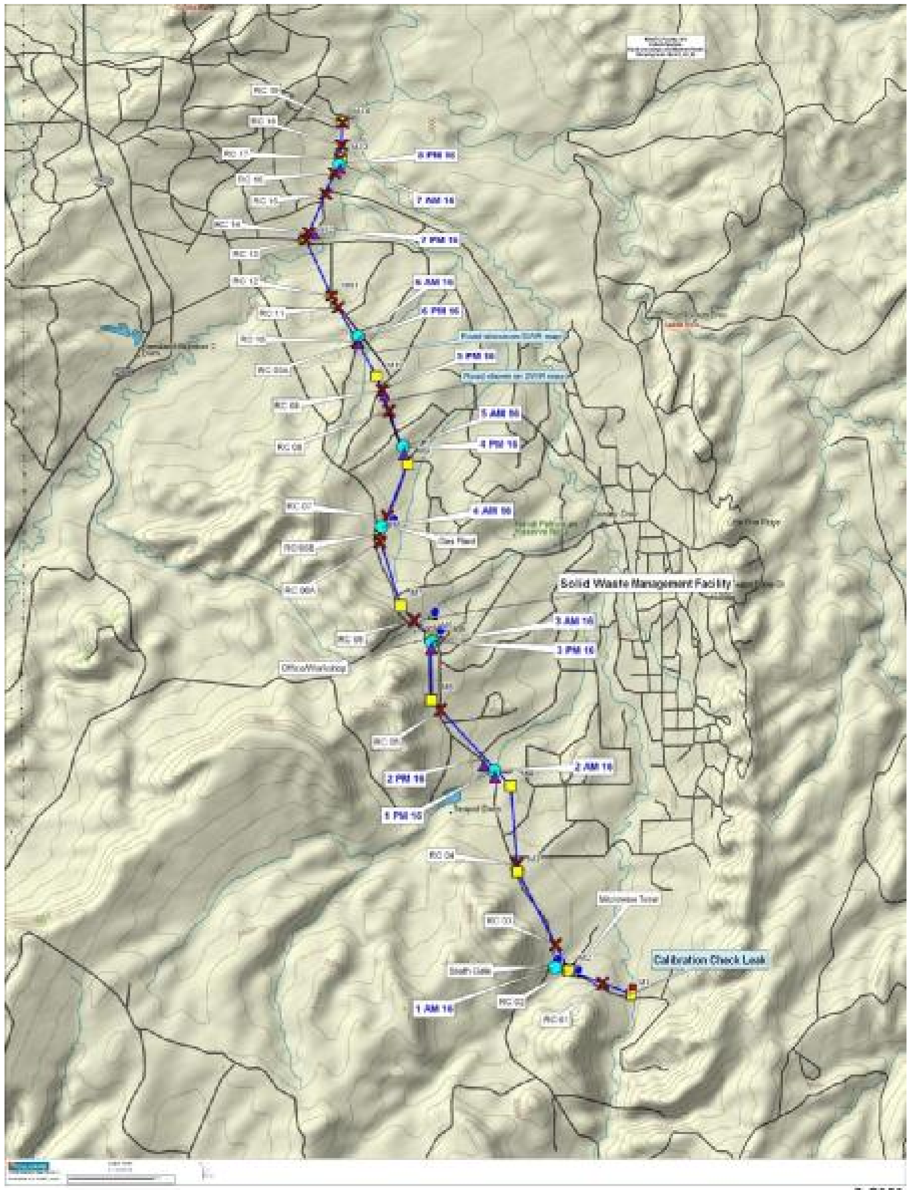
Equipment Provider: Physical Sciences Inc. Interviewer: Jim States Date: Sept. 16, 2004

Time	NAD 27 GPS Latitude (DD MM SS.S)	NAD 27 GPS Longitude (DD MM SS.S)	Assessment of Leak	Comments
7:28 a.m.	N 43 14 53.12	W 106 11 12.07	500 ppm-m	100 SCFH calibration leak Wind from SE
7:36 a.m.	N 43 15 03.44	W 106 11 49.47	Low level 100-150 ppm m Extended	130’ NE of road Wind from SE
7:52 a.m.	N 43 16 15.12	W 106 12 19.83	Large/narrow 5,000-1,000 ppm-m	60’ NE of road Mild to None
8:05 a.m.	N 43 17 2.47	W 106 12 51.56	Small/Int (wind) 100-150 ppm – m 120 average	60’ W of road Gusty from SW
8:18 a.m.	N 43 17 44.34	W 106 13 16.56	Unclear <50 ppm –m edge of detection (50-100)	70’ E of road Gusts from SE
8:29 a.m.	N 43 18 13.48	W106 13 05.56	Strong leak dispersed by wind +/-15,000 ppm-m (100 ft. area)	60’ W of road Very gusty from S
8:40 a.m.	N 43 18 56.95	W 106 13 28.10	Spread out 800-2,000 ppm-m	60’ W of road Mile gusty from SW
8:46 a.m.	N 43 19 12.29	W 106 13 41.71	Narrow plume 42’ 500 ppm–m Edge of Range Due to terrain	100’ E of road Gusts from SE
9:00 a.m.	N 43 20 12.32	W 106 13 37.60	Variable strength 8,000-15,000 ppm-m	40’ W of road Mild wind
9:07 a.m.	Done			

Table 3.4.2. Enhanced Methane Positions Thursday PM

Equipment Provider: Physical Sciences Inc. Interviewer: Jim States Date: Sept. 16, 2004

Time	NAD 27 GPS Latitude (DD MM SS.S)	NAD 27 GPS Longitude (DD MM SS.S)	Assessment of Leak	Comments
4:32 p.m.	N 43 14 53.11	W 106 11 12.15	800 ppm-m	100 SCFH calibration leak Gusty from NW
4:51 p.m.	N 43 16 15.21	W 106 12 19.79	Large seen downwind 200'+ 10,000 ppm-m	54' NE of road Gusty from WNW
4:55 p.m.	N 43 16 19.43	W 106 12 25.37	Medium 2,000-3,500 ppm-m	60' NE of road Gusty from WNW
5:07 p.m.	N 43 17 2.39	W 106 12 51.64	Small 60-250 ppm-m	54' W of road Mild from NW
5:22 p.m.	N 43 18 13.25	W 106 13 05.37	Large 3,000-8,000 ppm-m	66' W of road slight from NW
5:29 p.m.	N 43 18 35.48	W 106 13 15.26	Small 100-300 ppm-m	100' + W of road Gusty from NW
5:36 p.m.	N 43 18 55.84	W 106 13 28.56	Medium 1,000-4,000 ppm-m	90' W of road Gusty from W
5:46 p.m.	N 43 19 43.77	W 106 13 50.48	Tiny 50-100 ppm-m	72" W of road Moderate from W
5:52 p.m.	N 43 20 12.41	W 106 13 37.46	Medium 1,000-5,000 ppm-m	54' NW of road slight from WNW
5:57 p.m.	Done			



G-7953

Figure 7. Positions of survey vehicle when enhanced methane was observed on Thursday, September 16, ˜ AM, ▲ PM.

3.5 Day 5

Only the calibration leak was surveyed on Friday to verify detection threshold.

Table 3.5.1. Enhanced Methane Observation of Partial Course Friday AM

Equipment Provider: Physical Sciences Inc. Interviewer: Jim States Date: Sept. 17, 2004
Calibration Check Run

Time	NAD 27 GPS Latitude (DD MM SS.S)	NAD 27 GPS Longitude (DD MM SS.S)	Assessment of Leak	Comments
6:59	N 43 14 53.1	W 106 11 14.6	Gas detected Background 10-15 ppm-m Leak Site 500-600 ppm-m	15 SCFH calibration leak 20’ NW of road
7:06	Left cal leak site			

4. SUMMARY OF RESULTS

We did not keep detailed notes on the first run (Monday AM), noting only enhanced methane locations. For all other tests we tried to characterize the leak magnitude, variability, spatial extent and estimate its location relative to the survey vehicle. On a given run we were able to observe between 5 and 9 leaks (in addition to the calibration leak). The number of detected leaks increased slightly as the week progressed. This could be due to 1) there being more leaks present; 2) reduced wind conditions; or 3) improved survey technique.

Again we present in Section 3 the position of the survey vehicle, not the position of the leak origin. We will continue our analysis of the recorded column concentrations to search for small leaks. The RMLD exhibited a good ability to resolve two leaks close together as shown in Figure 8.

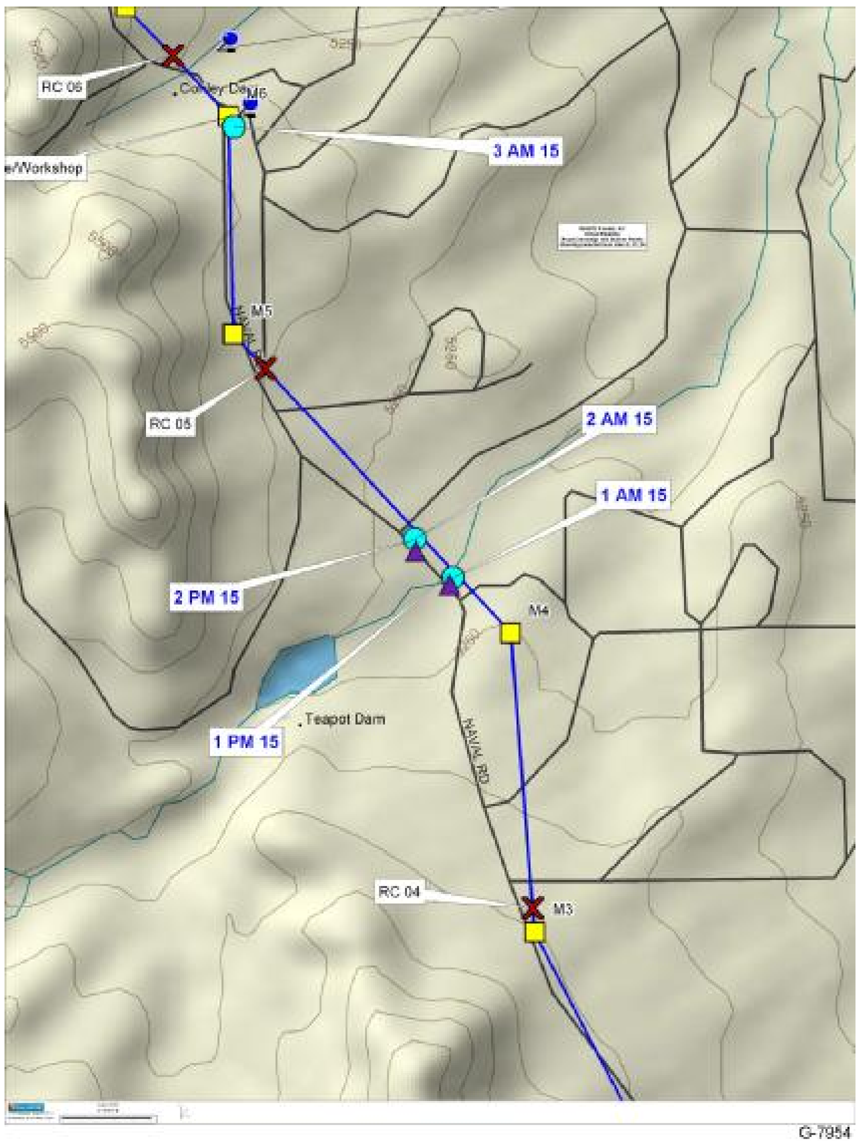


Figure 8. Positions of two adjacent leaks present both Wednesday AM and PM show resolving power.

5. CONCLUSIONS

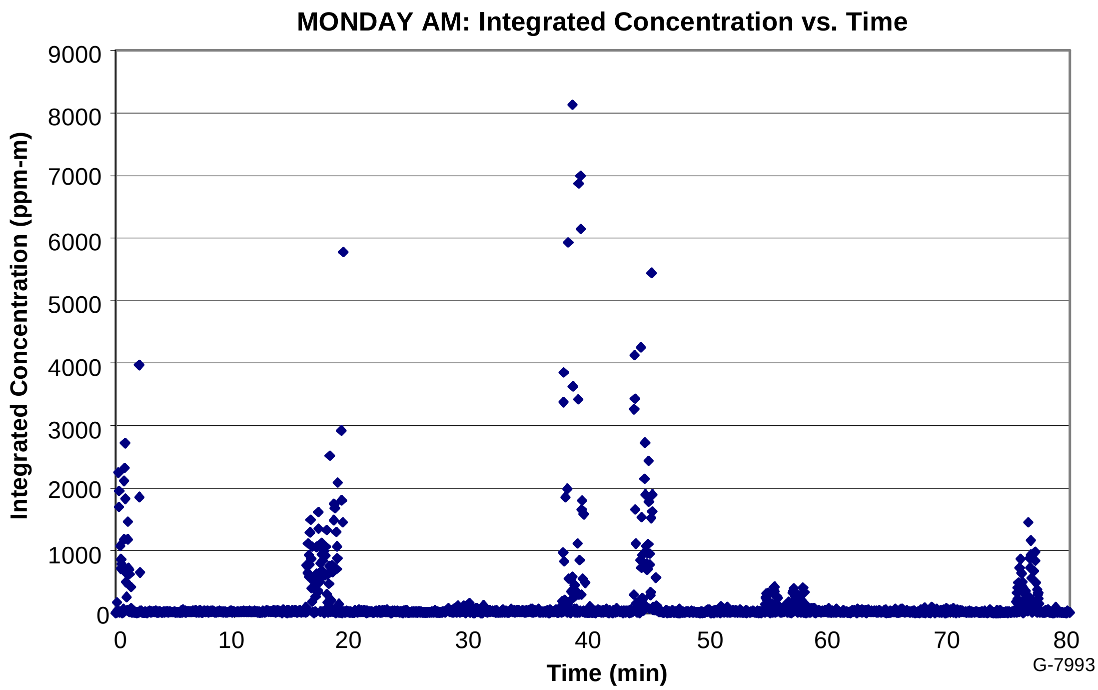
PSI and Heath were delighted to be allowed to participate in these tests at RMOTC. We were impressed with the care and thought that went into creating leak scenarios. A wide range of leak magnitudes and characteristics were presented to test participants. We found the variety stimulating and challenging, and we thank the test conductors.

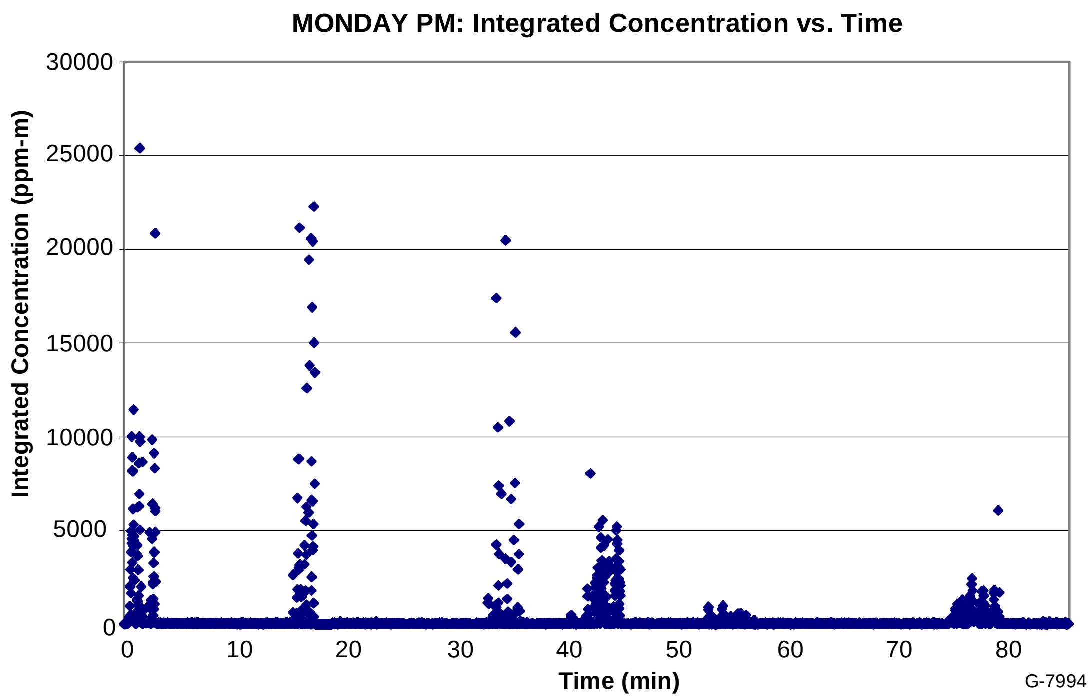
However, as in any simulated test there were artificial constraints that potentially limited the effectiveness of our detection approach. We had no opportunity to optimize the height of viewing. The slant angle to the ground is less well defined at passenger eye level, and thus more sensitive to road vibration moving the viewed volume. As our technique needs a surface to reflect light back to the receiver, we may have missed leaks located at (or just over) a ridge. There were a number of locations where the road passed between embankments, effectively blocking our view and preventing surveying. In a real survey, we would have either traveled the ridge or moved to another position (road) to view the obscured area. We understand that for these structured tests this could not be possible. During real world surveys, the vehicle would travel on the pipeline right-of-way viewing both sides of the pipeline at the maximum uncertain distance and keep the full field in view – stopping and maneuvering to access all areas, walking if necessary.

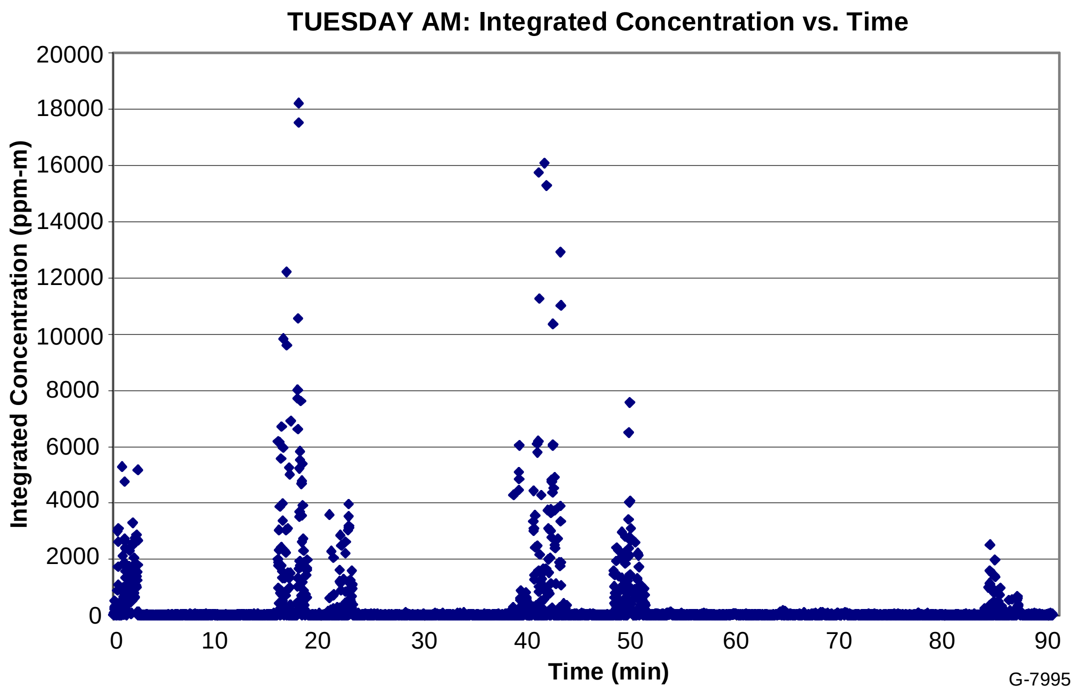
We feel there are many advantages to ground-based surveys. Leaks can be located and marked immediately. They can be investigated to find obvious sources. They can be assessed in the context of their surrounding (desert vs. grammar school). We did not try to optimize survey speed, but plan to do this in future efforts. We were urged to treat this test as if it were a real survey. We showed up the morning the test began, participated in every test run on schedule, packed up and left moving to the next survey.

