Final Report (REVISED) – PUBLIC VERSION

Methane Emissions Quantification Process

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Pipelines and Hazardous Materials Administration
Cooperative Research Project

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Table of Contents:

List of Figures:

List of Tables:

List of Graphs:

DISCLAIMER

Executive Summary

There are a growing number of technology providers approaching Local Distribution Companies with tools and instruments that need to be tested and validated for the acceptable application in the gas distribution environment. Local Distribution Companies (LDCs) currently lack a standard test protocol for assessing technologies claiming to be capable of quantifying methane emissions. The LDCs' need for test validation of these tools and instruments generates from the drive to add quantification of methane emissions to the process for prioritizing pipe repair and replacement for non-hazardous leaks. If the accuracy of a technology is validated, then the LDC operator can consider its use. NYSEARCH members who supported this project agreed that an independent process is necessary to be defined and tested for validating claims and data provided by third party contractors for methane emissions measurements.

The overall objective of this project is to develop a standard method for validating methane emission quantification technologies. This validation process is intended to be used to assess any technology that claims to quantify methane emissions within the gas distribution environment.

A collaboration of NYSEARCH funding members and an independent standards expert created the basis for this validation process. An existing standard API-1163 entitled *In-line Inspection Systems Qualification Standard* was used. Following various activities and discussions to gain feedback on a collaborative process, the funders agreed that API 1163 is a good framework for methane quantification because the methane emissions measurement is an indirect measurement like ILI inspection measurements. The approach is based on the technology provider describing the tool or instrument in detail including the science used for measuring methane emissions, its accuracy, precision and certainty of field measurements. The technology provider submits these specifics prior to the LDC's acceptance of performing the standard validation testing. If the technology appears to be promising and acceptable to the LDC's needs, then the process commences in order to validate the technology provider's technical claims.

Initial conception of an overall guideline provided the basis for the validation process. Through inter-company discussions, surveys, and internal as well as NYSEARCH group meetings, the teamwork lead to development of a test specification and field test plan before completing a new guideline. Statistical analysis and methods were integrated into the requirements for evaluation to ensure quantitative relevance to the process.

For testing the process and the new guideline, three technology providers were selected based on the differing science incorporated into their tools and instruments as applied to quantification of methane emissions. Each of the technology providers were tested sequentially at different LDC host sites. The validation process included a comparison of the original capability claims by each technology provider with the field test results that revealed the actual accuracy, precision and certainty. Improvements and practical application to the process were noted during and at the conclusion of each validation test.

Potential next steps for this validation test protocol could include approaching a national organization, such as the American Gas Association (AGA) or a standards organization such as the American Society for Testing and Materials (ASTM), and/or preparing and publishing a validation standard that would be utilized by LDCs and potential technology providers.

Background

The basis for the Methane Emissions Validation proposal to PHMSA in March 2015 and project that was executed in the 4th quarter of 2015 was derived from ongoing work by our NYSEARCH members and by a parallel effort that NYSEARCH members embarked on in early 2015 to evaluate various third-party Methane Emissions Technologies to quantify emissions for non-hazardous Type 3 leaks in the distribution sector. LDCs classify sub-surface leak indications from a safety perspective using additional factors such as proximity to buildings, sub-surface structures, and extent of paving. Potentially hazardous (Type 1 and Type 2) leaks are scheduled for repair while non-hazardous leak indications (Type 3) are given a lower priority from a safety perspective and can be monitored rather than scheduled for repair. By adding a process for validating methane emissions, gas company operators and their constituents are adding an element to the prioritization process that factors in environmental considerations.

From the start, detection of leaks was not intended to be part of the process within this project. Typically, detection of leaks can be performed in a separate leak survey.

Members who supported this project agreed that an independent process is necessary to be defined and tested for validating claims and data provided by third party contractors for methane emissions measurements. These contractors and new technology providers can be classified with varying qualifications: 1) those who have worked in the gas industry with LDCs, 2) those who have worked in the production sector of the gas industry but are not familiar with distribution sector conditions in urban and suburban environments and, 3) others who are not familiar with LDC applications and come from using various technologies in academic and environmental applications.

