# R-PLUME update – September 2022

R-Plume project started on the 28th October 2020

**Table 1 Tasks and scheduled during for the R-PLUME project**

| Task | Task Name | Duration |
|---|---|---|
| 0 | Kick-off meeting | 1 day |
| 1 | Establish a collaborative structure | 8 wks |
| 2 | Survey first responder RPs | 16 wks |
| 3.1 | Sensor bench/in-ground testing - Analyse existing leak methods and identify ways to improve | 16 wks |
| 3.2a | Modify test bed at for gas flows up to 600 SCFH | 8 wks |
| 3.2b | Install additional emission points/rates and sampling methods into amended test bed | 13 wks |
| 3.3 | Document method in project reports/journal article | 8 wks |
| 4.1 | METEC tests - Measure gas migration rates in a range of conditions, 20 tests | 26 wks |
| 4.2 | Test summary/reporting | 12 wks |
| 4.3 | Follow-up experiments - Wet gas, PDFA Hazmat, QC/QA data | 20 wks |
| 6 | Extend results via modeling Numerical simulations | 52 wks |
| 7.1 | Initial guidance draft | 4 wks |
| 7.2 | Guidance revision | 4 wks |
| 8.1 | Final guidance doc | 4 wks |
| 8.2 | Final reporting | 16 wks |

**Task 0, Kick-off meeting - completed 28th October 2020**

The R-PLUME (Recommended Practices for Large Underground Methane Emissions) kick-off meeting was held on the 28th of October 2020. Attendees were: Dan Zimmerle, Kate Smits, Kristine Bennett, Stuart Riddick, Clay Bell, Aidan Duggan, Younki Cho, Bo Gao, Chris McLaren, Brian Pierzina, Bob Smith

**Task 1 Establish a collaborative structure - completed 1st January 2021**

A working group has been put together and tasks from the proposal have been allocated:

- Dan Zimmerle – Co-PI
- Kate Smits – Co-PI
- Kristine Bennett – Project Manager
- Wendy Hartzell – Project Manager
- Stuart Riddick – CSU Technical lead
- Clay Bell – CSU Research Scientist
- Aidan Duggan – CSU Research Associate
- Younki Cho -UT Arlington Postdoc
- Bo Gao – UT Arlington Postdoc
- Navodi Jayarathne – UT Arlington GRA

- Fancy Cheptonui – CSU GRA
- Laurie Williams – Consultant Specialist

Also, a Technical Advisory Board has been Assembled including representation from distribution companies, regulatory agencies, and first responder groups.

**Task 2 Survey first responder RPs – Completed 1st June 2021**

The survey of first responders' recommended practices was completed on 1st June 2021. In December 2020 and January 2021, we met with the Technical Advisory Board to discuss aims of the project and identify first responder recommended practices. The Advisory Boards comprises industry partners, emergency first responders and regulators at both state and federal level: Rick Trieste (ConEd), Ed Newton (SoCalGas), Francois Rongere (PG&E), Robert Smith (PHMSA), Chris McLaren (PHMSA), Mark Schlagenhauf (COGCC), Brian Pierzina (PHMSA), Steven Wheeler (COGCC), Matt Housley (Poudre Fire Authority), Tony Arcuri (West Metro FD), Richard Lyman (Chief WPFD) and Adam Caponera (Deputy Chief WPFD).

The report on first responders' recommended practices was generated from both discussion with TAB members and PHMSA incident reports. Data used to compile this first draft were presented to Brian Peirzina of PHMSA on the 23rd March 2021 and the presentation was also shared with PHMSA in March 2021. This document was internally review at CSU and UT Arlington before being presented to all TAB members at a TAB meeting on the 20th May 2021.

**Task 3.0 Methods for estimating gas migration and leak size – Completed 1st February 2021**

A method to measure the extent and speed of gas flow from a leak point using methane concentration measurements in the Rural and Urban testbeds built at the METC site in Fort Collins was determine on February 1st 2021.

Using the emission points in the rural and urban testbeds (Figure 2 and 4), natural gas will be released at rates between 4 and 300 SCFH. In the rural testbed methane concentrations will be measured at 30 locations between 1' and 6' below the surface to determine:

- Horizontal and vertical speed of gas flow
- The maximum extent subsurface of gas flow
- The maximum extent of the lower explosive level of methane.
- Persistence of subsurface gas

Experiments will be repeated to test how the following affects the speed and extent of gas migration:

- Environmental conditions: wind speed, irradiance, temperature and atmospheric pressure
- Surface cover: snow, ice and frost
- Soil conditions: moisture, pressure and temperature
- Depth of release
- Gas composition

In addition to the above, experiments will also be conducted in the Urban testbed. These will focus on the effects of subsurface infrastructure (open/closed pipes) and surface coverage (permeable/semi-permeable and impermeable cover). These experiments will also be conducted in a range of environmental and soil conditions. One of the main outcomes of the Urban testbed experiments is to investigate if and when the houses become explosive. The same experiment will be conducted at the each of the houses to investigate the effects of the house foundation. Concentrations within the house will be measured by dedicated methane sensors.