ATTACHMENTS

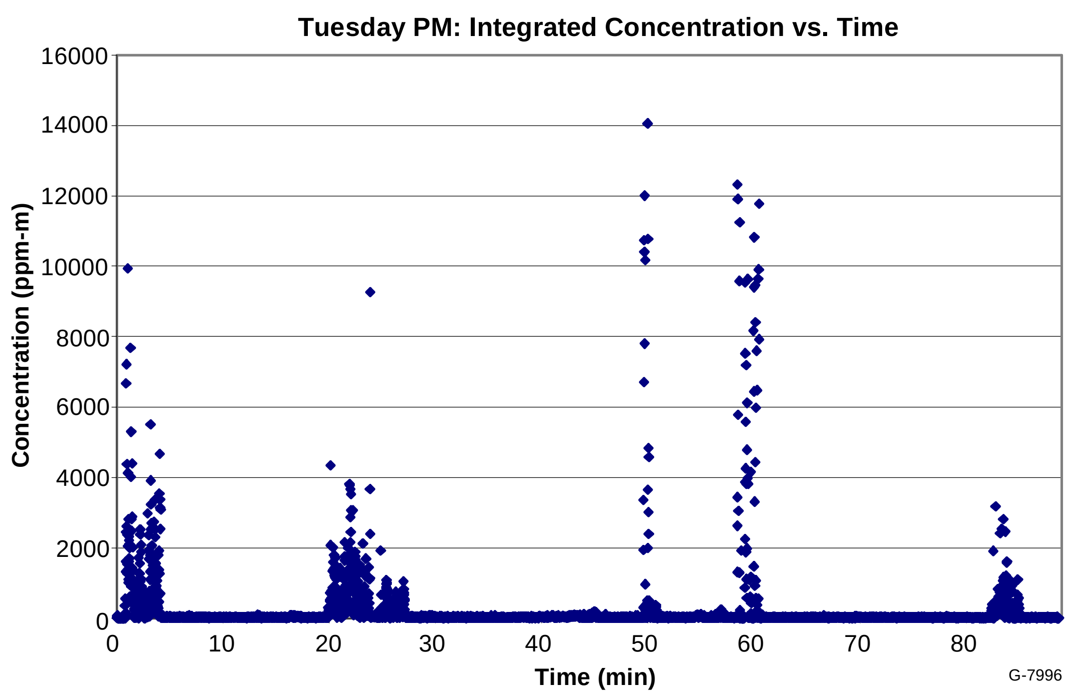
RMLD Observed Column Concentrations


MONDAY AM: Integrated Concentration vs. Time
Integrated Concentration (ppm-m)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
Time (min)
G-7993

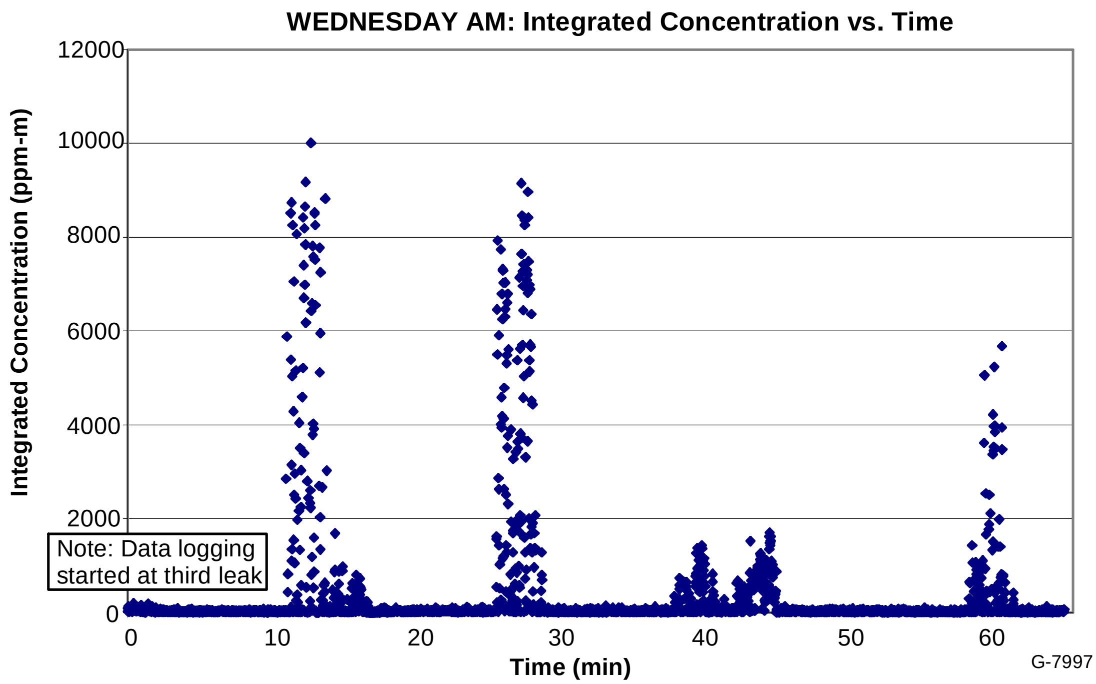

MONDAY PM: Integrated Concentration vs. Time
Integrated Concentration (ppm-m)
30000
25000
20000
15000
10000
5000
0
0
10
20
30
40
50
60
70
80
Time (min)
G-7994

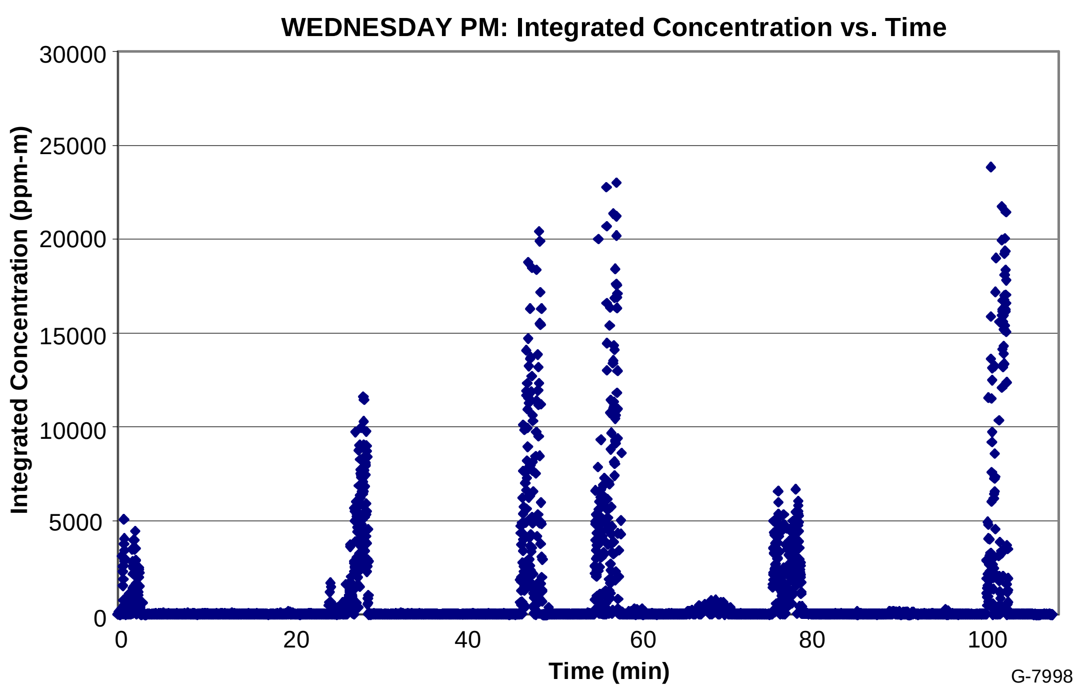


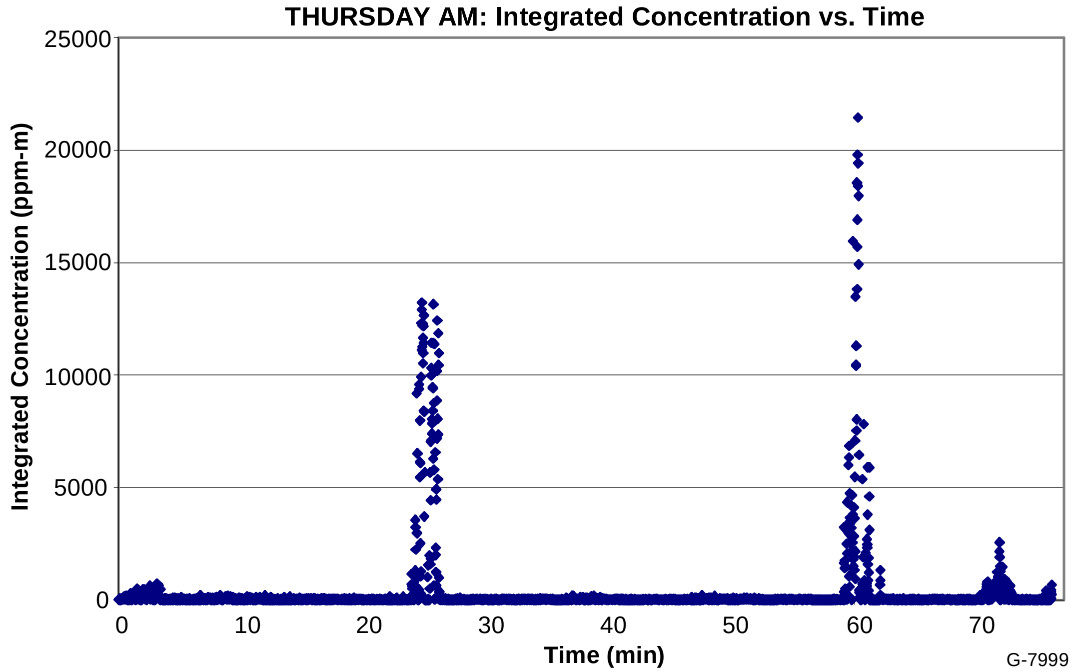
TUESDAY AM: Integrated Concentration vs. Time
Integrated Concentration (ppm-m)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
0
10
20
30
40
50
60
70
80
90
Time (min)
G-7995

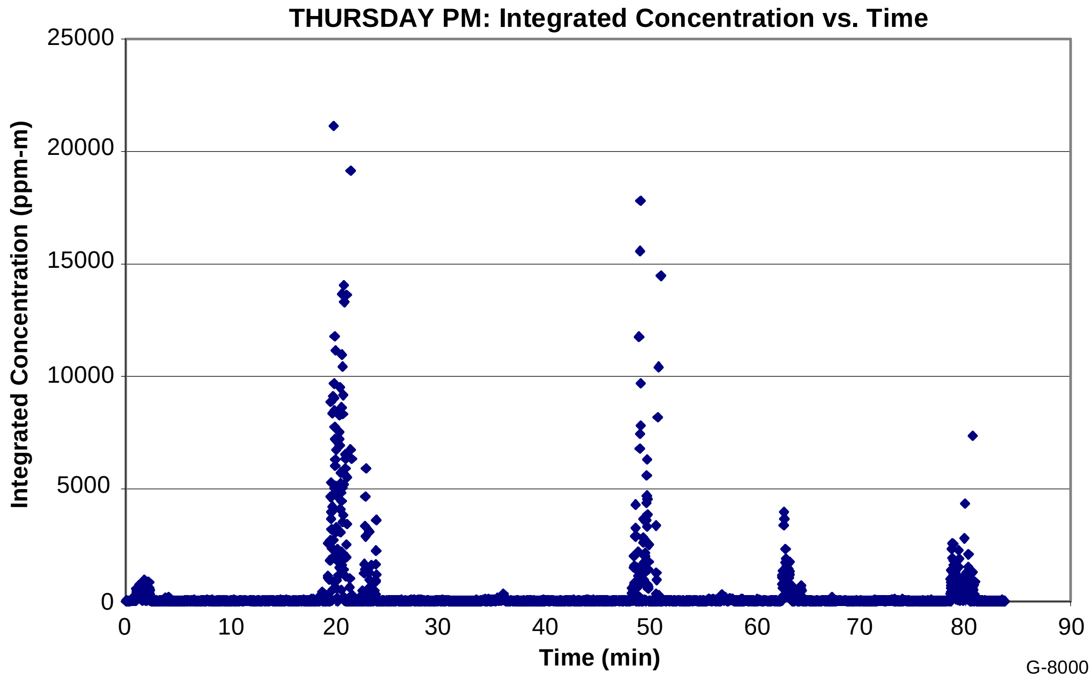


Tuesday PM: Integrated Concentration vs. Time
Concentration (ppm-m)
0
2000
4000
6000
8000
10000
12000
14000
16000
0
10
20
30
40
50
60
70
80
Time (min)
G-7996


WEDNESDAY AM: Integrated Concentration vs. Time
Integrated Concentration (ppm-m)
12000
10000
8000
6000
4000
2000
0
Note: Data logging
started at third leak
0
10
20
30
40
50
60
Time (min)
G-7997


WEDNESDAY PM: Integrated Concentration vs. Time
Integrated Concentration (ppm-m)
30000
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
Time (min)
G-7998


THURSDAY AM: Integrated Concentration vs. Time
Integrated Concentration (ppm-m)
25000
20000
15000
10000
5000
0
0
10
20
30
40
50
60
70
Time (min)
G-7999


THURSDAY PM: Integrated Concentration vs. Time
Integrated Concentration (ppm-m)
25000
20000
15000
10000
5000
0
0
10
20
30
40
50
60
70
80
90
Time (min)
G-8000

APPENDIX J

Company-Specific Test Reports

Section 1 - ITT Report for Tuesday, September 14
Section 2 - ITT Report for Wednesday, September 15
Section 3 - ITT Report for Thursday, September 16
Section 4 - ITT Report for Friday, September 17

Note: These reports were completed by the equipment provider prior to SwRI divulging the actual leak sites and leak rates. That is, they include “blind” test results. Any claims of leaks detected should be considered preliminary, and the analysis of the results is provided in Section 4.3. The claims and comments of the equipment provider do not reflect the opinions of the Department of Energy.

Section 1

ITT Report for Tuesday, September 14

Note: This report was completed by the equipment provider prior to SwRI divulging the actual leak sites and leak rates. That is, they include “blind” test results. Any claims of leaks detected should be considered preliminary, and the analysis of the results is provided in Section 4.3. The claims and comments of the equipment provider do not reflect the opinions of the Department of Energy.

ANGEL Service Customer Report

Rocky Mountain Oilfield Testing Center (RMOTC) Virtual Pipeline Inspection

DATE(s) INSPECTION DATA ACQUIRED:

September 14,2004

CONTRACT NUMBER:

DOE/National Energy Technology Laboratory Cooperative Development Agreement # DE-FC26-03NT41877

IN RESPONSE TO RFP:

DOE Program Solicitation (PS) No. DE-PS26-02NT41613

SUBMITTED BY:

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SUBMITTED TO:

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P.O. Drawer 28510 (78228-0510)
San Antonio, Texas

REPORT DATE:

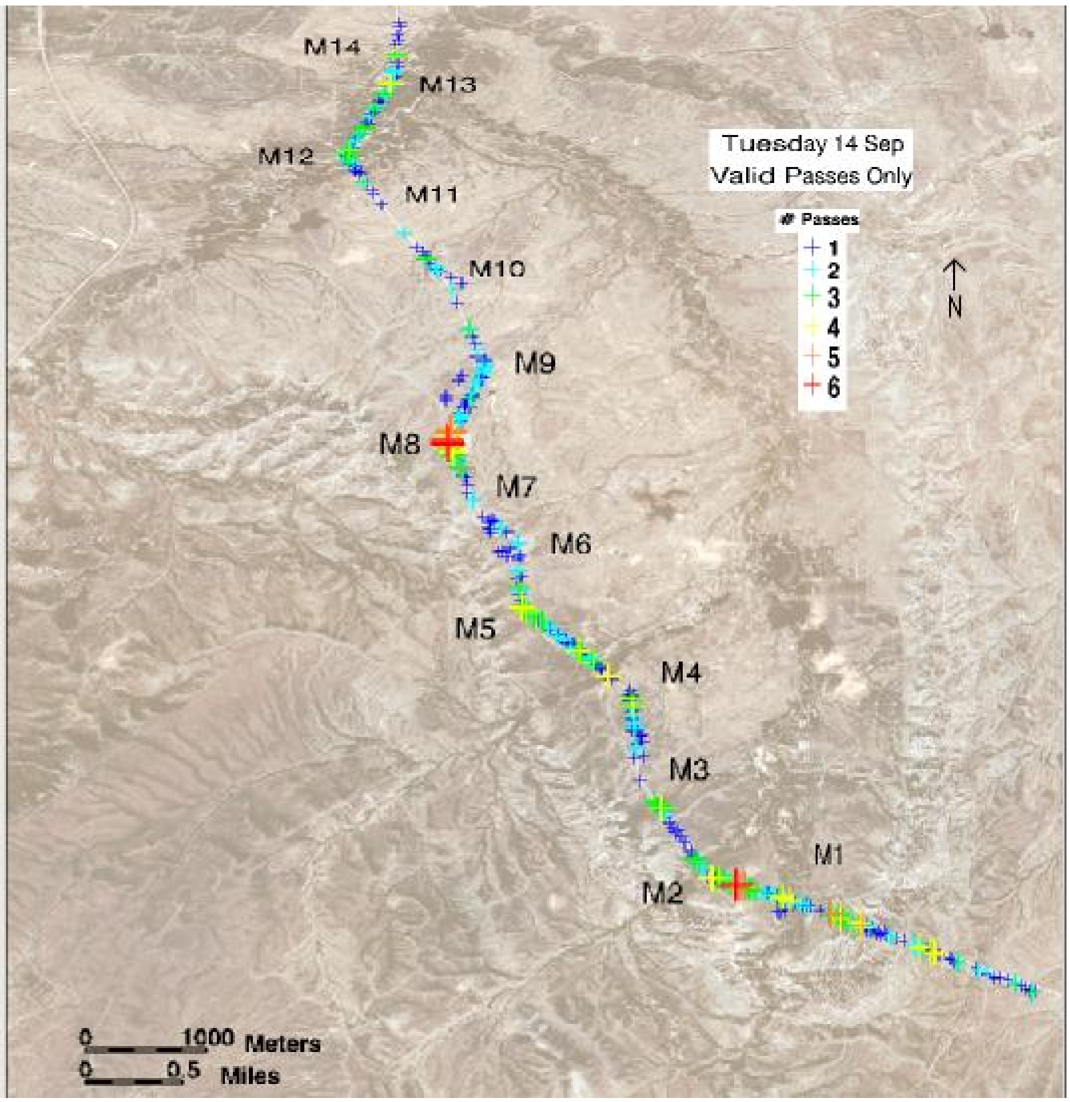
October 8, 2004

ITT Industries
Engineered for life

Executive Summary:

On September 14, 2004 we flew the route identified as "RMOTC Virtual Pipeline" with the ITT Industries ANGEL Sensor. This route was flown multiple times to ensure we had fully covered the complete Virtual Pipeline Route and to provide increased sample density to improve detection of smaller emissions. Analysis of the information collected indicates a number of areas of significant methane concentration along the pipeline right of way. The locations and relative size/concentration patterns for these are described in detail in this report.