The development of a process requires input from various entities in the gas companies who are familiar with existing leak survey processes and those who have embarked on their own in terms of evaluation and use of the methane emissions technologies. Typically, the methane emissions technologies can measure the size of the emission and/or categorize that emission in a bin of what is considered low, medium or high flow rate.

During both controlled tests and field tests in 2016 conducted in the other predecessor NYSEARCH project (which will be described in a subsequent section), the funders of this work drew from test experiences, their companies' reaction to these new technologies and those tests to develop an approach for an emissions validation process.

Objectives

The overall objective of the project was to identify, apply and test a methodology or set of methodologies that allow a gas distribution operator to validate the accuracy of measuring, locating and quantifying the methane emissions rate from non-hazardous natural gas infrastructure leaks.

The specific goals of this project were to: 1) work collaboratively on a validation methodology or set of methodologies so that there is consensus as to the commonality of a validation process for gas distribution operators, and, 2) come to consensus as an industry consortium working in conjunction with regulators and other peers as to what methodology can be applied both practically and reliably.

Methodology

At the beginning of the project, we worked as a team to solicit ideas and responses from our members on their preferred approach to an emissions validation process. An initial survey to confirm the bounding conditions of the technologies was completed. Following a group discussion in early 2016, the survey provided in the 2nd Quarterly Report was distributed to the NYSEARCH co-funders of this project. The February 2016 survey sought information about the type of data that was desired from third party service providers. It challenged the gas company personnel to respond on how to use the information, the desired accuracy, and other attributes needed to gain confidence that these third-party measurements could be used for augmenting non-hazardous leak assessments and prioritization.

As part of the survey analysis and follow-up discussions with the funders, we found that they were hesitant to engage in specific procedural discussions until they were more comfortable with test results and information coming from our parallel project and other projects in terms of knowing the readiness of the technology. To follow the envisioned process that was laid out in early 2015 in the PHMSA T & D Milestone Schedule, we requested that funders take the survey analysis and engage in individual company meetings to get more response and interpretation from their internal experts. In addition, to aid the funding companies in executing those meetings, the NYSEARCH Project Manager provided a common template to help the R & D project managers to conduct the in-house meetings.

While separate from the data analysis that NYSEARCH was performing on Validation processes in this PHMSA-cofunded project, the results from our parallel project controlled testing performed in spring of 2016 showed that the quantification methodologies by third parties were not advancing at a pace that is commensurate with public reports on use of these technologies for other applications. It was our general conclusion at that time that the application of these technologies to prioritize non-hazardous leaks on gas distribution pipeline segments still has accuracy and precision challenges. To gain the input of others outside of the NYSEARCH and PHMSA project, we also presented the interim findings from our parallel Emissions Technology Test Program at the AGA Operations Conference in April 2016 and numerous people from both the gas and vendor community attended that session.

In the summer of 2016, some of the funders provided summaries from internal meetings with experts in the gas leak detection area. We did not receive as much information as was expected from those meetings. This is because the users were still not sure about how validation for methane emissions could be a separated from leak detection. It was noted that there is a need to separate the priority of leak detection from validation and the need to get more communication at various levels of the gas companies on the importance of both. As a result, members of the NYSEARCH funding group agreed that we need to increase the emphasis for the development of validation requirements with our internal users. Following issuance of a Quarterly Report to PHMSA, the NYSEARCH funders decided to re-think how to gain operator input as the project moved forward.

The effort of field testing in the parallel project included a daily task relevant to independent validation that was separated from the technology service provider data collection task. As part of the test plan developed in that project for November 2016 field testing, it was decided that a separate crew would try to validate the technology providers' readings by using the funders' current preferred method which is the 'Surface Enclosure' method.