**Task 3.1, Sensor bench/in-ground testing - Completed 30th June 2021**

Identifying a method to improve measuring the speed and extent of gas flow from a subsurface leak was completed by 30th June 2021. This includes:

- A defined measurement methodology, namely with the use of a subsurface methane sensor to observe concentration changes in real-time. A description of the methodology to measure methane speed and extent of travel.
- Selection of a sensor that fulfilled all requirements defined in the proposal, the SGX INIR-ME100%.
- Python code has been developed that uses a laptop to read and log INIR sensor's serial output using an FTDI interface.
- Tests have been conducted to measure stability of the sensor in air and soil, the response rate of the sensor and an inter-comparison with previous subsurface methane concentration measurements.
- Weatherproofing of the data acquisition (DAQ), as the system will be left outside for extended periods.
- Construction of 47 methane sensors and 9 weatherproofed DAQ units.
- Installation of sensors including environmental (Soil moisture, soil temperature and soil pressure – TEROS 10, TEROS 11, TEROS 21 respectively (Figure 2)) and INIR sensors in suburban and rural testbeds after calibration at depths of 1', 2', and 3'. The boreholes of sensor placement were backfilled to pre-determined densities.

**Tasks 3.2a and 3.2 Modify test bed at METEC to accommodate gas flows up to 600 SCFH by increasing tubing sizes and installing larger flow meters. Install additional emission points/rates and sampling methods into amended METEC underground test bed. Sampling points installed. – Completed 1st July 2021**

The "rural" and "urban" testbeds were completed on 4th June 2021 (Figure 1).

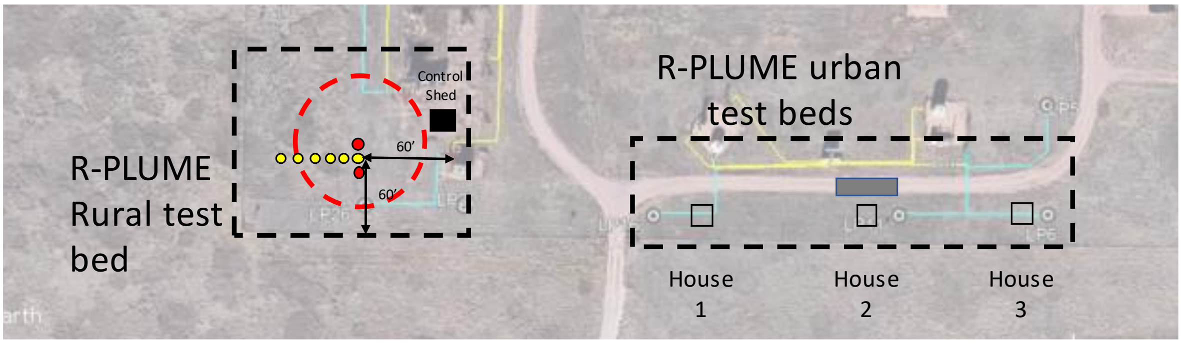


**Figure 1 Location of the testbeds at METEC, Fort Collins.**

Rural testbed

Thirty PVC tubes were installed in the testbed, 12 of 6' in length, 12 of 3' in length and 6 of 1' in length (Figure 2). During the experiments, probes held in especially designed carriers will be inserted into the tube prior to start of the experiment. The carrier will use an O-ring to isolate each sensor to measure the methane concentration at a specific sampling depth. During the experiment, sensors will be read by data acquisition systems on the surface at a sample rate of 1 Hz. After the experiment, the PVC tubes allow the sensors to be removed and redeployed during other tests. 24 soil moisture, soil pressure and soil temperature sensors at 1', 3' and 6' below the surface were also installed at each of the sampling points.