The route flown is depicted below. All detected concentration areas are labeled with crosses. Color-coding is used to indicate detection of the methane concentration on multiple passes, with red indicating that the specific methane concentration was detected (within 30 meters) on five separate passes. Eleven distinct methane concentration areas were detected with sufficient quantity and frequency (5 or 6 passes) that they are high confidence. Elevated concentrations of methane in the area of a 1,000 scfh calibration leak near M1 were detected 4 times throughout the day.



Methane Detections

The methane emissions with the highest confidence were captured on a relatively large number of passes as indicated in this table. The geographic coordinates provide the location of the aggregated multiple detections.

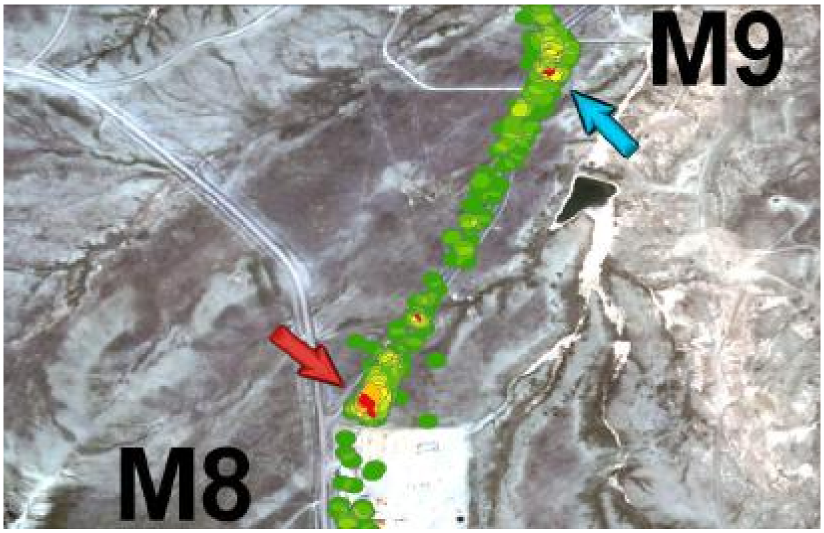
NAD 27 Data (DMS)						
Latitude	**Longitude**	**Leak Detection**	**Date**	**AM Passes**	**PM Passes**	**Comments**
43 14 57.966	-106 11 27.3228	6	09/14/04	3	1,2,3,4,6	south of M2
43 14 58.992	-106 11 31.6464	5	09/14/04	3	2,3,4,7	M1-M2
43 15 0.0216	-106 11 35.0844	5	09/14/04	3	2,3,4,7	south of M2
43 15 1.0188	-106 11 37.7412	5	09/14/04	3	2,3,4,7	vicinity of M2
43 16 39.8244	-106 12 50.6232	5	09/14/04	3,4	1,2,7	vicinity of M5
43 17 45.3624	-106 13 15.4164	6	09/14/04	3	1,2,4,6,7	already have M8 (gas plant)
43 18 6.048	-106 13 4.1844	5	09/14/04	3,4	1,2,7	vicinity of M9
43 18 57.0096	-106 13 30.9792	5	09/14/04		2,3,4,6,7	south of M11
43 19 37.128	-106 13 53.7888	5	09/14/04	3,4	1,3,7	many discrete points just south of M12
43 19 40.0908	-106 13 53.7852	6	09/14/04	3,4	1,2,3,4	just north of M12
43 19 51.2508	-106 13 48.5724	5	09/14/04	3	2,4,6,7	single small area M12-M13

Methane emissions detected with lesser, but still significant confidence are listed in the table below. In all cases these were detected on multiple passes as well, but not as consistently as the detections documented above.

NAD 27 Data (DMS)			
Latitude	**Longitude**	**Date**	**Comments**
43 19 54.7284	-106 13 47.3628	14-Sep-04	M12-M13
43 15 25.2	-106 11 58.9632	14-Sep-04	M2-M3
43 16 14.304	-106 12 17.406	14-Sep-04	M4-M5
43 17 28.8132	-106 13 12.5976	14-Sep-04	M8 - south of gas plant
43 17 45.7188	-106 13 15.3012	14-Sep-04	M8 (gas plant)
43 19 40.08	-106 13 53.778	14-Sep-04	just north of M12
43 14 57.9336	-106 11 27.3732	14-Sep-04	north of M1
43 18 56.826	-106 13 30.6768	14-Sep-04	south of M11
43 14 59.964	-106 11 35.2896	14-Sep-04	south of M2
43 15 1.0728	-106 11 38.3712	14-Sep-04	vicinity of M2
43 15 5.5764	-106 11 45.0348	14-Sep-04	just north of M2
43 16 23.0772	-106 12 29.3076	14-Sep-04	north of M4-M5
43 14 59.0316	-106 11 31.704	14-Sep-04	north of M1
43 19 51.0384	-106 13 48.5292	14-Sep-04	single small area M12-M13
43 19 37.2	-106 13 53.7888	14-Sep-04	just south of M12
43 19 31.6884	-106 13 50.8584	14-Sep-04	many discrete points south of M12
43 20 8.0916	-106 13 40.4868	14-Sep-04	south of M13
43 16 49.8504	-106 12 51.5232	14-Sep-04	south of M6
43 14 53.9196	-106 11 14.2692	14-Sep-04	vicinity of M1
43 16 39.954	-106 12 50.5296	14-Sep-04	vicinity of M5
43 18 6.246	-106 13 4.044	14-Sep-04	vicinity of M9

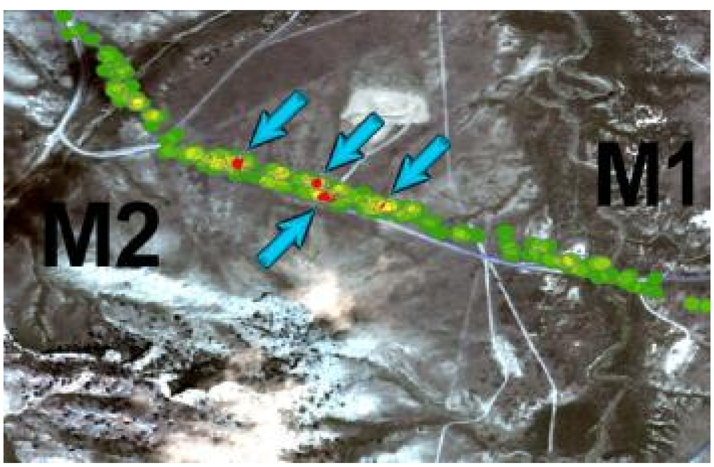
Significant Emissions

In this survey there are several areas that stand out due to the size and concentration-pathlength values of methane plume and frequency of detection. These are identified in the images provided below with red and orange plume position markers. The green markers are areas where there were potential indicators for methane but these were only detected on single passes. These do not represent highly significant indicators.



- N 43 18 6.048
- W -106 13 4.1844
- Detected on 5 passes
- Vicinity of M9

- N 43 17 45.3624
- W -106 13 15.4164
- Detected on 6 passes
- Area North of Gas Plant
- Note 2nd possible area (without arrow) to the NE

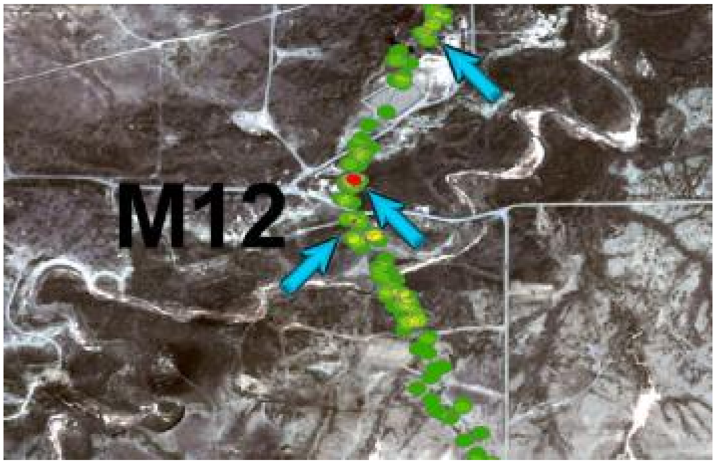


- N 43 14 57.966
- W -106 11 27.3228
- Detected on 6 passes
- South of M2

- N 43 14 58.992
- W -106 11 31.6464
- Detected on 5 passes

- N 43 15 0.0216
- W -106 11 35.0844
- Detected on 5 passes

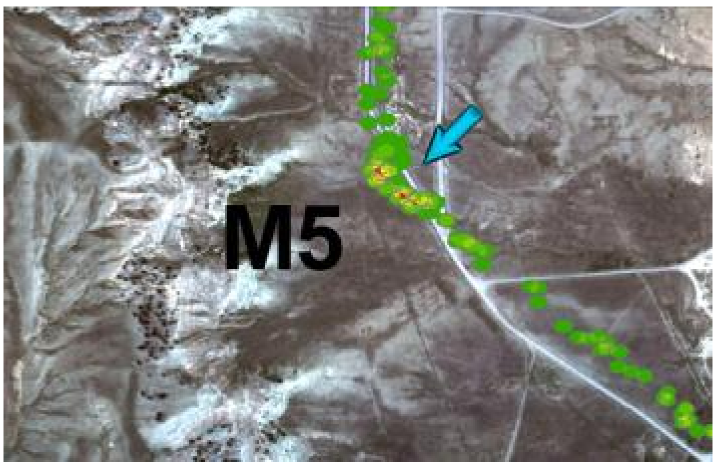
- N 43 15 1.0188
- W -106 11 37.7412
- Detected on 5 passes



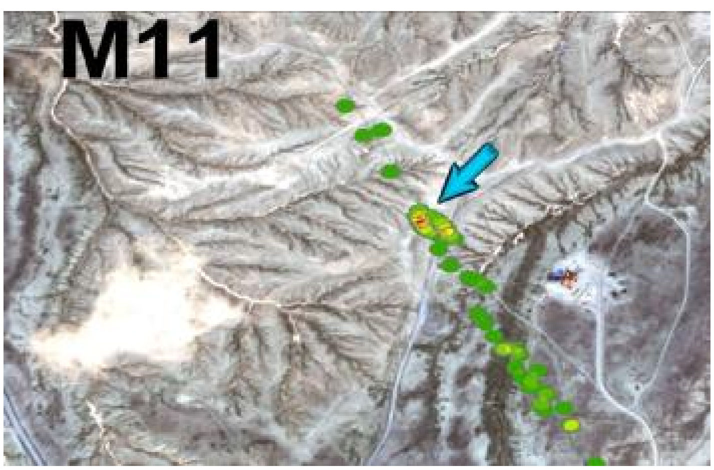
- N 43 19 51.2508
- W -106 13 48.5724
- Detected on 5 passes

- N 43 19 40.0908
- W -106 13 53.7852
- Detected on 6 passes
- Just north of M12

- N 43 19 37.128
- W -106 13 53.7888
- Detected on 5 passes



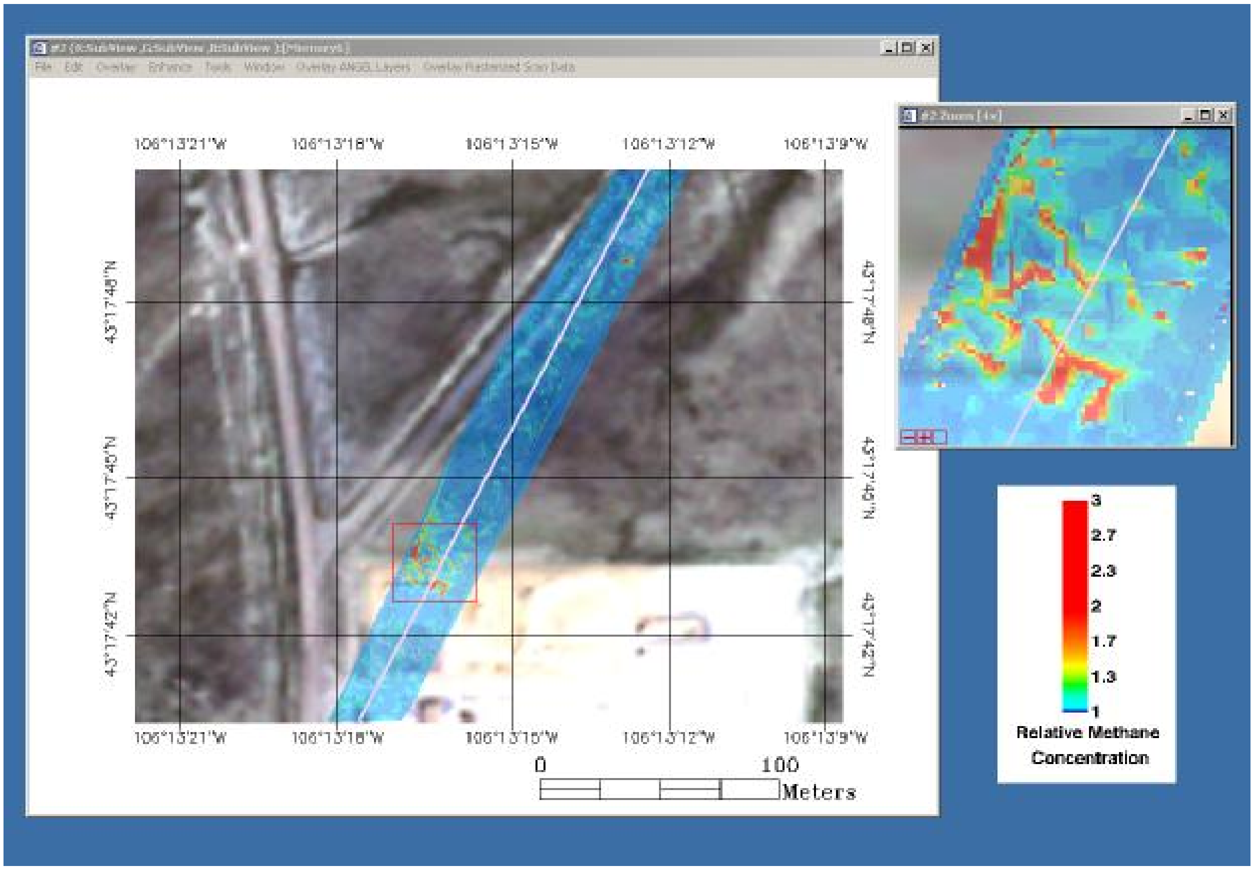
- N 43 16 39.8244
- W -106 12 50.6232
- Detected on 5 passes
- Vicinity of M5



- N 43 18 57.0096
- W -106 13 30.9792
- Detected on 5 passes
- South of M11

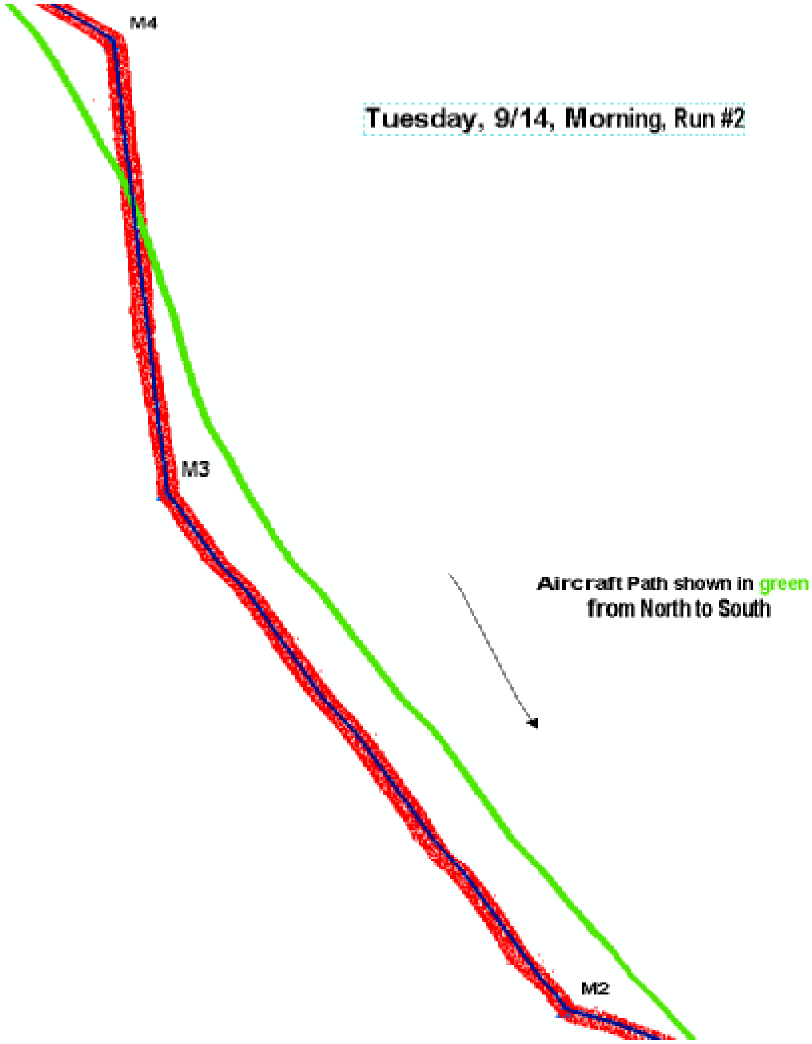
Special Case Analysis

From the collection on Tuesday, September 14, 2004 one location north of M8 stood out above all the others and warranted additional analysis. A raster-based analysis and methane images of the area north of the RMOTC Gas Plant area and an area of significant emission are shown below. This is the methane image map from pass 4 on the AM of Tuesday, September 14th, 2004.



Right of Way Coverage

ANGEL collection planning starts with developing a flight plan that will place the aircraft over the pipeline route. In most cases the aircraft flight path cannot perfectly match the pipeline route but the ANGEL sensor can still track the full right of way. This is important to ensure that we provide adequate collection coverage of the full right of way for the entire length of the pipeline segment being surveyed. As the aircraft then flies the designated route, the sensor tracks and images the actual right of way, even when not directly under the aircraft and regardless of minor flight variations. The information collected from each flight is analyzed to determine that the right of way was fully covered as planned. The graphic below shows the actual results from a small segment of one such flight path over the designated pipeline route. The green line is the path of the aircraft and the red band is made up of all the individual sensor collects throughout the flight. In this case the sensor accurately tracked the pipeline and provided full coverage of the right of way. This post flight analysis provides confidence that we have adequately covered the pipeline path and right-of-way for the full 7.5-mile length of the survey.

