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1 Executive Summary

The purpose of this project was to develop a recommended practice (RP) for external based leak detection on natural gas transmission and distribution pipelines that includes guidance for establishing a technology certification organization. The purpose of this final report is to briefly summarize the extensive research that went into seven reports that were prepared during the development of the RP.

2 Introduction

2.1 Purpose of Report

The purpose of this project is to develop a recommended practice (RP) for external based leak detection on natural gas transmission and distribution pipelines that includes guidance for establishing a technology certification organization. The RP submitted along with this final report is a stand-alone document focused on the steps and factors that a company needs to consider when establishing and operating a leak detection system. To develop the RP, a series of interim reports were prepared to fully detail the rationale and background behind the information and recommendations included in the RP. This final report will serve as a high-level summary of the interim reports that were generated.

2.2 Background

In 2019, increases in natural gas-fueled electricity generation meant that natural gas accounted for 34.3% of total U.S. total energy production and 37% of electricity production [1]. The energy and electricity production was facilitated by ~2.3 million and ~300,000 miles of natural gas distribution and transmission pipelines, respectively [2]. One important aspect of ensuring the safe operation of that infrastructure is incorporating advanced leak detection technologies. This need is not unique to natural gas transmission and distribution, as there have been extensive efforts to produce guidance documents and recommended practices for hazardous liquids and natural gas pipelines. This report builds on current literature, knowledge, and practices to develop a document that is relevant and adaptable as new technologies become available.

New, more efficient and/or economical sensors, natural gas leak detection technologies, and methodologies are being frequently introduced to the market. Some of the technology recently developed or under development are immediately applicable to natural gas transmission pipelines while some are not; however, in the absence of a guideline or RP, significant time and funds are allocated to determine what is usable. The extensive efforts extend from operators who must evaluate new technologies to suppliers who are developing new technologies for seemingly unknown markets. The RP developed in this project offers a framework to bridge the gap between these two entities, operators and suppliers, taking into account a direct working knowledge of both product development and practical use.

During the development of the RP, types of technologies that could be used to detect leaks along with a determination of how those technologies were validated was researched and documented. Further, an analysis was conducted to examine whether current methods of validation were enough for sophisticated, multi-faceted leak detection systems that have come on the market today. Figure 1 shows a comparison of traditional validation and a more holistic method-based validation. The traditional validation has typically focused on individual performance abilities of a single sensor. However, leak detection systems are becoming complex with integrated sub-sensors, real time analytics, modeling algorithms and advanced data logging. The additional components mean that a single methane sensor may have very different results in the field depending on how it is deployed and integrated in a system of other types of sensors.

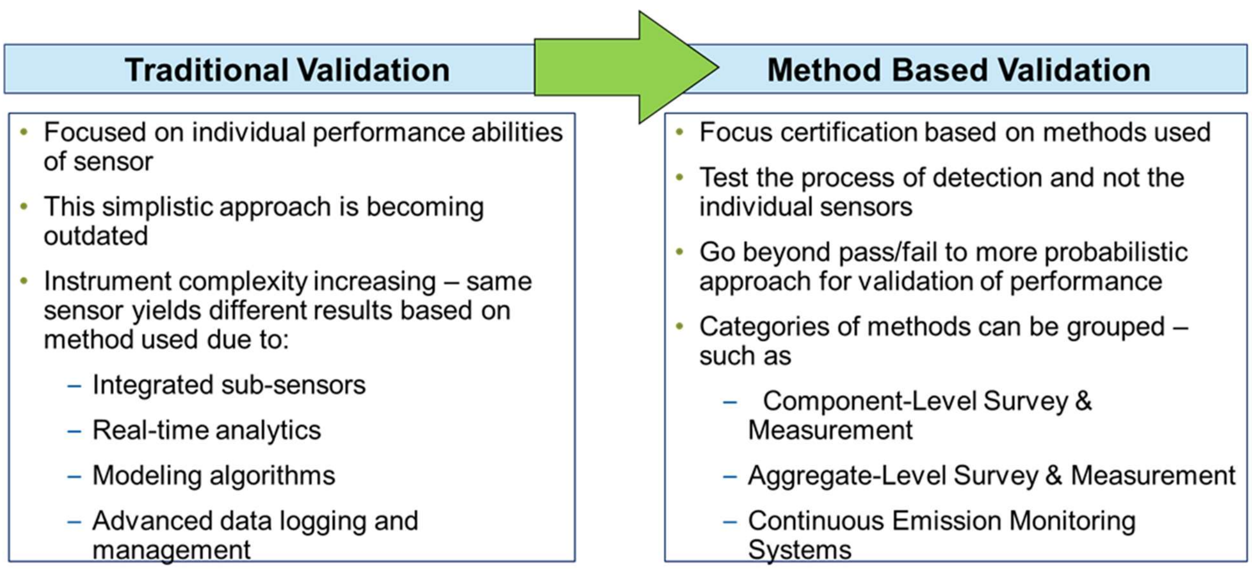

Figure 1. Comparison of traditional leak detection system validation with a more whole method-based validation.