In late 2016, in consultation with PHMSA, our funding group decided from the previous feedback that came from surveys and conference calls, that the plan for envisioning and scoping a validation protocol by gaining detailed input from SMEs needed additional input. Thus, we worked as a group on a plan to using a procedural guideline, API 1163 to help detail the project plan for validation work. PG & E, who was active in standards development with In Line Inspection and working on multiple projects in Methane Emissions technology development, offered justification materials to the full group for use of API 1163 as a starting point for a validation protocol in this project.

To finalize our plan to move to the API 1163 guideline approach, we agreed on the following:

- API 1163 is a good framework for methane quantification because the methane emissions measurement is an indirect measurement like the ILI inspection measurements. Also, the ILI measurements covered in API 1163 apply to three different areas, like methane emissions information: detection, identification and quantification. In addition, both processes have the involvement of various entities; the sensor manufacturer, the system integrator (algorithm developer), the surveyor (data collector) and the utility.

Once the funding group agreed on using API 1163 as a guideline, the skills/background necessary for an Independent Consultant to convert that guideline to something that was useable in this project was evident. Thus, in the first quarter of 2017, Mark Hereth of P-PIC was first educated under Non-Disclosure Agreement about this project and our related NYSEARCH project and then contracted to aid with the various documents that advanced API 1163 to a new set of documents for a Methane Emissions Validation process (provided in Attachment A).

The NYSEARCH program manager, independent consultant and NYSEARCH funders worked in the 2nd Quarter of 2017 on the development of the specification. The specification captured the specific basis of the guideline to consider the intent and approach to the field testing. The specification also became the platform for the field test plan basis.

The test plan development reflected the validation guideline and specification. The test plan provided potential Technology Service Providers with procedural structure for implementing measurements of methane emission quantification during the field tests. In parallel, the NYSEARCH project manager conducted numerous discussions with P-PIC and the funders on the guideline documents and also lined up potential technology providers for the planned field tests.

A variety of technologies were pursued as this validation testing format was to be capable of evaluating any technology interested in a gas distribution industry application. P-PIC, our independent consultant, assisted in preparing overall project guidelines, resulting test specification and details for a field test plan.

Several technology providers were approached to participate in this testing. Based on an interest to test a variety of technologies in this validation test approach, three technology providers were selected. The variety of technologies included instruments using cavity ringdown spectroscopy (CRDS), tunable diode laser absorption spectroscopy (DIAL) and Off-axis integrated cavity output spectroscopy (OA-ICOS). Each technology quantifies methane concentrations differently which is the bases for calculating an emissions flow rate.

The validation process specification and field test plan were finalized. These documents reflected the overall validation guidelines. The specification and test plan were provided to the three technology providers to prepare for active field testing. Each of the three technology providers participated in sequential field tests that were conducted by the NYSEARCH project manager in funding company customer territories (in live conditions). The NYSEARCH project manager lead the three technology providers through the field tests, adhering to the agreed-on test plan and intent on ensuring consistency between the different tests.

After each completed test, the resulting raw field test data was summarized for the project funders.

The Methane Emissions Validation process guidelines are intended to ensure the following:

a. Users make clear, uniform, and verifiable statements describing methane emissions quantification system performance.
b. Users select a methane emissions quantification system suitable for the conditions under which the survey will be conducted. This includes, but is not limited to, the pipeline operating conditions, operating environment, wind speed, temperature, humidity, area type (urban, suburban, rural, industrial), time of day and atmospheric stability among others.
c. The methane emissions quantification system operates properly under the conditions specified.
d. Procedures are followed, before, during and after the methane quantification emissions tests.
e. Methane emissions quantification indications are described using a common nomenclature, as described in these guidelines.
f. The reported data and results provide the expected accuracy and quality in a consistent format.

One of the initial requirements of the technology provider was to describe the technical details to be validated during this testing, illustrated in Figure 1.