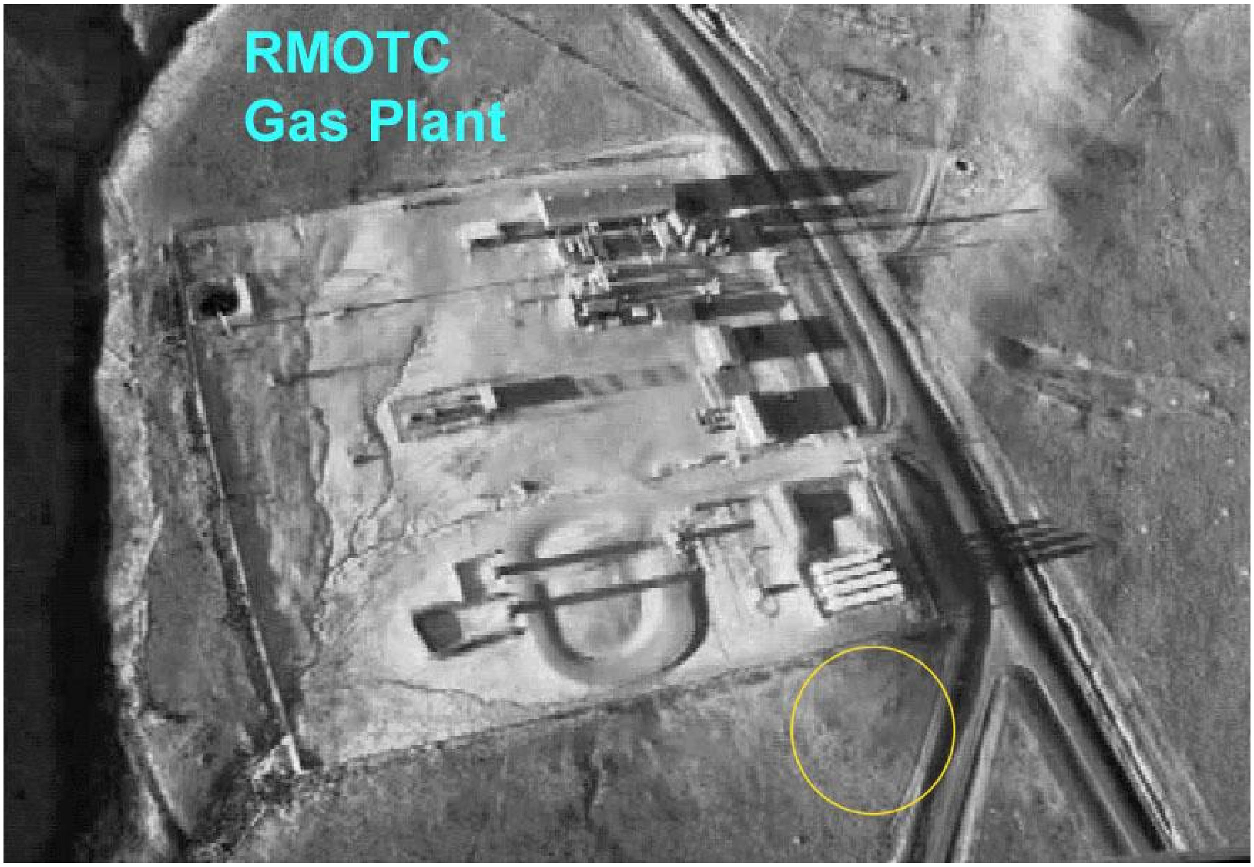


Flight Path Verification

The base imagery for this analysis is from Quickbird multispectral collection provided by DOE/NETL. The methane concentration pathlengths were measured from a single pass (4th flight on the morning of September 14, 2004) and the colors represent the relative concentration pathlength of methane within the ANGEL swath. Normal background methane levels are shown in dark blue. ANGEL collector scan swath is approximately 25 meters wide and is superimposed on the base image. Elevated concentrations of methane clearly stand out in red and the highest concentrations are located north of the Gas Plant (north of location M8 on the Virtual Pipeline route). It should be noted that the imagery used as purchased was not perfectly geo-registered and is provided to give approximate context (+/- 15 meters) to the ANGEL analysis data, not absolute positioning.

If no satellite or aerial photography imagery is available for a survey, the ANGEL aircraft has been fitted with a monochrome video camera that is used for flight path verification. This camera collects looking forward at 15 degrees from nadir and provides MPEG2 motion video imagery with approximately 1.4 ft raw GSD resolution. A sample frame is shown below. The video camera currently in use was designed only to provide engineering flight test information and will soon be replaced with a much higher resolution color and false color IR digital camera designed to collect a continuous strip of geo-referenced imagery as the sensor is flown along the pipeline right-of-way.

The ANGEL aircraft image below shows the RMOTC Gas Plant viewed from the North during one of the early morning passes. The yellow circle indicates the approximate location of the elevated levels of methane seen throughout the day in the Northwest corner of the Gas Plant.



Section 2

ITT Report for Wednesday, September 15

Note: This report was completed by the equipment provider prior to SwRI divulging the actual leak sites and leak rates. That is, they include “blind” test results. Any claims of leaks detected should be considered preliminary, and the analysis of the results is provided in Section 4.3. The claims and comments of the equipment provider do not reflect the opinions of the Department of Energy.

ANGEL Service Customer Report

Rocky Mountain Oilfield Testing Center (RMOTC) Virtual Pipeline Inspection

DATE(s) INSPECTION DATA ACQUIRED:

September 15, 2004

CONTRACT NUMBER:

DOE/National Energy Technology Laboratory Cooperative Development Agreement # DE-FC26-03NT41877

IN RESPONSE TO RFP:

DOE Program Solicitation (PS) No. DE-PS26-02NT41613

SUBMITTED BY:

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P.O. Drawer 28510 (78228-0510)
San Antonio, Texas

REPORT DATE:

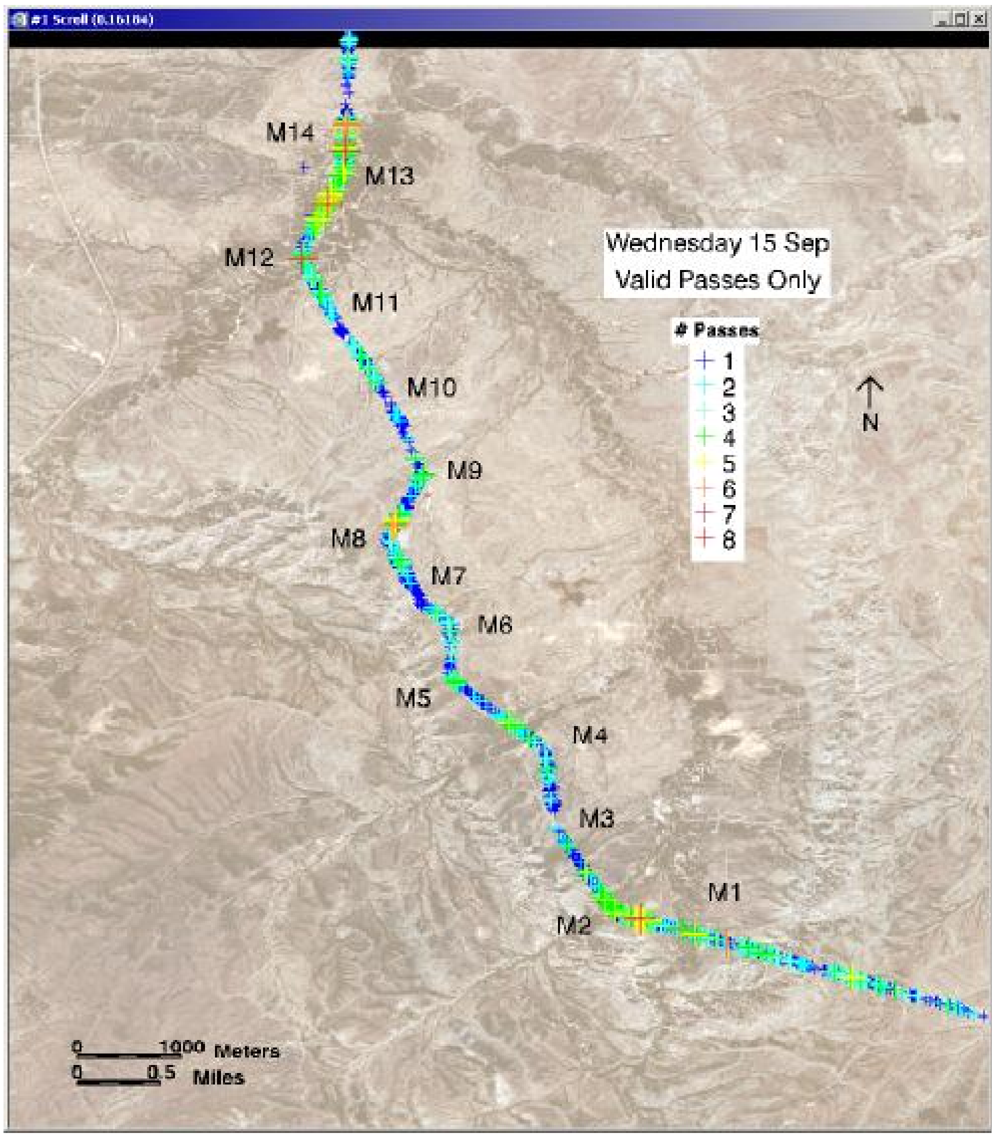
October 8, 2004

ITT Industries
Engineered for life

Executive Summary:

On September 15, 2004 we flew the route identified as "RMOTC Virtual Pipeline" with the ITT Industries ANGEL Sensor. This route was flown multiple times to ensure we had fully covered the complete Virtual Pipeline Route and to provide increased sample density to improve detection of smaller emissions. Analysis of the information collected indicates a number of areas of significant methane concentration along the pipeline right of way. The locations and relative size/concentration patterns for these are described in detail in this report.

The route flown is depicted below. All detected concentration areas are labeled with crosses. Color-coding is used to indicate detection of the methane concentration on multiple passes, with red indicating that the specific methane concentration was detected (within 30 meters) on eight separate passes. Six distinct methane concentration areas were detected with sufficient quantity and frequency (7 or 8 passes) that they are high confidence.



Methane Detections

The methane emissions with the highest confidence were captured on a relatively large number of passes as indicated in this table. The geographic coordinates provide the location of the aggregated multiple detections.

NAD 27 Data (DMS)					
Latitude	**Longitude**	**Date**	**AM Passes**	**PM Passes**	**Comments**
43 15 13.374	-106 11 24.1836	15-Sep-04	1,2,3,4,5,6	1,5,6	between M1 & M2
43 15 21.69	-106 11 39.5916	15-Sep-04	4,5,6	1,2,4,5	northwest of M2
43 17 58.9236	-106 13 8.9328	15-Sep-04	1,2,4,5,6	1,3,4,5,6	north of gas plant (high confidence)
43 20 9.312	-106 13 39.972	15-Sep-04	2,3,4,6	1,4,5	area #1 between M12 & M13
43 20 15.0252	-106 13 36.498	15-Sep-04	2,3,4,5,6	1,6	area #2 between M12 & M13
43 20 38.0976	-106 13 29.28	15-Sep-04	1,4,5,6	2,3,4,5,6	area between M13 & M14

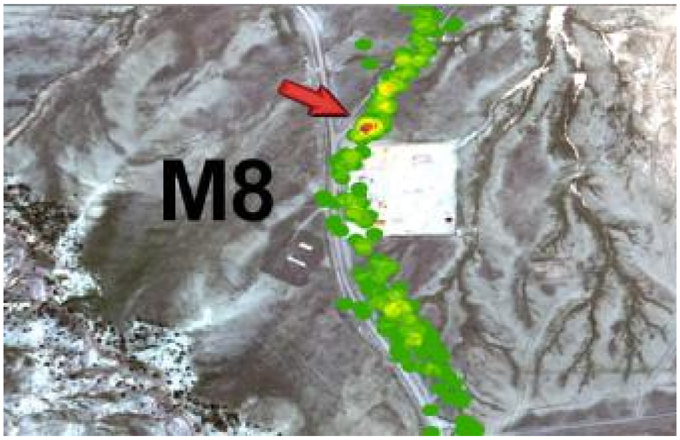
Methane emissions detected with lesser, but still significant confidence are listed in the table below. In all cases these were detected on multiple passes as well, but not as consistently as the detections documented above.

NAD 27 Data (DMS)			
Latitude	**Longitude**	**Date**	**Comments**
43 14 57.948	-106 11 27.7332	15-Sep-04	M1-M2 middle
43 19 29.9784	-106 13 50.232	15-Sep-04	M11-M12
43 19 38.6472	-106 13 54.2496	15-Sep-04	M12 corner - large area extent
43 20 4.1208	-106 13 42.4884	15-Sep-04	M12-M13
43 15 1.98	-106 11 42.324	15-Sep-04	M2
43 17 8.7396	-106 12 58.0896	15-Sep-04	M6-M7
43 17 30.8184	-106 13 14.16	15-Sep-04	M7-M8
43 15 6.786	-106 11 46.5684	15-Sep-04	
43 14 59.316	-106 11 33.0324	15-Sep-04	M1-M2 - big leak
43 20 0.9492	-106 13 43.8204	15-Sep-04	M12-M13
43 17 44.5092	-106 13 15.8808	15-Sep-04	just north of M8
43 20 23.9784	-106 13 36.3252	15-Sep-04	just south of M14
43 19 54.714	-106 13 47.1072	15-Sep-04	north of M12
43 20 17.142	-106 13 36.966	15-Sep-04	just north of M13
43 15 3.6936	-106 11 43.62	15-Sep-04	just north of M2
43 16 20.046	-106 12 24.4044	15-Sep-04	just north of M4
43 15 1.1808	-106 11 38.8716	15-Sep-04	just south of M2 - many discrete areas
43 16 59.9124	-106 12 51.7608	15-Sep-04	just south of M6
43 20 13.3116	-106 13 37.6644	15-Sep-04	just south of M13
43 19 49.0008	-106 13 49.9116	15-Sep-04	north of M12
43 15 5.1228	-106 11 44.7972	15-Sep-04	north of M2
43 17 47.1984	-106 13 14.5956	15-Sep-04	north of M8
43 19 57.9792	-106 13 45.0264	15-Sep-04	north of M12
43 16 22.3572	-106 12 27.3528	15-Sep-04	north of M4
43 19 51.8916	-106 13 48.0252	15-Sep-04	north of M12
43 15 9.5652	-106 11 48.3612	15-Sep-04	north of M2
43 20 31.2504	-106 13 36.5376	15-Sep-04	on M14
43 15 18.63	-106 11 55.0932	15-Sep-04	single M2-M3
43 18 45.8568	-106 13 22.3068	15-Sep-04	single north of M10
43 15 29.7684	-106 12 1.8612	15-Sep-04	single south of M3
43 16 38.9388	-106 12 49.554	15-Sep-04	small areas just south of M5
43 16 7.2192	-106 12 11.3256	15-Sep-04	small area just south of M4
43 20 28.6656	-106 13 36.2064	15-Sep-04	small areas just south of M14
43 16 5.502	-106 12 11.2752	15-Sep-04	south of M4
43 20 8.9772	-106 13 40.2024	15-Sep-04	tiny area south of M13
43 16 41.1564	-106 12 51.678	15-Sep-04	tiny area at M5
43 17 38.5584	-106 13 17.076	15-Sep-04	tiny area just south of M8
43 18 5.2884	-106 13 4.278	15-Sep-04	tiny areas just south of M9
43 19 22.0044	-106 13 45.6276	15-Sep-04	tiny area north of M11
43 14 54.7188	-106 11 15.9504	15-Sep-04	vicinity of calibration leak

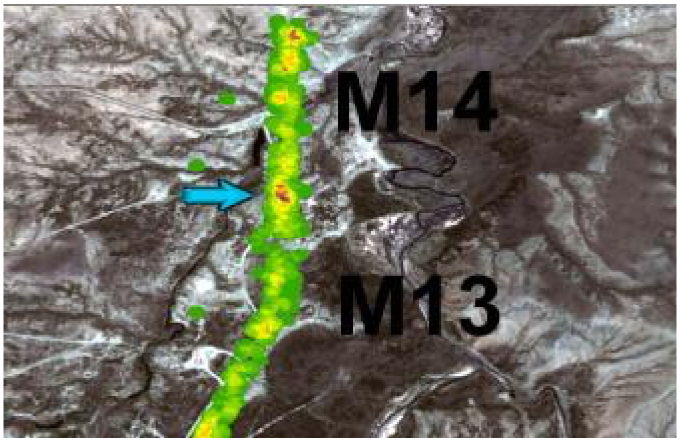
ANGEL Service Customer Report

Significant Emissions

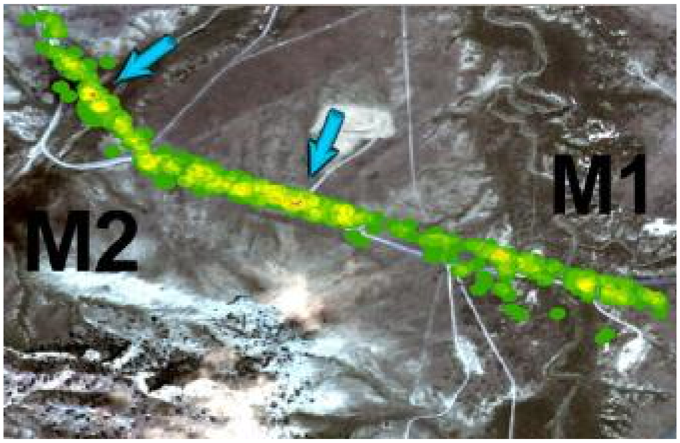
In this survey there are six areas that stand out due to the size and concentration-pathlength values of methane plume and frequency of detection. These are identified in the images provided below with red and orange plume markers. The green markers are areas where there were potential indicators for methane but these were only detected on single passes. These do not represent highly significant indicators.