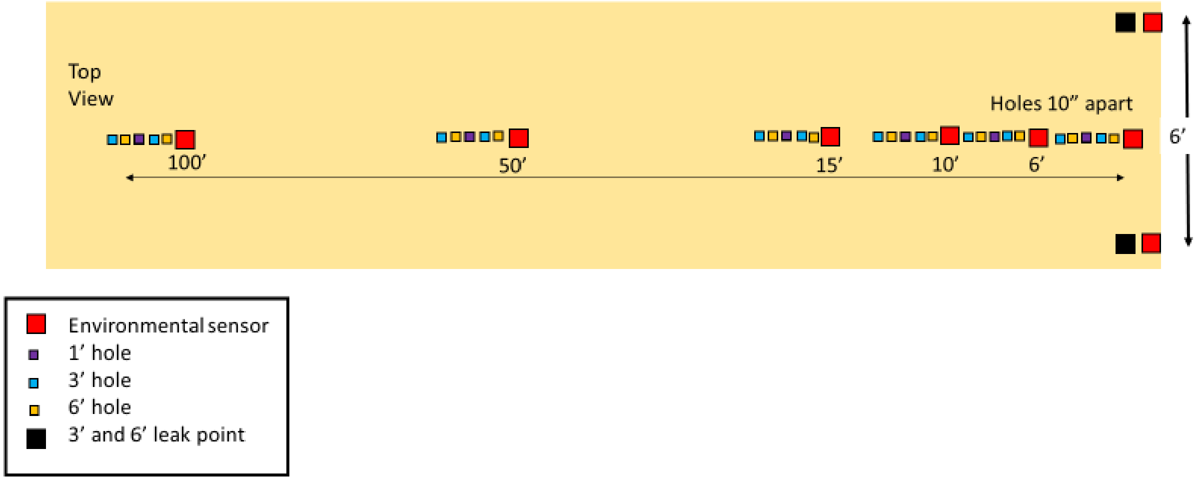


**Figure 2 Design of the emission points, environmental sensors and methane sensor measurement points in the "Rural" testbed at METEC**

Urban testbed

A second testbed was constructed at METEC to investigate differences in gas transport more complex environments. The aims of this testbed are to simulate the surface and subsurface conditions in urban and suburban settings. We installed dummy pipelines between a leak and a "house" and well as using different surface cover to represent surface permeable and impermeable to gas flow (Figure 3). The ultimate object of these experiments is to investigate under which conditions gas will move through the soil to build in explosive concentrations in "houses" (*sic*. sheds) 18' away. This will guide the recommended practices presented to first responders.

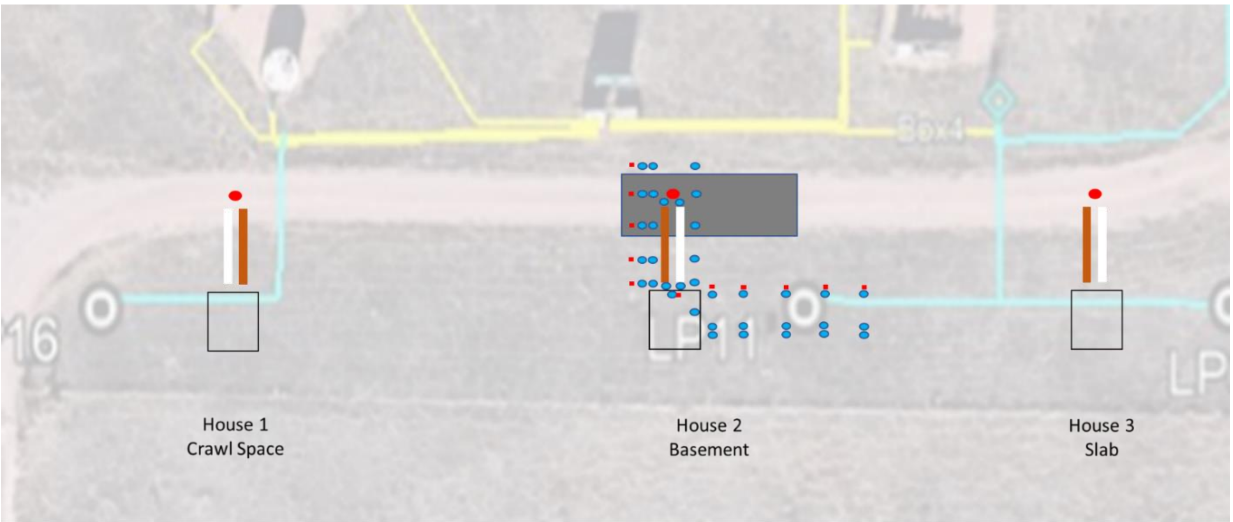


**Figure 3 Schematic of the three houses in the urban testbed at METEC**

- Measurement ports were installed in each of the holes in both the rural and urban testbeds (Figure 4).
- The foundation of house 1 "Crawlspace" was set with concrete.
- 50' of asphalt was laid outside house 2 "Basement".
- Sheds were built on the foundations at the 3 houses.