NYSEARCH Test Log - Validation Testing Methane Emission Quantification - Specifed Technology

Date:	Test Location:
Technology Provider:	Test Plan:

Technology Providers Background and History - Operational and Physical Characteristics

1 Name of device

2 Description of device
- a Science of the methane sensor (e.g., DIAL, CRDS)
- b Physical characteristics of the methane emissions surveyor and quantification equipment, including size, weight, power requirements and environmental limitations
- c Survey sampling frequency
- d Description of algorithm and data analyses
- e Reporting capability
- f Operational reliability of survey equipment
- g Operational constraints

3 Information Provided By The Gas Company, Required and Ideally
- a What specific information would assist in the optimal methane emission survey?

4 Pre-Survey Operational Requirements
- a Initial set up time prior to survey
- b Calibration requirements
- c Specific location set up time just prior to survey

5 On-site Survey Requirements
- a Required distance required to emissions source (minimum and maximum)
- b Measurement time required (e.g., minimum and maximum time)

6 Reporting Measurement Calculation Results
- a Time required to finalize measurement
- b Accuracy expected of measurement
- c Sizing or characterization accuracy (e.g., +/- 5% or 10% or flowrate)
- d Certainty (e.g., 80% - 90% of the time)
- e Statistical confidence level (e.g., 95%)

7 Technology Limitation and Restrictions
- a Weather condition (e.g.- wind velocity, humidity, cloud cover, precipitation)
- b Survey time of day (e.g., optimum daylight, night time hours)
- c Detectable thresholds and limits
- d Likelihood of false positive detections
- e Minimum measurable methane emission (e.g.- 0.5 scfh minimum)
- f Maximum measurable methane emission (e.g.- 50 scfh maximum)
- g Distances between device and methane emission (e.g. - 2 feet minimum / 50 feet maximum)
- h Obstructions influence and limitations of measurement (e.g.- concreate, vegetation, structures, other)

Figure 1: *Requested validation specifics to be provided by the technology provider*

Testing and Results

The Project funders stated the most important capabilities of interest were:

1) emission quantification accuracy and precision, and
2) certainty of determining the proper emission quantification category.

The accuracy and precision, illustrated in Figure 2, for each of the technology providers identifies the overall accuracy, defined as average bias (scfh). Throughout this evaluation, accuracy and precision were the two critical values of interest.

Accuracy is defined as the difference between the best estimate quantified emission quantification and the known or actual value (actual from the NYSEARCH control metering equipment and the surface expression quantify). Precision is defined as the variation (standard deviation), or lack of accuracy, for all the quantifications.

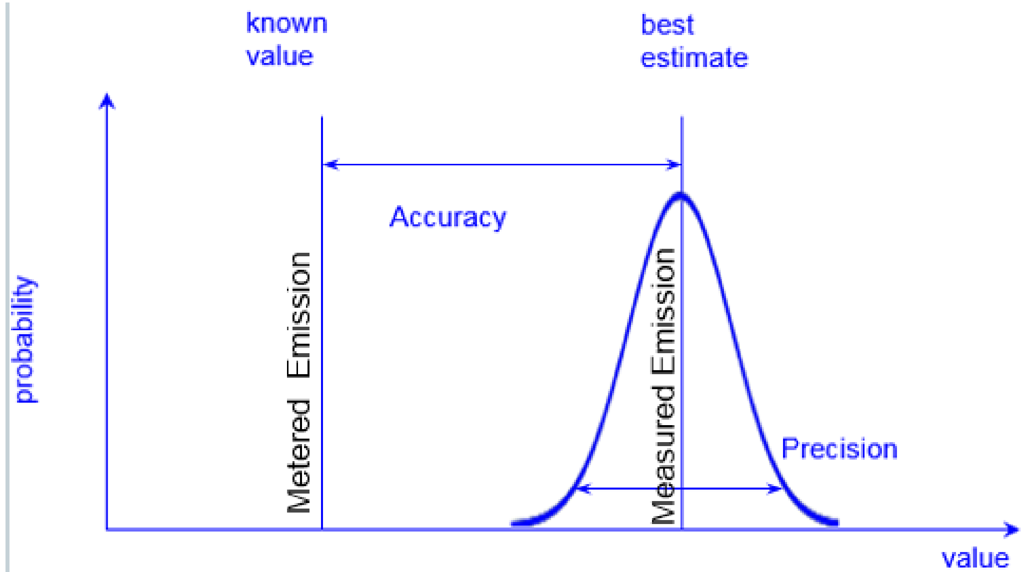


Figure 2: *Accuracy and Precision Relating to Metered emission and Quantified emission*

The Technology Providers were asked to estimate certainty of the technology's capability based on the ability to correctly state the emission quantification category, refer to Table 1.