- N 43 17 58.9236
- W -106 13 8.9328
- Detected on 10 passes
- North of Gas Plant

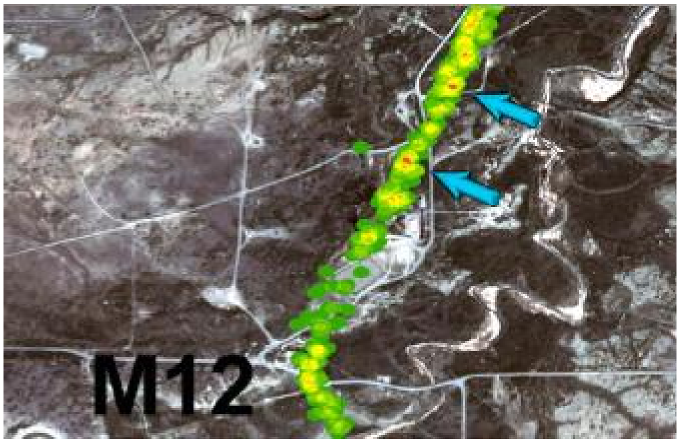


- N 43 20 23.68
- W -106 13 36.43
- Detected on 9 passes



- N 43 15 7.23
- W -106 11 46.72
- Detected on 7 passes

- N 43 14 58.91
- W -106 11 31.31
- Detected on 9 passes



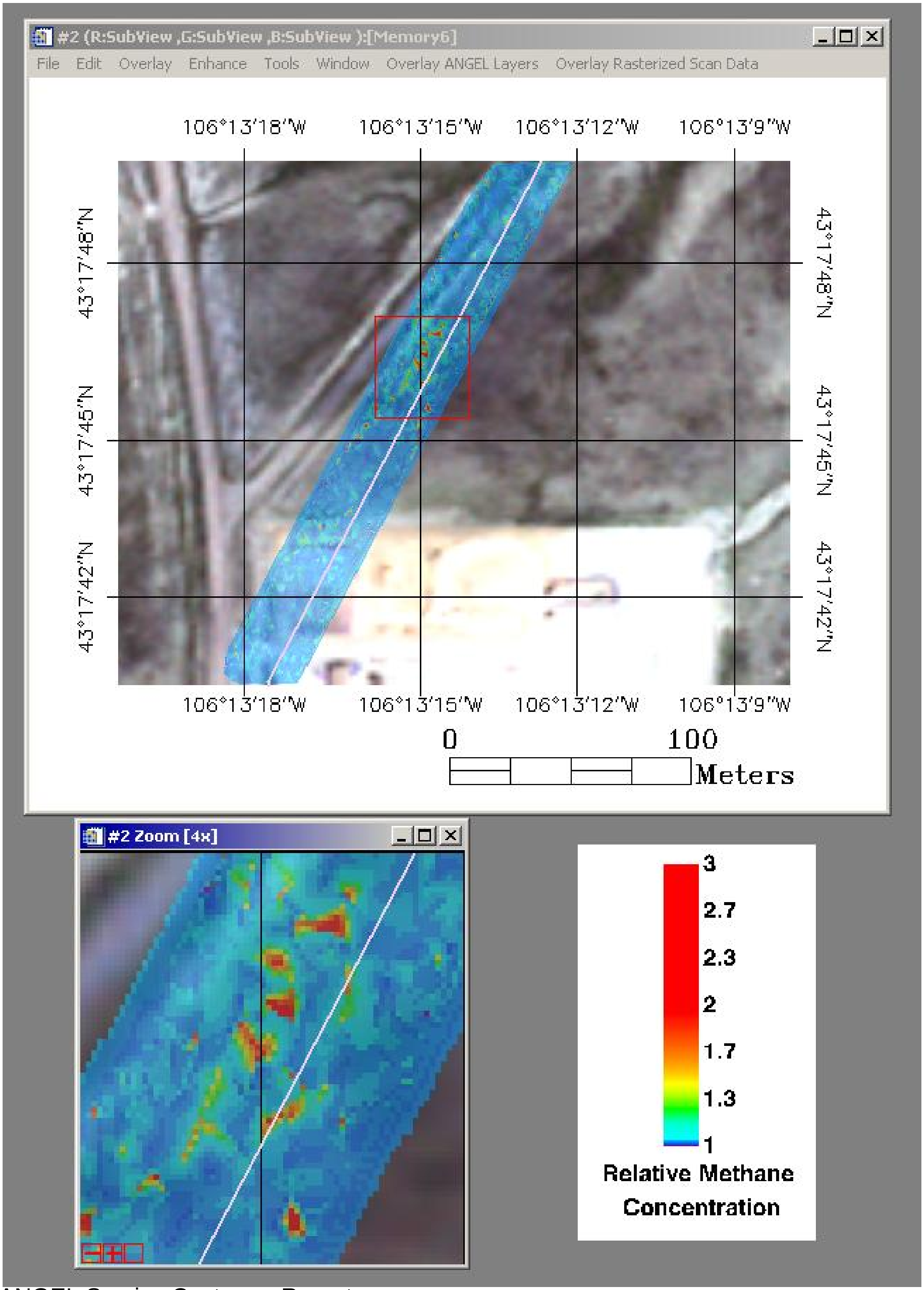
- N 43 20 9.312
- W -106 13 39.972
- Detected on 7 passes

- N 43 20 15.0252
- W -106 13 36.498
- Detected on 7 passes

Special Case Analysis

From the collection on Wednesday, September 15, 2004 a location North of the Gas Plant stood out above all the others and warranted additional analysis. A raster-based analysis and methane images of the RMOTC Gas Plant area are shown below. The methane concentration pathlengths were measured from a single pass (2nd pass on the morning of September 15, 2004) and the colors represent the relative concentration pathlength of methane within the ANGEL swath. Normal background methane levels are shown in dark blue. ANGEL collector scan swath is approximately 25 meters wide and is superimposed on the base image. Elevated concentrations of methane clearly stand out in red. Over the course of the day, elevated level of methane were seen in a zone stretching from the NW corner of the Gas Plant to a point roughly 30-40 meters to the northeast. The image shown below is the result of analysis of thousands of individual methane measurements. The patchy nature of the highlighted plume is at least partially due to the algorithms used to analyze the ANGEL data stream. In reality the plume is likely to be somewhat more homogenous in nature.

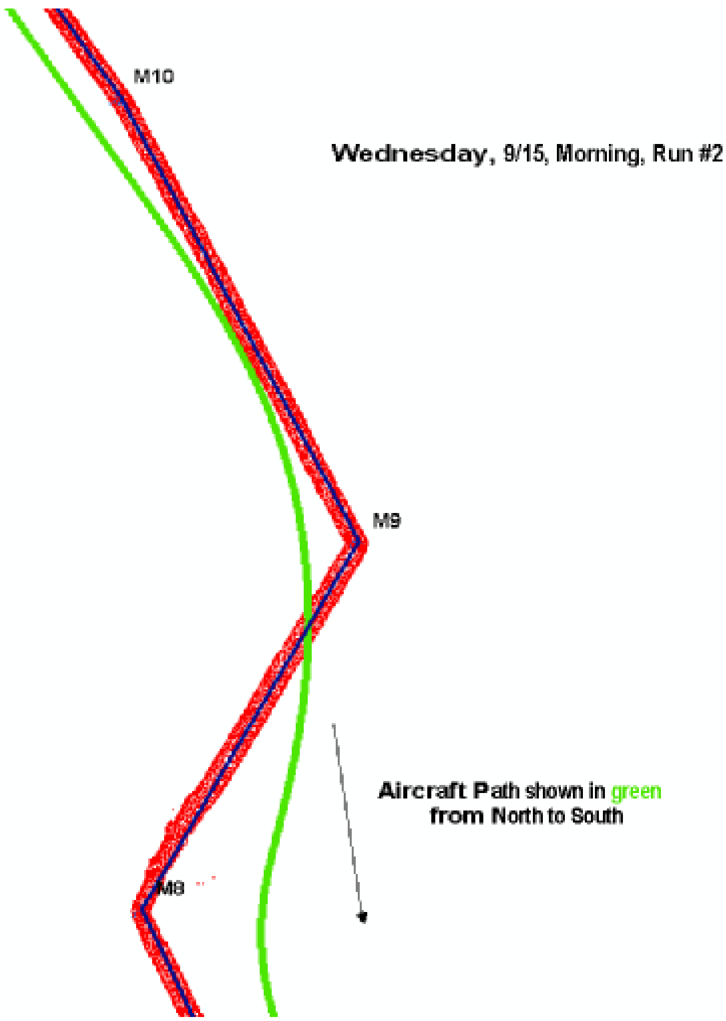
The base imagery for this analysis is from a Quickbird multispectral collection provided by DOE/NETL. It should be noted that the imagery used as purchased was not perfectly geo-registered and is provided to give approximate context (+/- 15 meters) to the ANGEL analysis data, not absolute positioning.



ANGEL Service Customer Report

Right of Way Coverage

ANGEL collection planning starts with developing a flight plan that will place the aircraft over the pipeline route. In most cases the aircraft flight path cannot perfectly match the pipeline route but the ANGEL sensor can still track the full right of way. This is important to ensure that we provide adequate collection coverage of the full right of way for the entire length of the pipeline segment being surveyed. As the aircraft flies the designated route, the sensor tracks and images the actual right of way, even when not directly under the aircraft and regardless of minor flight variations. The information collected from each flight is analyzed to determine that the right of way was fully covered as planned. The graphic below shows the actual results from a small segment of one such flight path over the designated pipeline route. The green line is the path of the aircraft and the red band is made up of all the individual sensor collects throughout the flight. In this case the sensor accurately tracked the pipeline and provided full coverage of the right of way. This post flight analysis provides confidence that we have adequately covered the pipeline path and right-of-way for the full 7.5-mile length of the survey.



Flight Path Verification

The ANGEL aircraft has been fitted with a monochrome video camera that is used for flight path verification. This camera collects looking forward at 15 degrees from nadir and provides MPEG2 motion video imagery with approximately 1.4 ft raw GSD resolution. A sample frame is shown below from one of the PM passes. The video camera currently in use was designed only to provide engineering flight test information and will soon be replaced with a much higher resolution color and false color IR digital camera designed to collect a continuous strip of geo-referenced imagery as the sensor is flown along the pipeline right-of-way. The image below was acquired during a PM run as the ANGEL aircraft was inspecting the pipe from North to South. The yellow circle indicates the approximate area North of the RMOTC Gas Plant in which elevated levels of methane were detected.

Section 3

ITT Report for Thursday, September 16

Note: This report was completed by the equipment provider prior to SwRI divulging the actual leak sites and leak rates. That is, they include “blind” test results. Any claims of leaks detected should be considered preliminary, and the analysis of the results is provided in Section 4.3. The claims and comments of the equipment provider do not reflect the opinions of the Department of Energy.

ANGEL Service Customer Report

Rocky Mountain Oilfield Testing Center (RMOTC) Virtual Pipeline Inspection

DATE(s) INSPECTION DATA ACQUIRED:

September 16, 2004

CONTRACT NUMBER:

DOE/National Energy Technology Laboratory Cooperative Development Agreement # DE-FC26-03NT41877

IN RESPONSE TO RFP:

DOE Program Solicitation (PS) No. DE-PS26-02NT41613

SUBMITTED BY:

Steven Stearns
ITT Industries Space Systems Division
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Tel. (585) 762-5494
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SUBMITTED TO:

Chris Buckingham
Southwest Research Labs
6220 Culebra Road (78238-5166)
P.O. Drawer 28510 (78228-0510)
San Antonio, Texas

REPORT DATE:

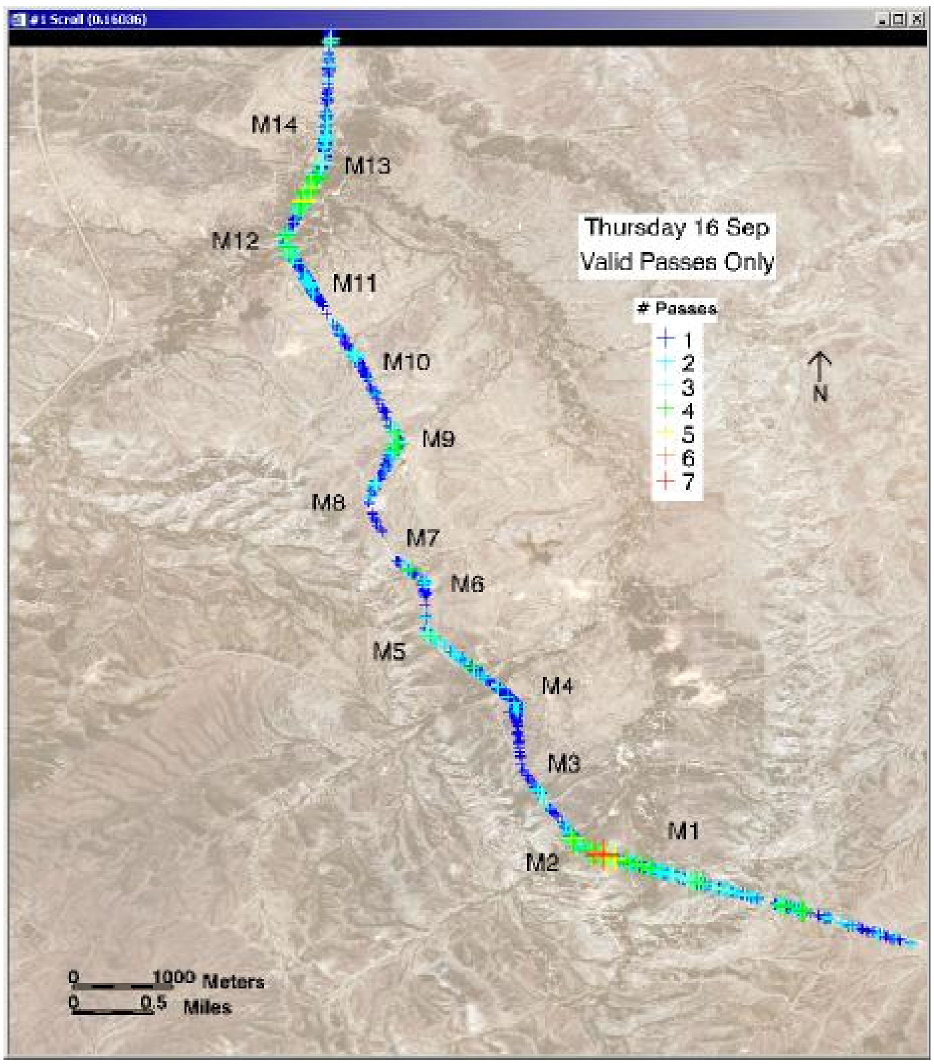
October 8, 2004

ITT Industries
Engineered for life

Executive Summary:

On September 16, 2004 we flew the route identified as "RMOTC Virtual Pipeline" with the ITT Industries ANGEL Sensor. This route was flown multiple times to ensure we had fully covered the complete Virtual Pipeline Route and to provide increased sample density to improve detection of smaller emissions. Analysis of the information collected indicates a number of areas of significant methane concentration along the pipeline right of way. The locations and relative size/concentration patterns for these are described in detail in this report.

The route flown is depicted below. All detected concentration areas are labeled with crosses. Color-coding is used to indicate detection of the methane concentration on multiple passes, with red indicating that the specific methane concentration was detected (within 30 meters) on seven separate passes. A number of distinct methane concentration "hot spots" were detected with sufficient quantity and frequency that they are very high confidence. Note that there are multiple "hot spots" in the vicinity of M2, which could indicate several smaller or a single large methane emission (see the Special Case Analysis later in this report).



Methane Detections

The methane emissions with the highest confidence were captured on a relatively large number of passes as indicated in this table. The geographic coordinates provide the location of the aggregated multiple detections.

NAD 27 Data (DMS)					
Latitude	**Longitude**	**Date**	**AM Passes**	**PM Passes**	**Comments**
43 14 55.2408	-106 11 17.322	16-Sep-04	1,2,3,4,6	5,6	area #1 between M1 & M2
43 14 58.1352	-106 11 27.726	16-Sep-04	1,2,3,4,5,6,7	5,6	area #2 between M1 & M2
43 14 59.6544	-106 11 32.8236	16-Sep-04	1,2,3,4,6,7	5,6	area #3 between M1 & M2
43 15 0.7272	-106 11 36.8484	16-Sep-04	1,2,3,4,6,7	5,6	area #4 between M1 & M2
43 16 39.0504	-106 12 50.0508	16-Sep-04	2,3,4,5,7	5,6	area southeast of M5
43 18 11.2464	-106 13 5.2284	16-Sep-04	1,2,3,4,7	5,6	area northwest of M9
43 19 40.9188	-106 13 53.9472	16-Sep-04	1,2,3,4,6,7	5,6	area #1 between M12 & M13
43 20 0.24	-106 13 44.04	16-Sep-04	1,2,5,6,7	6	area #2 between M12 & M13
43 20 3.2892	-106 13 42.6108	16-Sep-04	1,2,3,6,7	5,6	area #3 between M12 & M13

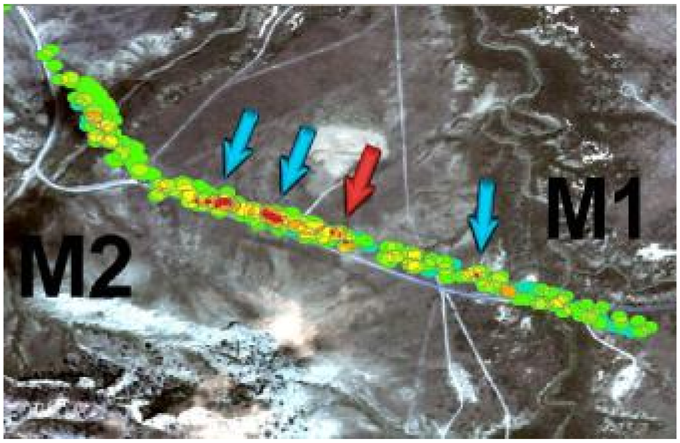
Methane emissions detected with lesser, but still significant confidence are listed in the table below. In all cases these were detected on multiple passes as well, but not as consistently as the detections documented above.

NAD 27 Data (DMS)			
Latitude	**Longitude**	**Date**	**Comments**
43 14 59.4276	-106 11 32.4816	16-Sep-04	M1-M2
43 14 53.2212	-106 11 10.8924	16-Sep-04	M1
43 20 14.5392	-106 13 37.6788	16-Sep-04	M13
43 16 24.8268	-106 12 30.69	16-Sep-04	M4-M5
43 16 39.6264	-106 12 50.6016	16-Sep-04	M5
43 17 8.6028	-106 12 58.428	16-Sep-04	M6-M7
43 18 7.4916	-106 13 4.2852	16-Sep-04	M9
43 19 40.8972	-106 13 53.9652	16-Sep-04	just north of M12
43 16 15.8808	-106 12 19.728	16-Sep-04	just north of M4
43 16 19.1316	-106 12 24.8364	16-Sep-04	just north of M4
43 19 35.76	-106 13 52.8996	16-Sep-04	just south of M12
43 19 54.8292	-106 13 47.0424	16-Sep-04	large area M12-M13
43 20 0.4416	-106 13 44.4	16-Sep-04	medium area M12-M13
43 14 54.3012	-106 11 15.4608	16-Sep-04	north of M1
43 18 46.7712	-106 13 23.0952	16-Sep-04	north of M10
43 20 23.7336	-106 13 36.2496	16-Sep-04	north of M13
43 15 6.3324	-106 11 45.6072	16-Sep-04	north of M2
43 17 48.5916	-106 13 13.7388	16-Sep-04	north of M8
43 18 11.1312	-106 13 5.0448	16-Sep-04	north of M9
43 14 56.3856	-106 11 22.1028	16-Sep-04	north of north of M1
43 18 13.1616	-106 13 6.24	16-Sep-04	north of north of M9
43 20 6.8676	-106 13 40.8	16-Sep-04	northern M12-M13
43 20 3.1704	-106 13 42.5928	16-Sep-04	northern area M12-M13
43 15 27.7668	-106 12 0.3528	16-Sep-04	single poly
43 19 31.2276	-106 13 50.862	16-Sep-04	south of M12
43 18 3.4668	-106 13 5.9772	16-Sep-04	south of M9

ANGEL Service Customer Report

Significant Emissions

In this survey there are a number of areas that stand out due to the size and concentration-pathlength values of methane plume and frequency of detection. These are identified in the images provided below with red and orange plume markers. The green markers are areas where there were potential indicators for methane but these were only detected on single passes. These do not represent highly significant indicators. Arrows indicate the positions of each significant emission detected.