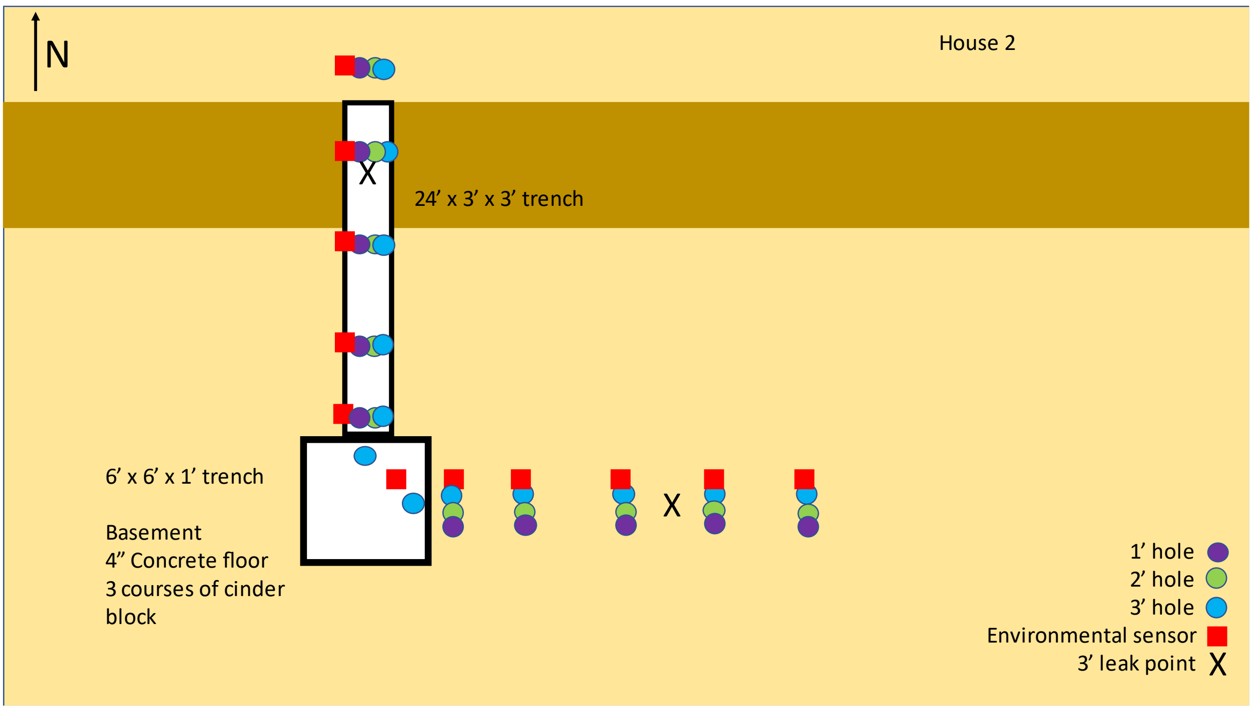


**Figure 4 Design of the emission points, environmental sensors and methane sensor measurement points at House2 "Basement" in the "Urban" testbed at METEC**

**Task 4.1, METEC Tests**

Field based methane release experiments are continuing at the METEC Urban testbed to determine subsurface expansion of gas transport from mid to large emissions in urban/suburban environments in accordance with the approved experimental plan. Continuing experiments investigate the effects of changing the surface covers (Experiment set 2: Surface cover). More than 24 tests have been completed (Table 2).

**Table 2 Summary of all experiments conducted to date. All subsurface emissions were released at 0.9 m below ground level for 24 hours.**