The RP is therefore focused on development of guidance for method-based validation of full leak detection systems consisting of all components used for a particular method. In this way, the process of leak detection can be tested or validated beyond the performance of an individual sensor. This type of validation advances pass/fail performance testing of sensors to more probabilistic approaches for validating performance of leak detection systems. In order to conduct this type of method validation, leak detection instrument types should be categorized into high-level classes. For the purposes of this report and the frameworks developed in the RP, the technologies are divided into three main method classes – component-level survey and measurement, aggregate-level survey and measurement and continuous monitoring systems shown in Table 1. Each method class of sensors can be deployed on different platforms involving different technology and instrument types. Descriptions of all method classes, deployment platforms, technology classes, and instrument types are included in the following sections.

Table 1. Current external leak detection systems categorized by method class and deployment platform

Method Class	Deployment Platform	Technology Class	Example Instrument Types
Component-Level Survey and Measurement	Handheld and Vehicle-Mounted	Ranged Laser	TDLAS
		In-Plume Laser	Miniature OPLAS
		Etalons	CIPS (ex. DPIR, OMD)
		Nondispersive IR	NDIR
		Flame Ionization (FI)	FID
		Photo Ionization	PID
		Thermal Conductivity	Thermal Conductivity
		IR Imaging	OGI
		Catalytic Combustion/Pellistor	Catalytic Pellistor
Aggregate-Level Survey and Measurement	Vehicle-Mounted	Ranged Laser	TDLAS
		In-Plume Laser	WMS, CRDS, OA-ICOS
		IR Imaging	OGI
	Unmanned Rotary (Drone) Mounted	Ranged Laser	TDLAS, LiDAR
		In-Plume Laser	Miniature OPLAS
	Manned Rotary (Helicopter) Mounted	Ranged Laser	TDLAS, DIAL
	Unmanned Fixed-Wing (Drone) Mounted	In-Plume Laser	TDLAS, OA-ICOS, WMS, Miniature OPLAS
	Manned Fixed-Wing (Airplane) Mounted	Ranged Laser	DIAL
		In-Plume Laser	CRDS, OA-ICOS, WMS
		IR Imaging	Imaging Spectrometer (i.e., Hyperspectral)
	Satellite Mounted	IR Imaging	Imaging Spectrometer (i.e., Hyperspectral)
		Ranged Laser	OPFTIR, TDLAS

Method Class	Deployment Platform	Technology Class	Example Instrument Types
Stationary Continuous Monitoring Systems	Semi-Permanent (Tripod or Truck) or Permanent (Tower)	In-Plume Laser	WMS, CRDS, ICOS, TDLAS, MCS
		In-Plume Point Sensor	CNT
		Catalytic Combustion/Pellistor	Catalytic Pellistor
		Metal Oxide Senor	MOS
		Nondispersive IR	NDIR
		IR Imaging	Imaging Spectrometer (i.e., Hyperspectral)

CIPS: Correlated Interference Polarization Spectroscopy
CNT: Carbon Nanotube
CRDS: Cavity Ringdown Spectroscopy
DIAL: Differential Absorption LiDAR
DPIR: Detekto-Pak Infrared
FID: Flame Ionization Detector
LiDAR: Light Detection and Ranging
MOS: Metal Oxide Sensor
NDIR: Nondispersive Infrared
OA-ICOS: Off Axis Integrated Cavity Output Spectroscopy
OGI: Optical Gas Imaging
OMD: Optical Methane Detector
OPFTIR: Open Path Fourier Transform Infrared
OPLAS: Open Path Absorption Spectrometer
PID: Photoionization Detector
TDLAS: Tunable Diode Absorption Laser