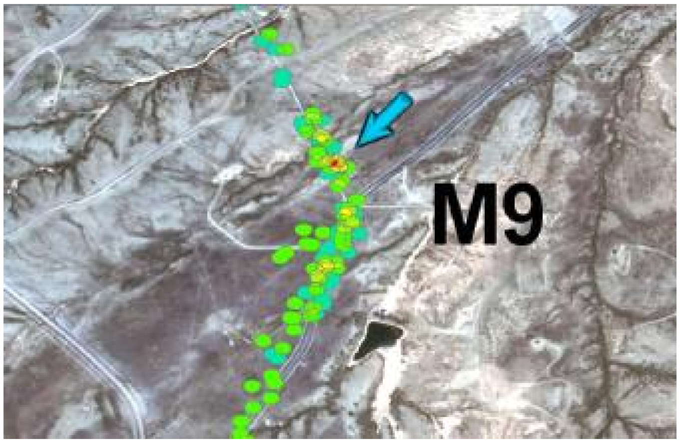
- N 43 15 0.7272
- W -106 11 36.8484
- Detected on 8 passes

- N 43 14 59.6544
- W -106 11 32.8236
- Detected on 8 passes

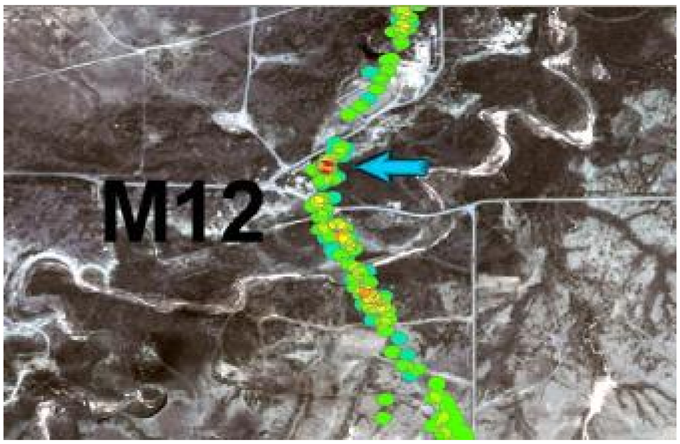
- N 43 14 58.1352
- W -106 11 27.726
- Detected on 9 passes
- High confidence

- N 43 14 55.2408
- W -106 11 17.322
- Detected on 7 passes

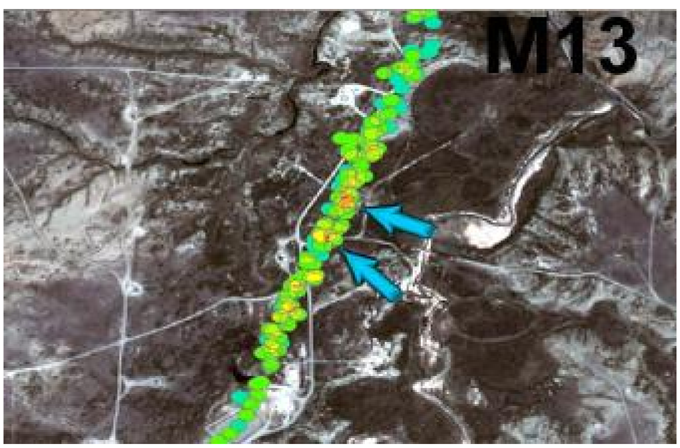
- N 43 16 39.0504
- W -106 12 50.0508
- Detected on 7 passes



- N 43 18 11.2464
- W -106 13 5.2284
- Detected on 7 passes



- N 43 19 40.9188
- W -106 13 53.9472
- Detected on 8 passes



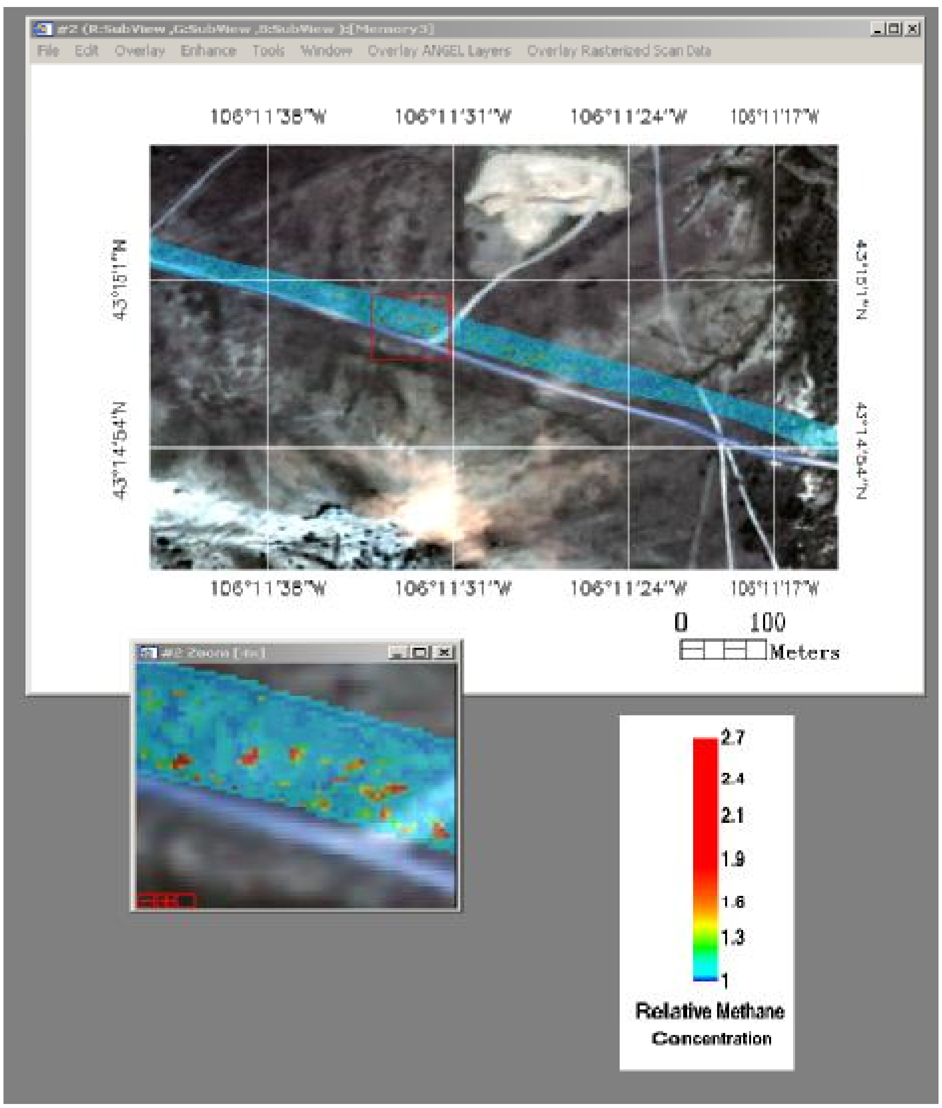
- N 43 20 3.2892
- W -106 13 42.6108
- Detected on 7 passes

- N 43 20 0.24
- W -106 13 44.04
- Detected on 6 passes

Special Case Analysis

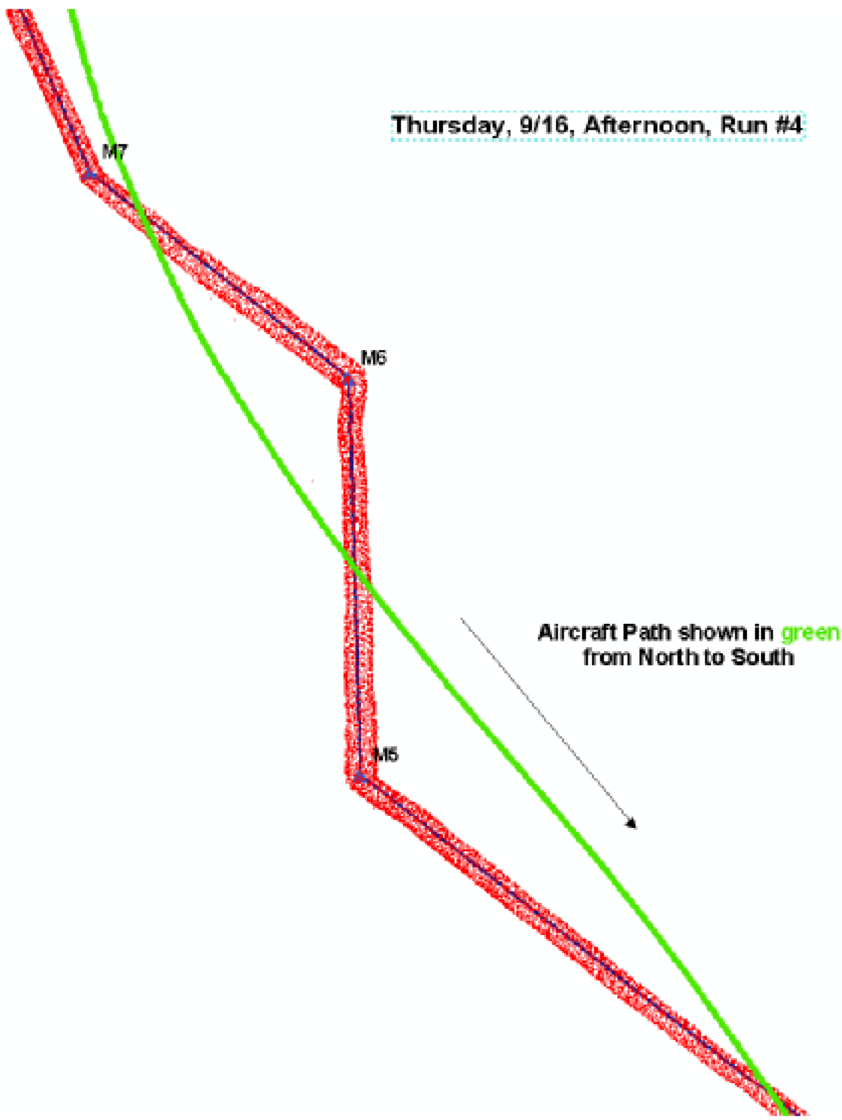
From the collection on Thursday, September 16, 2004, one location stood out and warranted additional analysis. This was the area of multiple methane "hot spots" east of Virtual Pipeline Marker 2 (M2). Multiple high methane areas were seen on multiple passes throughout the day. Raster-based analysis and methane images of the significant emissions are shown below. ANGEL data analysis suggests the possibility of leaks in the area between M1 and M2.

The base imagery for this analysis is from a Quickbird multispectral collection provided by DOE/NETL. The methane concentration pathlengths were measured from a single pass (4th pass on the afternoon of September 16, 2004) and the colors represent the relative concentration pathlength of methane within the ANGEL swath. Normal background methane levels are shown in dark blue. ANGEL collector scan swath is approximately 25 meters wide and is superimposed on the base image. It should be noted that the imagery used as purchased was not perfectly geo-registered and is provided to give approximate context (+/- 15 meters) to the ANGEL analysis data, not absolute positioning.



Right of Way Coverage

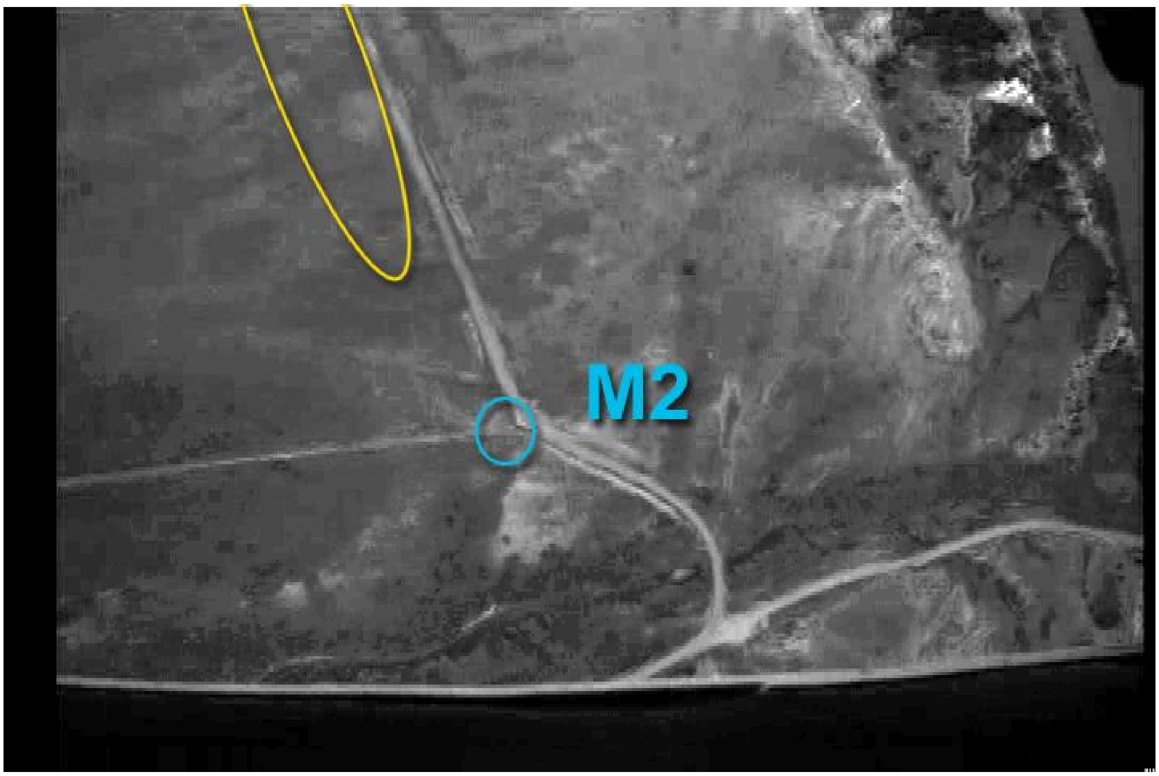
ANGEL collection planning starts with developing a flight plan that will place the aircraft over the pipeline route. In most cases the aircraft flight path cannot perfectly match the pipeline route but the ANGEL sensor can still track the full right of way. This is important to ensure that we provide adequate collection coverage of the full right of way for the entire length of the pipeline segment being surveyed. As the aircraft then flies the designated route, the sensor tracks and images the actual right of way, even when not directly under the aircraft and regardless of minor flight variations. The information collected from each flight is analyzed to determine that the right of way was fully covered as planned. The graphic below shows the actual results from a small segment of one such flight path over the designated pipeline route. The green line is the path of the aircraft and the red band is made up of all the individual sensor collects throughout the flight. In this case the sensor accurately tracked the pipeline and provided full coverage of the right of way. This post flight analysis provides confidence that we have adequately covered the pipeline path and right-of-way for the full 7.5-mile length of the survey.



Flight Path Verification

The ANGEL aircraft has been fitted with a monochrome video camera that is used for flight path verification. This camera collects looking forward at 15 degrees from nadir and provides MPEG2 motion video imagery with approximately 1.4 ft raw GSD resolution. A sample frame is shown below. The video camera currently in use was designed only to provide engineering flight test information and will soon be replaced with a much higher resolution color and false color IR digital camera designed to collect a continuous strip of geo-referenced imagery as the sensor is flown along the pipeline right-of-way.

The image below was taken from the East as the ANGEL aircraft was finishing up a North to South inspection pass. The approximate location of Marker 2 is noted. The location of the western edge of the M1-M2 zone of elevated methane detections is highlighted with a yellow ellipse.



Section 4

ITT Report for Friday, September 17

Note: This report was completed by the equipment provider prior to SwRI divulging the actual leak sites and leak rates. That is, they include "blind" test results. Any claims of leaks detected should be considered preliminary, and the analysis of the results is provided in Section 4.3. The claims and comments of the equipment provider do not reflect the opinions of the Department of Energy.

ANGEL Service Customer Report

Rocky Mountain Oilfield Testing Center (RMOTC) Virtual Pipeline Inspection

DATE(s) INSPECTION DATA ACQUIRED:

September 17,2004

CONTRACT NUMBER:

DOE/National Energy Technology Laboratory Cooperative Development Agreement # DE-FC26-03NT41877

IN RESPONSE TO RFP:

DOE Program Solicitation (PS) No. DE-PS26-02NT41613

SUBMITTED BY:

Steven Stearns
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Rochester, NY 14653-7225
Tel. (585) 762-5494
steven.stearns@itt.com

SUBMITTED TO:

Chris Buckingham
Southwest Research Labs
6220 Culebra Road (78238-5166)
P.O. Drawer 28510 (78228-0510)
San Antonio, Texas

REPORT DATE:

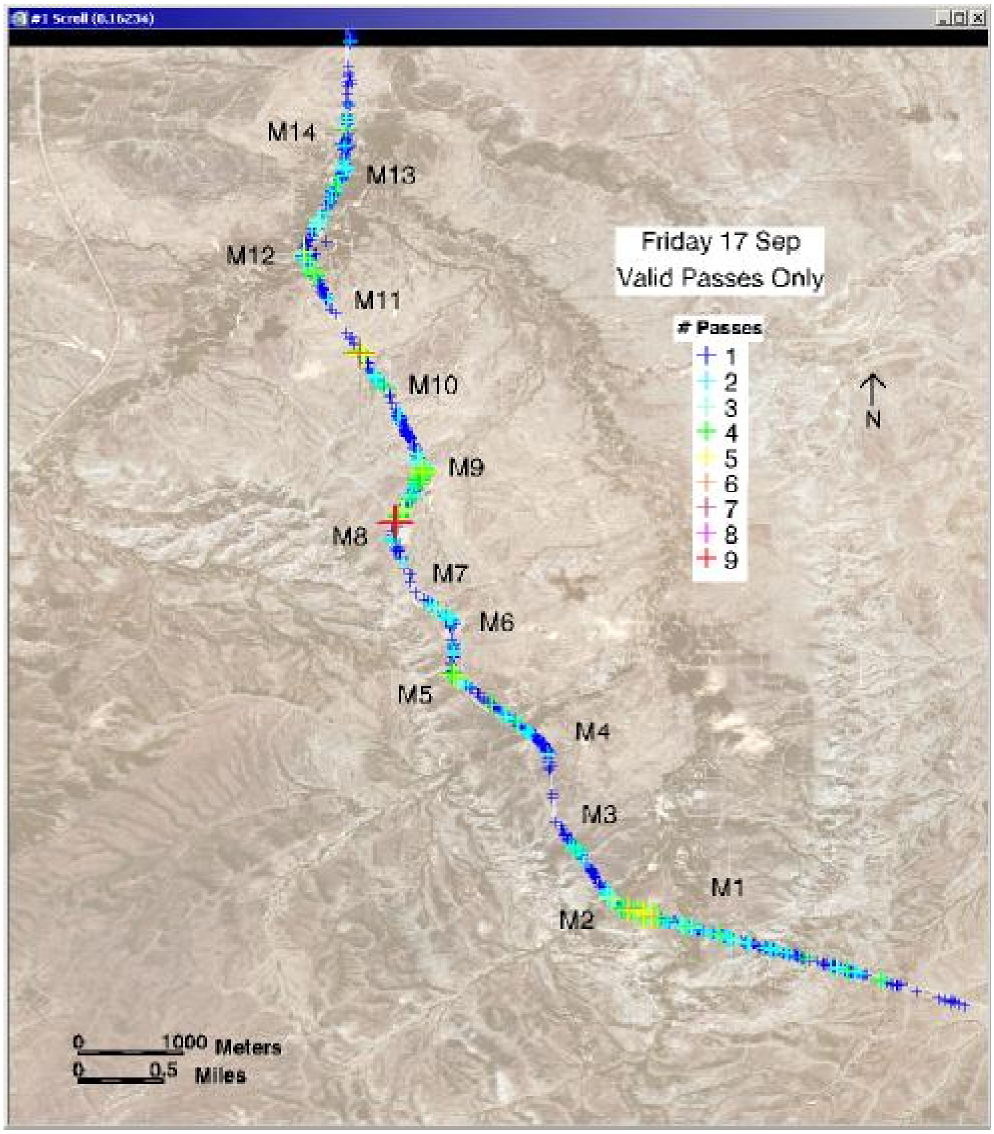
October 8, 2004

ITT Industries
Engineered for life

Executive Summary:

On September 17, 2004 we flew the route identified as "RMOTC Virtual Pipeline" with the ITT Industries ANGEL Sensor. This route was flown multiple times to ensure we had fully covered the complete Virtual Pipeline Route and to provide increased sample density to improve detection of smaller emissions. Analysis of the information collected indicates a number of areas of significant methane concentration along the pipeline right of way. The locations and relative size/concentration patterns for these are described in detail in this report.