| Exp No | Experiment Date | Time of leak start | Emission rate (slpm) | Covering | Sub-surface | Soil moisture (%) | Variable |
|---|---|---|---|---|---|---|---|
| 1 | 11/11/2021 | 10:36 | 10 | Grass | Soil | 25 | Leak rate |
| 2 | 11/11/2021 | 9:50 | 10 | Grass | Soil | 25 | Leak rate |
| 3 | 12/3/2021 | 11:00 | 35 | Grass | Soil | 25 | Leak rate |
| 4 | 12/1/2021 | 12:50 | 35 | Asphalt | Pipes | 25 | Leak rate |
| 5 | 11/15/2021 | 10:43 | 50 | Grass | Soil | 25 | Leak rate |
| 6 | 11/19/2021 | 10:55 | 50 | Asphalt | Pipes | 25 | Leak rate |
| 7 | 3/25/2022 | 11:09 | 10 | Grass | Soil | 40 | Soil moisture |
| 8 | 3/23/2022 | 12:25 | 10 | Asphalt | Pipes | 40 | Soil moisture |
| 9 | 4/5/2022 | 9:11 | 35 | Grass | Soil | 40 | Soil moisture |
| 10 | 3/30/2022 | 10:42 | 35 | Asphalt | Pipes | 40 | Soil moisture |
| 11 | 2/17/2022 | 6:33 | 10 | Snow | Soil | 25 | Covering |
| 12 | 2/23/2022 | 8:20 | 10 | Snow | Pipes | 25 | Covering |
| 13 | 3/2/2022 | 8:38 | 10 | Slush | Pipes | 25 | Covering |
| 14 | 3/7/2022 | 11:02 | 10 | Slush | Pipes | 25 | Covering |
| 15 | 12/8/2021 | 10:28 | 10 | Frost | Soil | 25 | Covering |
| 16 | 12/13/2021 | 12:12 | 35 | Frost | Soil | 25 | Covering |
| 17 | 6/21/2022 | 9:00 | 10 | Semi | Soil | 25 | Covering |
| 18 | 6/21/2022 | 9:00 | 10 | Semi | Soil | 25 | Covering |
| 19 | 4/21/2022 | 9:54 | 10 | Asphalt | Open | 25 | Subsurface |
| 20 | 4/11/2022 | 12:46 | 35 | Asphalt | Open | 25 | Subsurface |
| 21 | 5/2/2022 | 13:43 | 10 | Grass | Soil | 40 | Soil moisture* |
| 22 | 5/4/2022 | 11:05 | 10 | Asphalt | Pipes | 40 | Soil moisture* |
| 23 | 6/20/2022 | 9:00 | 100 | Grass | Soil | 25 | Leak rate |
| 24 | 6/27/2022 | 9:00 | 150 | Grass | Soil | 25 | Leak rate |

* Indicates experiments with simulated heavy rain fall

**Task 4.2, Test Summary/Reporting**

On-going work includes using MATLAB based algorithms to determine the (i) initial speed of the gas, (ii) maximum distance that the gas travels, (iii) the maximum distance that methane to LEL travels from the emission point, (iv) length of time methane to LEL is present in the soil and (v) the time it takes for gas to vent from the soil for each of the experiments in Table 1. Statistical analysis will then be performed using these metrics to establish the key drivers of the speed and distance travelled by gas in the subsurface after emission has been initiated.

**Publications/Presentations**

Tian, S., **Riddick, S. N.**, Cho, Y., Bell, C. S., Zimmerle, D. J. and Smits, K. M. (2022) Investigating Detection Probability of Mobile Survey Solutions for Natural Gas Pipeline Leaks Under Different Atmospheric Conditions. Environmental Pollution. In Press.

Tian, S., Smits, K. M., Cho, Y., **Riddick, S. N.**, Zimmerle, D. J. and Duggan, A. (2022) Estimating methane emissions from underground natural gas pipelines using an atmospheric dispersion-based method. Elementa: Science of the Anthropocene. In Press.

Jayarathne, J. R. R. N, K. Smits, **S. N. Riddick**, D. J. Zimmerle, Y. Cho, M. Schwartz, F. Cheptonui, K. Cameron, and P. Ronney. (2022). Understanding Mid-to Large Underground Leaks from Buried Pipelines as Affected by Soil and Atmospheric Conditions – Field Scale Experimental Study. REX2022 – PRCI Research Exchange conference.

Cho, Y., Smits, K. M, **Riddick S. N.**, and Zimmerle, D. J. (2022) Calibration and field deployment of low-cost sensor network to monitor underground pipeline leakage. Sensors and Actuators B Chemical 355(11):131276 DOI:10.1016/j.snb.2021.131276www.

**Riddick, S. N.**, Bell C., Duggan, A., Vaughn, T. L., Smits, K. M., Cho, Y., Bennett, K. E. and Zimmerle, D. J. (2021) Modelling temporal variability in the surface expression above a methane leak: The ESCAPE model. Journal of Natural Gas Science and Engineering. https://doi.org/10.1016/j.jngse.2021.104275

**Riddick, S. N.** (2021) Survey of first responders' operation practices. Report to Pipeline and Hazardous Materials Safety Administration, DoT, USA for the Validating models for predicting gas migration and mitigating its occurrence/consequence project.