3 Interim Report 1 – Establishing Sensor Technology Bounds

The purpose of Interim Report 1 was to establish the preliminary bounds of external leak detection technology types that were to be described in the RP. There were numerous sensor technologies and a wide range of methods and platforms that were determined to be usable to detect, locate, and/or quantify methane emissions along natural gas transmission lines – each of which has various strengths, weaknesses, and costs. A Leak Detection System (LDS) can include various kinds of sensors that are typically classified as either internal or external technology. External technology differs from internal technology in its ability to detect the presence of leaks *external* to the pipeline integrity shell. Interim Report 1 detailed that the RP would focus only on external LDS technologies. Key points considered in this report for establishing bounds of leak detection technologies were -

1. **Leak Detection sensors should be embedded within a robust LDS** as recommended in the American Petroleum Institute (API) RP 1175 [3] and should consider such factors as company goals for leak detection (e.g. surveying for large leaks vs. component-level emission rates); be appropriate for weather conditions as necessary (such as temperature extremes), comply with local regulatory requirements, and address specific site requirements (such as risk associated with pipeline proximity to sensitive areas).
2. **Evidence indicates that relying on one technology may miss leaks.** A sensor that is ideal

for monitoring around dense, urban-located natural gas transmission lines may not be the best fit for monitoring rural transmission lines that span hundreds of miles. In fact, where peer-reviewed studies have completed field trials that included a variety of pipelines and/or facilities, results indicated that using multiple technologies, methods, and/or platforms synergistically could be more successful in detecting leaks [4] [5] [6] [7] [8] [9].

3. **Disruptive sensors, platforms, and methods are anticipated within the next 10 years**. This means that cost and performance is expected to improve rapidly over the next decade for many sensor types. Therefore, it is equally important to become familiar with technologies that are under development and nearing commercialization.

Effective leak detection requires appropriate sensor platforms and sampling methods for any meaningful leak detection to occur. An excellent sensor deployed in an unsuitable way will not detect leaks or will be too resource-intensive to implement [4]. Sampling methods and associated sensor deployment platforms commonly used by industry were reviewed and the findings are shown in Table 2 of the Interim Report. In combination with applicable methods and platforms, applying the appropriately selected sensor is the key to an effective transmission pipeline LDS.

4 Interim Report 2 – Target Sensor Technologies

The purpose of Interim Report 2 was to build on Interim Report 1, where preliminary bounds of external leak detection technology classes were established. There are numerous methane measurement instruments as well as a wide range of methods and platforms that could be used to detect, locate, and/or quantify methane emissions along natural gas transmission lines – each of which has various strengths, weaknesses, and costs.

Commonly used methane measurement instrumentation was categorized into technology classes such as Laser-Ranged, Laser In-Plume, or Catalytic Combustion/Pellistor (Summarized in Table 1). Each category class was then aligned with preferred platforms and leak detection sampling methods. The remainder of the report described each of the technology classes and associated methane measurement instrumentation. Establishing an LDS is dependent on a clear understanding of the desired company objectives. The following are the top 3 external LDS objectives considered most common for natural gas transmission pipelines:

- **Objective 1:** The LDS should include one or more methane sensors capable of detecting gas concentrations above a pre-defined detection limit or difference from baseline concentration, while minimizing false positives. Several factors can affect false positives such as:

- Leak detection threshold
- Sensitivity of follow-up, handheld equipment (e.g. when a mobile survey instrument is more sensitive than the handheld instrument used to verify the leak indications).
- Presence of biogas in the area
- Changing weather conditions (during initial survey and follow-up)

- **Objective 2:** LDSs should include one or more methane sensors capable of conducting leak surveys of large areas, over multiple types of terrain in search of high emitting sources from below-ground pipes.
- **Objective 3:** LDSs should achieve compliance with both local and national regulations. 49 CFR Part 192 requires performance metrics quantifying the number of hazardous leaks either eliminated or repaired, and the total number of leaks either eliminated or repaired, categorized by cause.

5 Interim Report 3 – Sensor Evaluation Framework

The purpose Interim Report 3 was to begin framing the necessary metrics needed to defensibly and quantifiably evaluate external leak detection instrumentation for transmission pipelines. In response to a growing interest and growth in innovative LDSs, there has been concurrent development of approaches for evaluating the performance of these systems – the most recent being the Interstate Technology Regulatory Council (ITRC) [10] and the Pipeline Leak Detection Handbook [11]. The evaluation of leak detection systems should be based on an objective assessment of technology-neutral, quantitative metrics and directly related to stakeholder goals. Implementing and supporting an LDS requires that pipeline operators demonstrate measurable benefit. This means that the value of each leak detection instrument can be measured in both *defensible* and *quantifiable* terms. To that end, Interim Report 3 provided the background needed to develop an evaluation framework for the RP that effectively quantifies performance parameters of each instrument within an LDS that can ultimately be used to evaluate the LDS as a whole. The report included 2 primary focus areas -