Emission Quantification Categories	
Category	Leak Rate (scfh)
Very Low	0.2 to 0.5
Low	0.6 to 2.0
Medium	2.1 to 10.0
High	Greater than 10.0

Table 1 – *Emission Quantification Categories*

Three NYSEARCH funding members volunteered to host one (1) technology provider for each field test.

Ahead of the field tests, three (3) technology providers reviewed the Test Plan that was designed to confirm the technology providers' claims to their individual methane emission quantification ability and accuracy. During the testing, the Test Plan was consistently administered to each of the technology providers with enough flexibility to enable application unique features of their specific technology, for instance mobile quantification techniques or stationary techniques.

To ensure test consistency and a more statistically robust data set, three (3) steps were taken to perform calibration at stages throughout the testing. These three (3) steps were:

1) Calibration confirmation of the technology provider instruments prior to field testing.
2) Measurement of additive marker gas release within measurable distance to the native emission source.

3) Surface expression quantification of the same native emission source and additive marker gas release as the technology provider.

Calibration confirmation
At the start of testing, calibration was administered by the NYSEARCH Project Manager releasing a known and metered amount of gas for the technology provider to quantify and confirm. Immediately following the technology provider's measurement, the surface expression crew provided calibration in the same manner.

The metered gas was released through NYSEARCH-calibrated and accurate mass flow controllers, refer to Figure 3:

Figure 3 – *Calibration of technology provider based on accurate methane release*

Additive marker gas release
Field testing consisted of quantifying a number of actual native emissions identified by the host gas company. After the native emission quantification was measured, a specific metered release was provided at the discretion of the NYSEARCH Project Manager within range of the native emission source. It was provided as an additive marker gas volume to be quantified by the technology provider, refer to Figure 4.

Figure 4 – *Performing methane emission quantification at a targeted address, 1) measuring the native methane emission, and, 2) measuring the native methane emission with additive marker gas included.*

Surface expression quantification
An independent surface expression quantification was performed immediately after the technology providers' measurement. Using surface expression methods, the native emission

was measured and quantified. Additionally, the surface expression quantification process was performed on both the native emission and the emission from the additive marker gas, refer to Figure 5.

Figure 5 – *Immediately following the technology providers methane emission quantification, surface expression quantification is performed*

At the completion of each of the technology provider's field testing, the NYSEARCH Project Manager conducted a review with all participants; including the host utility, technology providers, and independent surface expression providers. The group discussed possible improvements to the validation process and lessons learned from the testing. The intent was to capture these possible improvements to circle back and integrate into the validation guidelines, specification and test plan.

Observations of Testing

The collective lessons that were learned and improvements revealed during the field testing were noted:

• Validation expectation information – The technology provider submitted information regarding their equipment and process but the information was too general. They did not provide this requested information until repeatedly prompted again on the first day of testing. Although the request for this information was made two (2) weeks before the testing, it was not received and could not be reviewed. Going forward, receipt and review of the adequacy of the providers' validation information must be a testing prerequisite.

• Additional leak address locations – Some of the leak address locations could not be handled or tested by the technology provider for a number of reasons (i.e. – too small to quantify, wind not in an appropriate direction to carry methane over to instrument). The host gas company provided additional leak addresses not listed on the NYSEARCH Test Log sheet to accommodate this issue. This proved to be a necessity to keep the testing going effectively.