The route flown is depicted below. All detected concentration areas are labeled with crosses. Color-coding is used to indicate detection of the methane concentration on multiple passes, with red indicating that the specific methane concentration was detected (within 30 meters) on nine separate passes. Six distinct methane concentration areas were detected with sufficient quantity and frequency (7, 8 or 9 passes) that they are very high confidence.



Methane Detections

The methane emissions with the highest confidence were captured on a relatively large number of passes as indicated in this table. The geographic coordinates provide the location of the aggregated multiple detections.

NAD 27 Data (DMS)					
Latitude	**Longitude**	**Date**	**AM Passes**	**PM Passes**	**Comments**
43 14 57.8148	-106 11 27.4776	17-Sep-04	2,3,4,5,6	2,3	area #1 between M1 & M2
43 14 58.7472	-106 11 31.8408	17-Sep-04	1,2,3,4,6	2,3	area #2 between M1 & M2
43 15 1.1592	-106 11 37.8132	17-Sep-04	1,2,3,6,7	1,3	area #3 between M1 & M2
43 17 44.8908	-106 13 15.8556	17-Sep-04	1,2,4,5,6,7	1,2,3	north of gas plant (high confidence)
43 18 56.9124	-106 13 31.0548	17-Sep-04	2,3,4,5,6,7	2	area between M10 & M11
43 19 40.0116	-106 13 53.8824	17-Sep-04	1,2,3,4,5	3,4	area northeast of M12

Methane emissions detected with lesser, but still significant confidence are listed in the table below. In all cases these were detected on multiple passes as well, but not as consistently as the detections documented above.

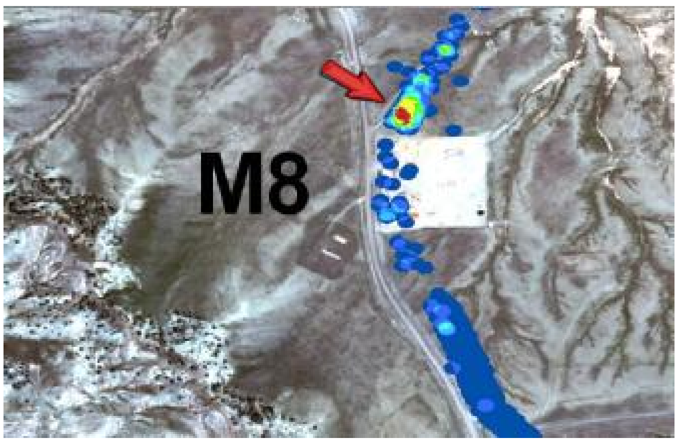
NAD 27 Data (DMS)			
Latitude	**Longitude**	**Date**	**Comments**
43 16 14.322	-106 12 17.3376	17-Sep-04	
43 15 27.0432	-106 12 0.3456	17-Sep-04	M2-M3
43 17 45.726	-106 13 15.2076	17-Sep-04	already have M8 (gas plant)
43 19 40.08	-106 13 53.8104	17-Sep-04	already have just north of M12
43 14 57.912	-106 11 27.348	17-Sep-04	already have north of M1
43 18 56.6784	-106 13 30.3636	17-Sep-04	already have south of M11
43 15 0.1368	-106 11 34.7856	17-Sep-04	already have south of M2
43 15 1.0908	-106 11 38.4576	17-Sep-04	already have vic M2
43 15 5.5692	-106 11 45.0132	17-Sep-04	just north of M2
43 14 59.0244	-106 11 31.7436	17-Sep-04	north of already have north of M1
43 19 51.2508	-106 13 48.5724	17-Sep-04	single sliver M12-M13
43 19 36.1452	-106 13 52.554	17-Sep-04	sliverama just south of M12
43 19 30.7308	-106 13 50.07	17-Sep-04	sliverama south of M12
43 14 53.7108	-106 11 13.5456	17-Sep-04	vic M1
43 16 40.3032	-106 12 51.1956	17-Sep-04	vic M5
43 18 6.246	-106 13 4.044	17-Sep-04	vic M9

Methane emissions detected at the location of the 5,000 scfh “calibration leak” were analyzed separately. A GIS analysis of just the Friday PM passes indicate that the leak was detected on three passes. The position of that leak is shown in the following table.

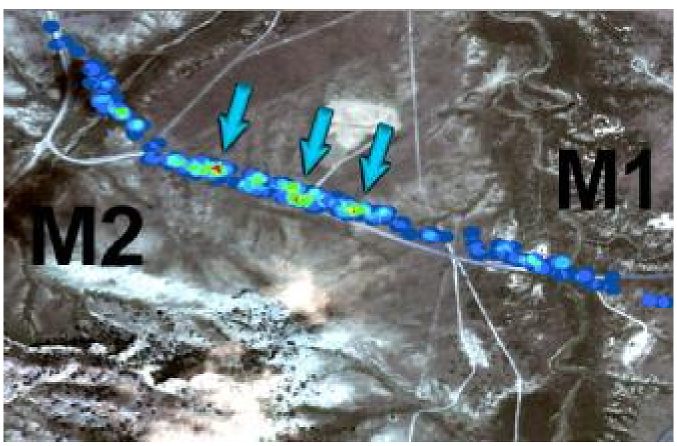
NAD 27 Data (DMS)					
Latitude	**Longitude**	**Date**	**AM Passes**	**PM Passes**	**Comments**
43 14 53.7036	-106 11 13.434	17-Sep-04	N/A	1,2,3	Calibration leak

Significant Emissions

In this survey there are six areas that stand out due to the size and concentration-pathlength values of methane plume and frequency of detection. These are identified in the images provided below with red and orange plume markers. The green markers are areas where there were potential indicators for methane but these were only detected on single passes and at low concentration pathlengths. These do not represent highly significant indicators. In addition, the 5,000 scfh calibration leak near M1was overflown and detected three times on Friday PM and is illustrated below.



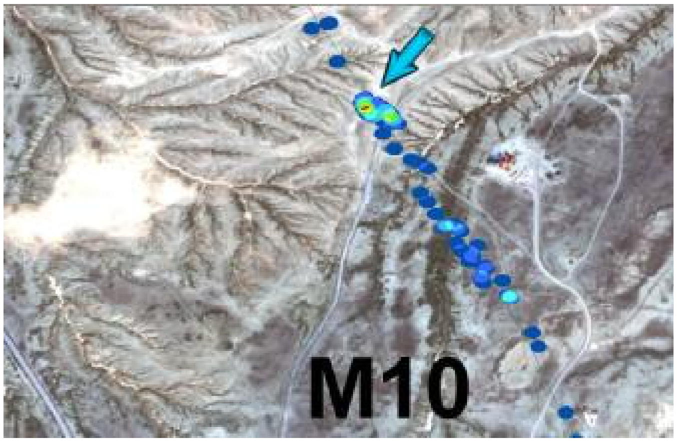
- N 43 17 44.8908
- W -106 13 15.8556
- Detected on 9 passes
- N of Gas Plant (High Confidence)



- N 43 15 1.1592
- W -106 11 37.8132
- Detected on 7 passes

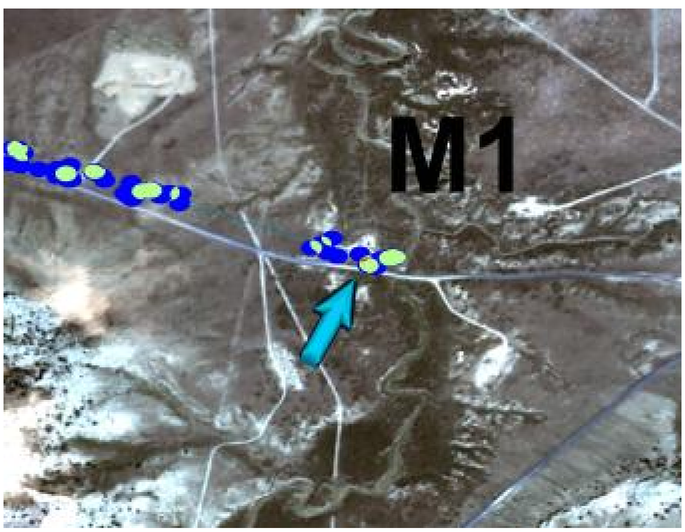
- N 43 14 58.7472
- W -106 11 31.8408
- Detected on 7 passes

- N 43 14 57.8148
- W -106 11 27.4776
- Detected on 7 passes



- N 43 18 56.9124
- W -106 13 31.0548
- Detected on 7 passes

- N 43 19 40.0116
- W -106 13 53.8824
- Detected on 7 passes

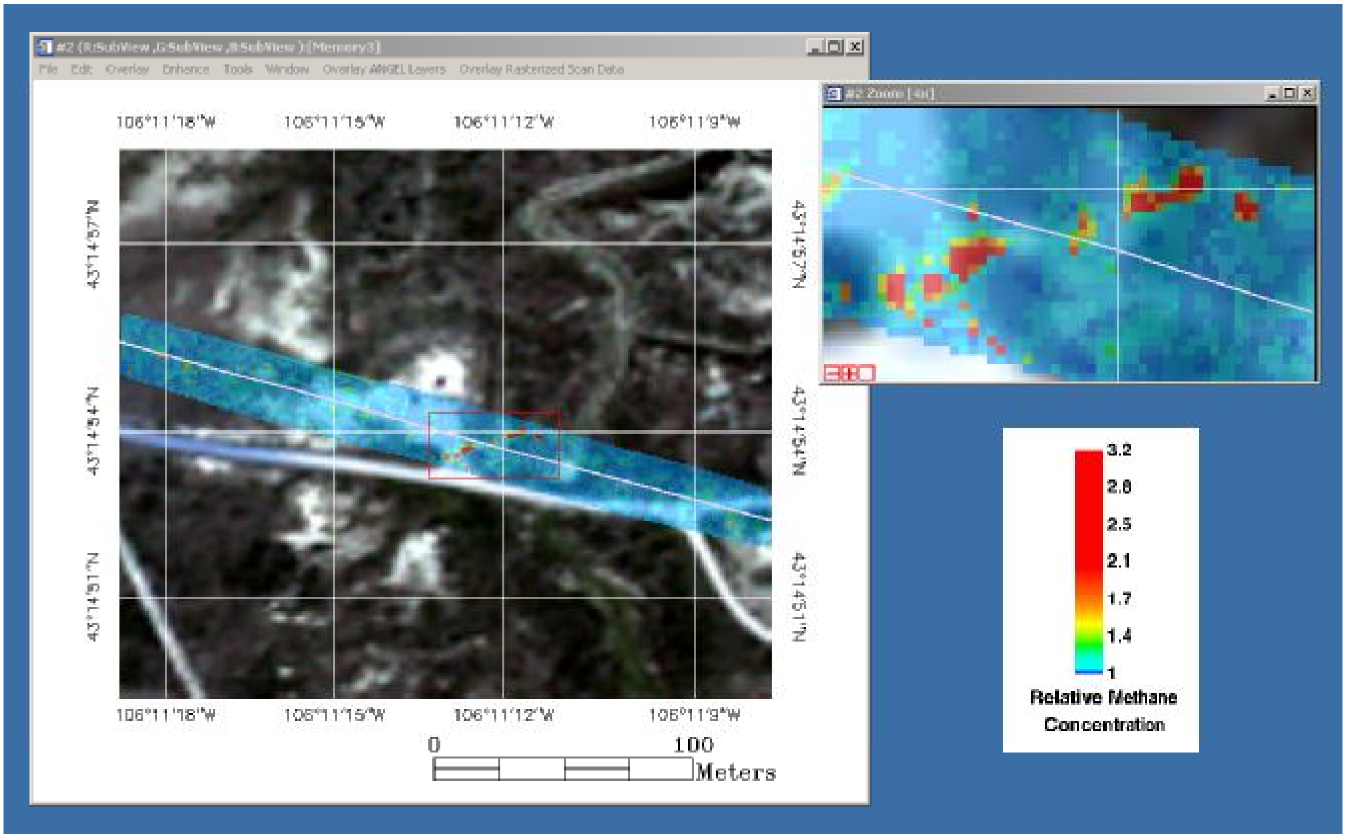


- N 43 14 53.7036
- W -106 11 13.434
- 5,000 scfh Calibration Leak detected on all three of PM passes

Special Case Analysis

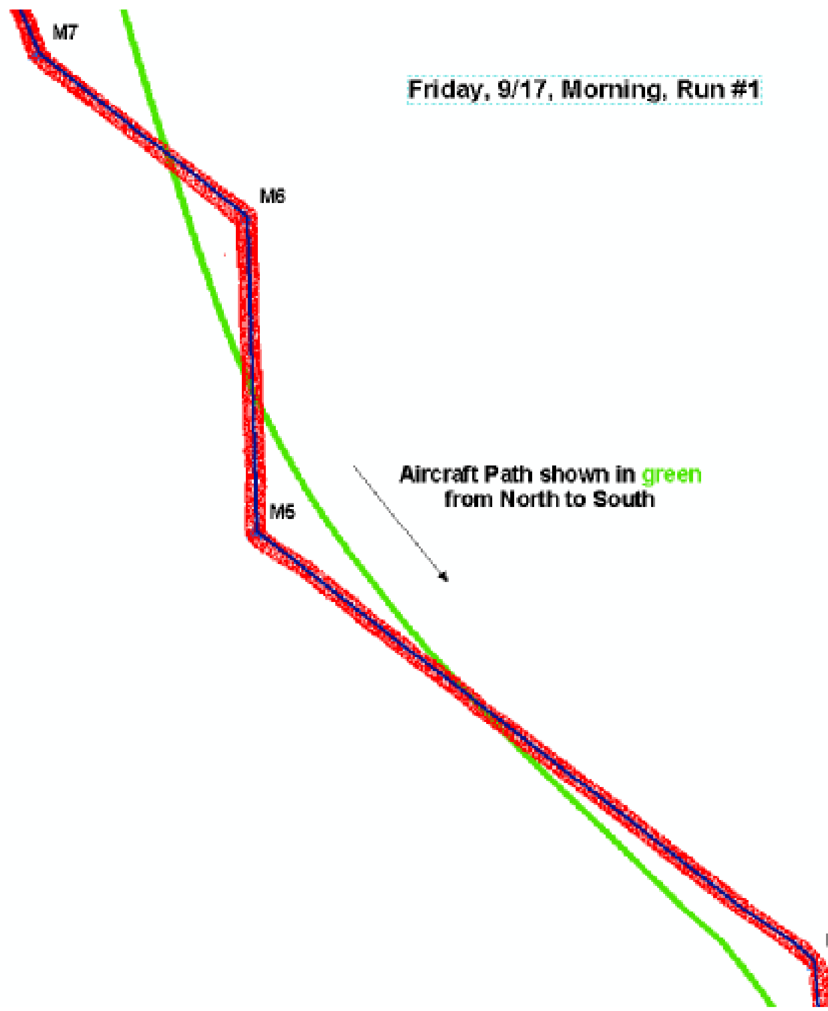
From the collection on Friday, September 17, 2004 one location stood out above all the others and warranted additional analysis. This was the 5,000 scfh "calibration leak"near M1 observed on the 3rd flight that afternoon. A raster-based analysis and methane images of the significant emissions are shown below. In this case the methane detected from the calibrated leak appears as an elongate plume.

The base imagery for this analysis is from Quickbird multispectral collection provided by DOE/NETL. The methane concentration pathlengths were measured from a single pass and the colors represent the relative concentration pathlength of methane within the ANGEL swath. Normal background methane levels are shown in dark blue. The ANGEL collection scan swath is approximately 25 meters wide and is superimposed on the base image. It should be noted that the imagery used as purchased was not perfectly geo-registered and is provided to give approximate context (+/- 15 meters) to the ANGEL analysis data, not absolute positioning.



Right of Way Coverage

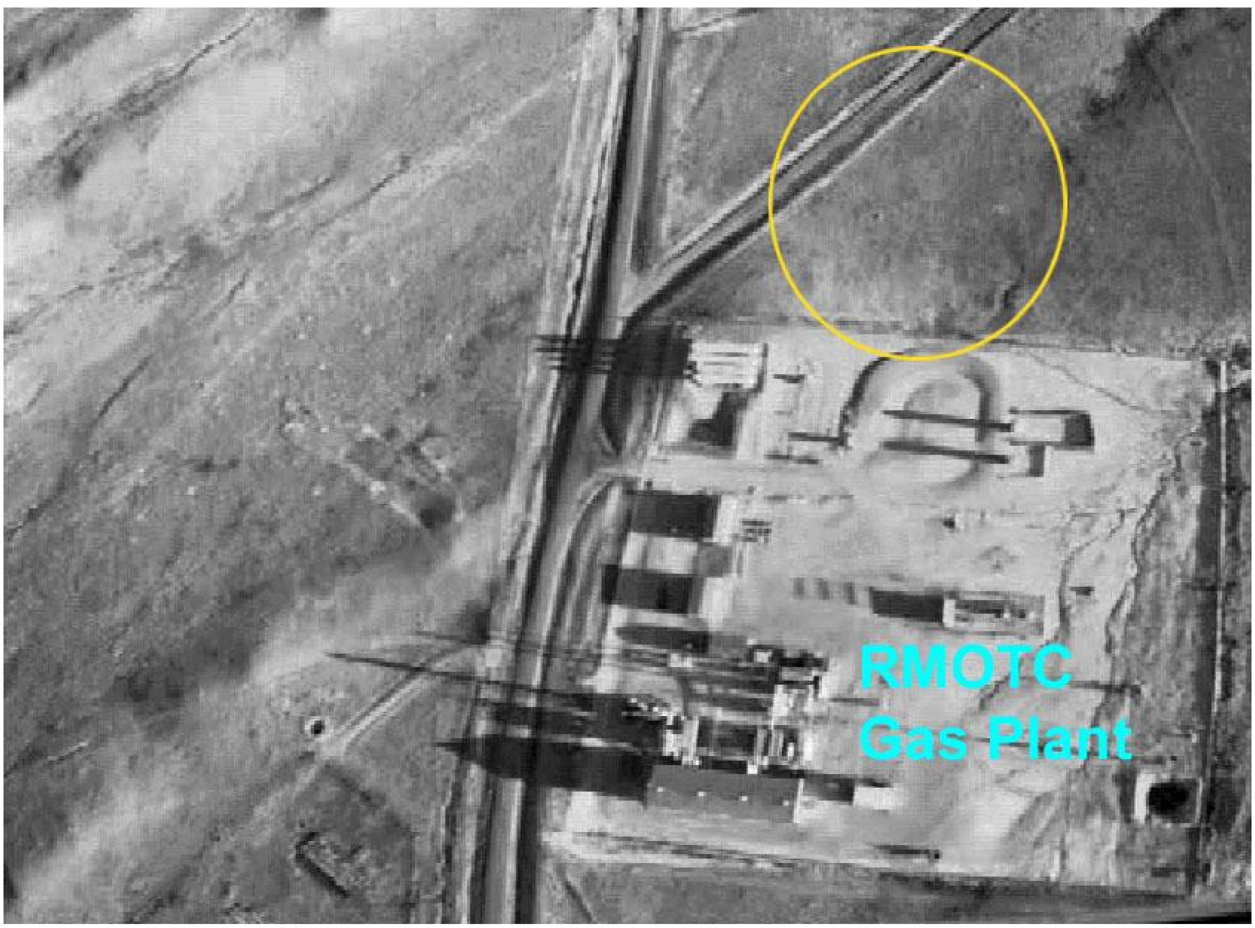
ANGEL collection planning starts with developing a flight plan that will place the aircraft over the pipeline route. In most cases the aircraft flight path cannot perfectly match the pipeline route but the ANGEL sensor can still track the full right of way. This is important to ensure that we provide adequate collection coverage of the full right of way for the entire length of the pipeline segment being surveyed. As the aircraft then flies the designated route, the sensor tracks and images the actual right of way, even when not directly under the aircraft and regardless of minor flight variations. The information collected from each flight is analyzed to determine that the right of way was fully covered as planned. The graphic below shows the actual results from a small segment of one such flight path over the designated pipeline route. The green line is the path of the aircraft and the red band is made up of all the individual sensor collects throughout the flight. In this case the sensor accurately tracked the pipeline and provided full coverage of the right of way. This post flight analysis provides confidence that we have adequately covered the pipeline path and right-of-way for the full 7.5-mile length of the survey.