- First, instrument *user requirements* were identified and matched with desired sampling methods and platforms. It is important to complete this step first when evaluating an instrument. As one embarks on a leak detection technology project, a set of initial specifications at the outset will be necessary – and developing the full range of functional and technical performance requirements will be essential to applying the appropriate evaluation metrics.
- Second, a framework of key instrument *performance metrics* was designed to enable effective sensor evaluation and ultimately define the measurable benefit of a chosen leak detection instrument. Measurable benefit implies that value is provided in (or assessed in) defensible and quantifiable terms. Since there is no single metric that will fully define the performance of a leak detection instrument, development of a range of useful metrics was developed to provide greater insight into the overall value each instrument contributes to the LDS and ultimately how well the entire LDS functions for the company.

6 Interim Report 4 – Technology Performance Specifications and The Human Element

The purpose of Interim Report 4 was to address human factors as they relate to external pipeline leak detection. This included the incorporation of the human element in the context of technology-based leak detection systems as well as how the design, implementation, and maintenance activities associated with the physical, mental, and workload aspects of the pipeline operator interacts with leak detection technologies in the working environment. In particular, this report focused on instrument validation approaches that could be used to ensure leak detection technology was best suited to its environment, its intended use, and company objectives.

7 Interim Report 5 – Target Technologies, Performance Specifications and Technology Evaluation Procedures

The purpose of Interim Report 5 was to aggregate key information from each of the four prior interim reports to create a wholistic document that ultimately served as a foundation for the RP. A first draft outline of the RP was provided in Section 6 of this report.

8 Interim Report 6 – Certification Center Requirements

The purpose of Interim Report 6 was to develop a framework that could be used by an independent certification organization to develop specific certifications for leak detection systems used on transmission pipelines. The framework was designed to provide general guidance and topics for a certification organization to consider in order to provide a comprehensive yet flexible, and efficient approach to leak detection system evaluation and certification. Effective leak detection requires appropriate deployment of instruments for any meaningful leak detection to occur. An excellent leak detection system deployed using an unsuitable sampling method may not detect leaks. Therefore, Interim Report 6 focused on the process of validating and certifying leak detection instruments (or systems of instruments) being deployed under refined sampling methods and platforms.

Method classifications and performance determination procedures designed in this report were intended to be general enough to allow flexibility as new leak detection instruments are developed and placed within a method category. The framework presented was a working framework. Neither the inclusion of methods, the definition of classes, or the probabilistic approaches for defining performance were intended to be completely prescriptive or exhaustive. Rather, the structures within the certification organization framework presented in Interim Report 6 were intended to provide a functional foundation and suggested procedures for test protocol development.

9 Summary Report 7 – Certification Organization

The purpose of Summary Report 7 was to finalize the information presented in Interim Report 6 – Certification Center Requirements, providing additional clarification in some areas. Interim Report 6 thoroughly detailed the requirements and framework for the organization and this summary report succinctly finalized the major topics that a certification organization would need to consider when performing evaluations of a leak detection system.

The considerations presented in this summary report could be used by an independent certification organization to develop specific certifications for leak detection systems used on transmission pipelines. This summary report was designed to provide general guidance and topics for a certification organization to consider in order to provide a comprehensive yet flexible, and efficient approach to leak detection system evaluation and certification.

Effective leak detection requires appropriate deployment of instruments for any meaningful leak detection to occur while balancing the presence of false positives (identifying a leak when one does not exist) and false negatives (missing leaks). A highly sensitive measurement system deployed using an unsuitable sampling method may not detect leaks or may detect leaks that do not exist, wasting limited company labor resources to investigate leaks that do not exist. Therefore, this report focused on the process of validating and certifying full leak detection systems being deployed under refined sampling methods and platforms.

Topics presented in this report were intended to be flexible as new leak detection instruments, systems, and methods are developed. It is important to note that this was a working or foundation document. Neither the inclusion of methods, the definition of classes, or the probabilistic approaches for defining performance were intended to be completely prescriptive or exhaustive. Rather, the structures presented in this report were intended to provide a functional foundation along with suggested procedures for test protocol development.

10 Conclusions

Extensive research has been conducted on all aspects of the external leak detection for onshore natural gas transmission pipelines. The extensive information collected has been summarized and presented in the RP submitted with this report.

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