Flight Path Verification

The ANGEL aircraft has been fitted with a monochrome video camera that is used for flight path verification. This camera collects looking forward at 15 degrees from nadir and provides MPEG2 motion video imagery with approximately 1.4 ft raw GSD resolution. The video camera currently in use was designed only to provide engineering flight test information and will soon be replaced with a much higher resolution color and false color IR digital camera designed to collect a continuous strip of geo-referenced imagery as the sensor is flown along the pipeline right-of-way.

In image of the RMOTC Gas Plant shown below was captured during an early AM S to N pass. The yellow circle North of the Gas Plant indicates the approximate position of elevated methane levels detected throughout the day on Friday 9/17/2004.



APPENDIX K

Equipment Provider Comments

Section 1 - En'Urga Inc.
Section 2 - ITT Industries, Inc.
Section 3 - LaSen, Inc.
Section 4 - Lawrence Livermore National Laboratories
Section 5 - PSI Corporation

Note: The comments in these letters were completed by the equipment providers after SwRI divulged the actual leak sites and leak rates, but prior to receiving SwRI's evaluation. Therefore, claims of the equipment providers regarding the performance of their systems may not be consistent with the evaluation in Section 4.3. The claims and comments of the equipment providers do not reflect the opinions of the Department of Energy.

Section 1

En'Urga Inc.

Note: The comments in this letter were completed by the equipment provider after SwRI divulged the actual leak sites and leak rates, but prior to receiving SwRI's evaluation. Therefore, claims of the equipment provider regarding the performance of their system may not be consistent with the evaluation in Section 4.3. The claims and comments of the equipment provider do not reflect the opinions of the Department of Energy.

En'Urga Inc.

1291-A Cumberland Avenue, West Lafayette, IN 47906-1385
Phone: 765-497-3269 Fax: 765-463-7004

Mr. J. Christopher Buckingham
Southwest Research Institute
San Antonio, TX 78238

October 22, 2004

Dear Mr. Christopher Buckingham:

The following are the comments we have on the natural gas leak tests conducted at RMOTC in Casper Wyoming.

(1) The multi-spectral scanner was mounted on a mini-van with a maximum scan distance of 50 feet. Most of the leaks were beyond 50 feet. Therefore, small leaks were not detected with the system. Only the plume from large leaks was detected with the system.

(2) Only portions of the pipeline were scanned each time. In addition, since the system had to scan the pipelines at 2/3 the speed of aircraft inspection, we could not obtain live data. This precluded accurate specification of the leak location. All leak locations provided during the tests were rough estimates based on the location of road (between road crossing markers). This information was obtained by assuming the location in the saved file where a leak was observed corresponded to the vehicle location on the road (which would be strictly true if the vehicle moved at a constant speed).

Based on our analysis of the data provided in your ground truth summary, and reviewing the stored data files, of the twelve leaks reported by us, eight were probably positive indications of plume signatures and four were definitely false indications. The positive indications were assumed when the leak rates were sufficiently big so that the plume could be roughly where we were on the road between the two road crossing markers. However, a definite conclusion cannot be drawn due to lack of accuracy in our GPS coordinate estimates as stated above.

For future tests, it would be desirable to have an access way on top of the pipeline. Failing that, all leaks should be located within 50 feet from the middle of the road, or prior notice of the maximum distance of the leak location from the road should be provided.

We are grateful for the opportunity provided by DOE for evaluating the multi-spectral scanner.

Thank you very much.

Sincerely

Yudaya Sivathanu
Technical Director

Section 2

ITT Industries, Inc.

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ITT Industries
Engineered for life

Lessons Learned

ITT Industries was pleased to participate in the DOE/DOT facilitated Demonstration of Remote Gas Leak Detection Systems at RMOTC. At this event we were able to demonstrate for the first time many aspects of the ANGEL (Airborne Natural Gas Emission Lidar) System's capabilities. These included the ability to efficiently detect, qualify, geolocate and image natural gas leak plumes from the air. During this demonstration the ANGEL team learned a number of very valuable lessons, including:

- We validated the concept of using Differential Absorption Lidar (DIAL) for gas leak detection from a fixed wing aircraft. Integration of the sensor into the test aircraft was completed at the Casper Airport. The first fully integrated ANGEL DIAL data ever collected was on 14 September 2004, the second day of the RMOTC test. The ANGEL system was successful at detecting a majority of leaks of 500 scfh and larger.

- We confirmed that the ANGEL Intelligent Pointing and Scanning System allowed the aircraft to fly the Virtual Pipeline end-to-end at high speed and inspect 100% of the pipeline on a single pass. The ability to collect data accurately, rapidly, and efficiently is critical to future commercial operations.

- We demonstrated the robustness of the prototype ANGEL System by flying 8 successful missions over the last 4 days of the demonstration with more efficient data capture and improved sensor performance as the week progressed.

- We challenged the Beta version of our ground data processing software and it worked well throughout the week. The experience of having to rapidly process vast quantities of data during the demonstration is currently driving major improvements in the area of automated data processing and analysis.

- We verified the importance of laser power to our ability to detect leaks. This was one of the most important lessons learned at RMOTC. Increasing laser power greatly improves our ability to lock on a set wavelength and greatly improves the signal to noise ratio of the data. On Monday of the test, the ANGEL team more than doubled sensor laser power output by replacing a damaged optic and further hardware improvements are continuing.

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Qualitative Comments on ANGEL Technology

The ANGEL technology demonstrated at RMOTC proved to be enormously productive. Flying at over 130 Knots, the test aircraft was able to fully inspect the relatively short 7.5 mile Virtual Pipeline route in roughly 4.5 minutes. As a result, we were able to collect 7 complete inspections of the RMOTC Virtual Pipeline in our allotted 50-minute window. Productivity would have been even greater if the aircraft was not required to continuously turn-around after each pipeline pass.

During pre-RMOTC ground tests, ANGEL laser power levels were less than 50% of specification. Modeling of expected sensor performance given these output levels predicted that ANGEL would be able to confidently detect leaks of roughly 1000 scfh. Upon receipt of the actual size and position of the leaks from SWRI, we demonstrated our ability to detect and image a number of leaks of 500 scfh or larger even in the relatively high wind conditions experienced at RMOTC. While the ANGEL system demonstrated at RMOTC is at an early stage of development, data collection of this quality at this stage is extremely encouraging.

Initial data analysis focused on the spatial analysis of multiple collections in a single day. Data from multiple passes improved our confidence in our ability to interpret ANGEL data and detect leaks. Recent algorithmic improvements (since the submission of the final report to DOE) now allow better leak identification with the data from a single pass. Over the next few months, sensor hardware upgrades will allow confident detection of appreciably smaller leaks. Integration of the ethane laser bench (not used at RMOTC) combined with improvements in signal-to-noise ratio will result in significantly better sensor system performance.

Custom software designed to process the ANGEL data and display an image of a gas plume worked extremely well from the first day of the demonstration. Furthermore, this software was continuously improved over the course of the week. Subsequent improvements in determining the exact position of "laser spots" on the ground now allow us to more accurately display the size and shape of natural gas plumes.

Our understanding of the phenomenology of DIAL gas leak detection has been greatly improved by our participation in the DOE/DOT sponsored field test. Over the course of the week we imaged gas leak plumes of various sizes and shapes literally hundreds of times. The data collected during our time in Wyoming has been invaluable for gaining a better understanding gas leak behavior under a range of conditions.

Section 3

LaSen, Inc.

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LASEN
Advanced Laser Sensors

Oct. 20, 2004

LaSen, Inc. wishes to thank the sponsors and organizers of the leak detection technologies demonstration at the Rocky Mountain Oilfield Testing Center (RMOTC). This event that we were a part of during the week of September 13 gave us a valuable opportunity to test our Airborne Lidar Pipeline Inspection System (ALPIS) in a variety of field conditions and over a wide range of leak rates and types. We also appreciate the chance to work side by side with our peers and gain further insight into the status and capabilities of alternative technologies.

The results confirmed our prior assessment of the system's sensitivity. Our ability to detect leaks in these test was somewhat hindered by the lack of visual indicators of the simulated pipeline. Tracking the "invisible" pipeline in a helicopter inevitably resulted in some following errors and a few missed leaks. We hope that this problem will be taken into consideration for future demonstrations.

It should be noted that the level of performance demonstrated at the RMOTC does not set the limit on the system's ultimate capability. LaSen is continuously improving the leak detection technology. By the end of 2004, the next generation of ALPIS will become available, allowing for higher survey speed and increased accuracy of leak detection.

Russell R. Jennett

President, LaSen, Inc.

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Section 4

Lawrence Livermore National Laboratories

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University of California
Lawrence Livermore
National Laboratory

11/15/2004
4:17 PM

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TO	Chris Buckingham
FROM	William L. Pickles
SUBJECT	Demo Comments

The manned hyperspectral Imaging took place on two days. Wed Sept 9 and Wed Sept 15. The underground "Pickles Leaks" were started on August 30. This was done to allow time for the methane from the leaks to saturate the soils and produce pant stress be excluding oxygen from the plant root systems. On both days, the entire NPR3-RMOTC site was successfully imaged. At this time of year, the vegetation at NPR3-RMOTC is largely in hibernation. The exception is in the gullies where there is some moisture. Therefore, we were able to look for unusually stressed plant "patches" in the gullies as possible leak points. We found five locations that were along the "virtual pipeline leak. We used the September 15 images to identify the patches. We do not need "before and after images to detect plant stress. We use the spectral signatures of the plants reflected sunlight to determine their relative health. The "Pickles Leaks" were only between M9 and M14. The leak locations and relative size can be determined from the images in one day of flying.

We do see several patches of stressed vegetation that are adjacent to healthy vegetation in the hyperspectral imagery. This pattern is a signature of a possible underground CH4 gas leak. We have seen small, medium, large and very large patches of stressed vegetation. However, we can only see any vegetation signatures in the gullies, because of the local ecology and the season. We will be analyzing all the flight lines to produce a whole site images later.

Please keep in mind that this is a tough test for the vegetation stress technique. The only place we see vegetation signatures is in the gullies and I suspicion that there is lots of "run off" of plant damaging substances in those gullies. That will create some false positives. In the case of a real pipeline however, the exact geolocation of the pipeline would be available as a GIS layer and the leaks would only be along that narrow pipeline route, thus reducing the false positives.

We have used only the second day of imaging done on Wednesday September 15, 2004. The vegetation stress detection technique for identifying possible underground CH4 leaks only requires one image. It is not a "before and after", change detection technique. The second day of imaging was chosen because the leaks were running one week longer than when the first image was taken on September 9, 2004.

It is clear that since our technique only looks for stressed vegetation as a signature of an underground leak it will work better in an area that does have relatively healthy vegetation coverage along the pipeline. The RMOTC NPR-3 site can be a test site for above ground CH4

Page 1of 2

leaks into the air but is not appropriate for testing the vegetation stress technique. Perhaps if the tests were done in June during "green-up" it might have been more appropriate. We have just today received the QuickBird high resolution "after" image of all of the NPR-3 site. We will be using the before and after high resolution satellite imagery to try and develop vegetation stress signatures during the coming year. The UAV Hyperspectral imaging that was done on one day is the first data we have ever seen from this entirely new technique. We are working with the way the imagery data that was acquired by the UAV to move the technique forward. This new technique was started in the spring of 2004 and will require further development to test its usefulness. PG&E feels the technique offers enough possibilities that it should be pursued in the coming year. Apparently NASA AMES is willing to continue to fund developing the hyperspectral UAV system in FY 05. We feel we should continue to participate in this effort.

Section 5

PSI Corporation

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PHYSICAL SCIENCES INC.

PSI-1402

22 October 2004

Mr. Chris Buckingham
Southwest Research Institute
San Antonio, TX 78238

Physical Sciences (PSI) thanks SwRI and DoE for this opportunity to review actual leak data and compare the results with data acquired at RMOTC during our driving survey with the Remote Methane Leak Detector. Our findings are summarized in tabular form by Table 1 and its notes. Figure 1 displays the data graphically.

There are 88 leaks identified in Table 1 that were active during our testing period. Nine of the 88 were at the calibration site. Thirty leaks (at Leak Sites 2C, 2D/1F, P2, 6, and P3) were located 100 ft or more from the road, beyond the RMLD's specified detection range. 14 of those 30 were at or just beyond the 100 ft range and had small leak rates, 15 scfh or less. The data plotted in Figure 1 indicate that detection of these smaller leaks becomes increasingly challenging as distance increases beyond 70 ft. Eight leaks (at Leak Site P5) had flow rates of only 1 scfh, yielding gas concentrations of less than 3 ppm at 10 ft from the source. Plumes from these leaks are below the 10 ppm-m mobile RMLD detection threshold. Of the remaining 41 leaks, four were not detected by our equipment, including: the 15 scfh leak at site 2B on Monday PM, and three of eight passes at Leak Site 4. Table 1 Note b offers an explanation for missing the leaks at Site 4. Unexpectedly, during favorable wind conditions we were able to detect plumes from Leak Sites 6 and P2, despite the leak sources being located well beyond reach of the RMLD.

Some of our reported detection events cannot be correlated with the leak locations. On three occasions we detected methane in the vicinity of N43 17 3, just north of the ES&H building. Other events, noted in our reports as small and momentary, include: 1) a distinct signal, reported in our Equipment Provider Test Report Table 3.3.2 and plotted in the Wednesday PM data record, located at N43 18 18.7, just north of P1 (this may have been a gust associated with P1); and 2) fleeting signals recorded on Wednesday PM at the site of Leak 3 and Thursday AM at Leak 5, despite the leaks (which had previously been quite large) being shut off at the time. During a survey of a real pipeline, these events would have warranted a closer walking inspection.

The RMOTC experience has taught that the RMLD is generally an effective mobile survey tool, but to optimize the detection probability the survey vehicle would preferably drive within a nominal 100 ft of a pipeline and view down at the surface of the ground. Furthermore, leak detection and location can be enhanced by allowing a walking survey at sites of small detection signals. Survey planners and RMLD operators should recognize that the RMLD operates like a flashlight and detects gas in the path between the light source and the surface it illuminates. The absence of a surface behind the leak plume, or an obstruction in front, will preclude detection.

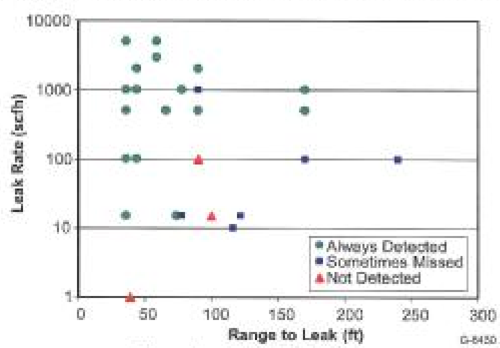

Figure 1. Graphical leak summary

Sincerely,

Mickey Frish
Manager, Industrial Sensors

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Table 1. Leak Detection Table

Site	Range	9/13			9/14			9/15			9/16			9/17		Fraction Found
		Rate	am	pm	Rate	am	pm	Rate	am	pm	Rate	am	pm	Rate	am	
cal	36	5000	Y	Y	1000	Y	Y	500	Y	Y	100	Y	Y	15	Y	9/9
P5[e]	39	1	N	N	1	N	N	1	N	N	1	N	N	---	---	0/8
3	44	1000	Y	Y	2000	Y	Y	100	Y	?[f]	2000	Y	Y	---	---	7/7
5	59	2900	Y	Y	5000	Y	Y	5000	Y	Y	---	?[f]	---	---	---	6/6
P4	66	500	Y	Y	500	Y	Y	500	Y	Y	500	Y	Y	---	---	8/8
2E	74	---	---	---	---	---	---	---	---	---	15	Y	Y[a]	---	---	2/2
2A	76	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
P1	78	1000	Y	Y	1000	Y	Y	1000	Y	Y	1000	Y	Y	---	---	8/8
2B	78	15	Y[a]	N	---	---	---	---	---	---	---	---	---	---	---	1/2
4	90	100	N[b]	N[b]	500	Y	Y	2000	Y	Y	1000	N[b]	Y	---	---	5/8
1F[c]	100	---	---	---	---	---	---	15	N	N	---	---	---	---	---	0/2
2D[c]	100	---	---	---	15	N	N	---	---	---	---	---	---	---	---	0/2
P3[c]	116	10	N	N	10	N	N	10	N	Y	10	N	Y	---	---	2/8
2C[c]	122	---	---	---	---	---	---	15	N	N	---	---	---	---	---	0/2
6[c,d]	170	500	Y	Y	100	Y	N	1000	Y	Y	500	Y	Y	---	---	7/8
P2[c]	240	100	N	N	100	N	N	100	N	Y	100	N	Y	---	---	2/8

Notes to Table 1:

a) The PSI team recognized and noted brief intermittent very small gas detection signals at Leak Sites 2B and 2E during survey. The surveyors subjectively chose to not report these signals as positively-identified leaks. Subsequent data review shows a distinct rise in signal above the background at these sites. With knowledge that these were actual leaks, we now record them as successfully identified. In actual practice, when a questionable signal of this sort is detected, the surveyor would leave the vehicle and perform a more detailed investigation on foot.

b) Our data show no indication of gas at Leak Site 4 on Monday AM, Monday PM, and Thursday AM. We readily identified Leak Site 4 at other times. On Monday, the combination of relatively small leak rate, location on a ridge above the road limiting opportunities for laser backscatter, and wind blowing from SW (perpendicularly away from the road), may have precluded detection of the leak plume. On Thursday, wind was again SW in the morning but NW, parallel to the road, in the evening. The NW wind facilitated detection.

c) Leak Sites 2C, 2D/1F, P2, 6, and P3 were too far from the road for normal detection with PSI equipment which has a nominal range of 100 ft. It appears that the NW wind Wednesday PM and Thursday PM enabled detection of P2 and P3. Photographs of 2D and P3 suggest that optical access to the leak site may have been obstructed by brush.

d) The very high rate of Leak 6 and favorable winds made its plume generally detectable despite the leak source distance from the road.

e) The very small leak rate and possible obstruction of the laser beam by surrounding brush precluded detection of this leak.

f) Although these leak sites are listed as inactive, we detected and our data files recorded small but distinct and momentary signals at or near them.