• Surface expression error - Based on discussions early in the project by the NYSEARCH funders, it was concluded that the technology provider would be judged on two metrics that are most relevant to the operators: accuracy and precision. During the field tests performed during this project, the Surface expression quantifications were inconsistent and not as accurate as previously documented during fall 2016 field tests in the parallel project. In this project, Surface expression results showed that calibration of the technology providers' tools by quantification of metered gas releases was essential to determine accuracy of the technology provider's measurements. Based on the Surface expression measurements that inherently contained error, it is important that this equipment be calibrated to within acceptable ranges prior to the testing. The error of the Surface expression measurement has been compensated for in the test results and the statistical analysis of those results.

• The technology provider's remarks and input to Test Plan – Since one technology provider had been involved with this NYSEARCH testing from both this project and the predecessor project, we asked them for their input on the Test Plan and our overall concepts for a standardized validation performance test. They provided basic ideas for consideration but stated the present NYSEARCH Test Plan was robust, rigorous and fair. They stated it was a practical approach to fairly testing new instrumentation that claim to have capability to quantify methane emissions.

• Allow the Technology Provider a defined survey area (more of an open range) – The Technology Provider suggested providing a defined survey area to determine leak indications and perform quantification measurements rather than going to specific addresses of known leaks to demonstrate the technology.

• Preparation of additional addresses – There are many reasons why a leak at a specific address is not able to be used during a test, so it was suggested to have at least three (3) times the number of leak addresses than desired to have a sufficient dataset for validation testing.

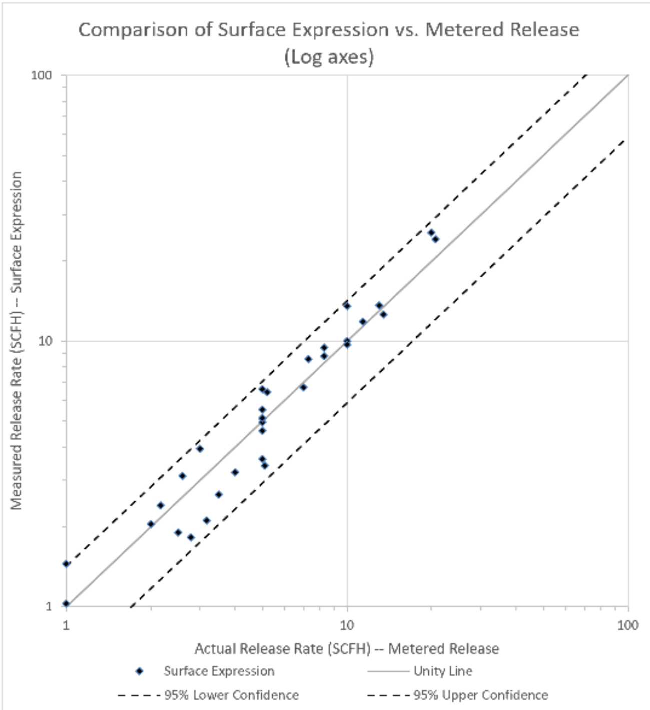
• Timing of testing influences results – A technology provider was concerned with performing the test during the day compared with testing at night. A technology provider had experienced better results when testing at night because of atmospheric conditions more conducive to this type of technology.

Results

Adherence to the test plan proved to deliver consistency throughout each of the technology provider's field tests, data collection process and preparation for a statistical evaluation. An independent statistician performed the evaluation of the test data consistent with the intent of API-1163. The independent statistical evaluation uses a confidence level of 80 percent for a unity (1:1) evaluation. The statistical evaluation began by compiling the three (3) technology providers' data sets collected during the field tests. The compiled field data consistently capture: 1) the NYSEARCH metered release and additive marker gas releases, 2) the technology providers' field (raw) and final quantification measurements, and, 3) the Surface expression quantification measurements, as provided in the Confidential Funders' Report.

Surface Expression Technique

The surface expression technique is used to measure gas rates of emission at the ground surface. It is recognized that the surface expression technique use has inherent error but is assumed to be consistently accurate in performing methane emission quantification.



Graph 1: *Surface expression methane quantification measurements are in close agreement with the metered emission releases, illustrated with 95% confidence factor.*

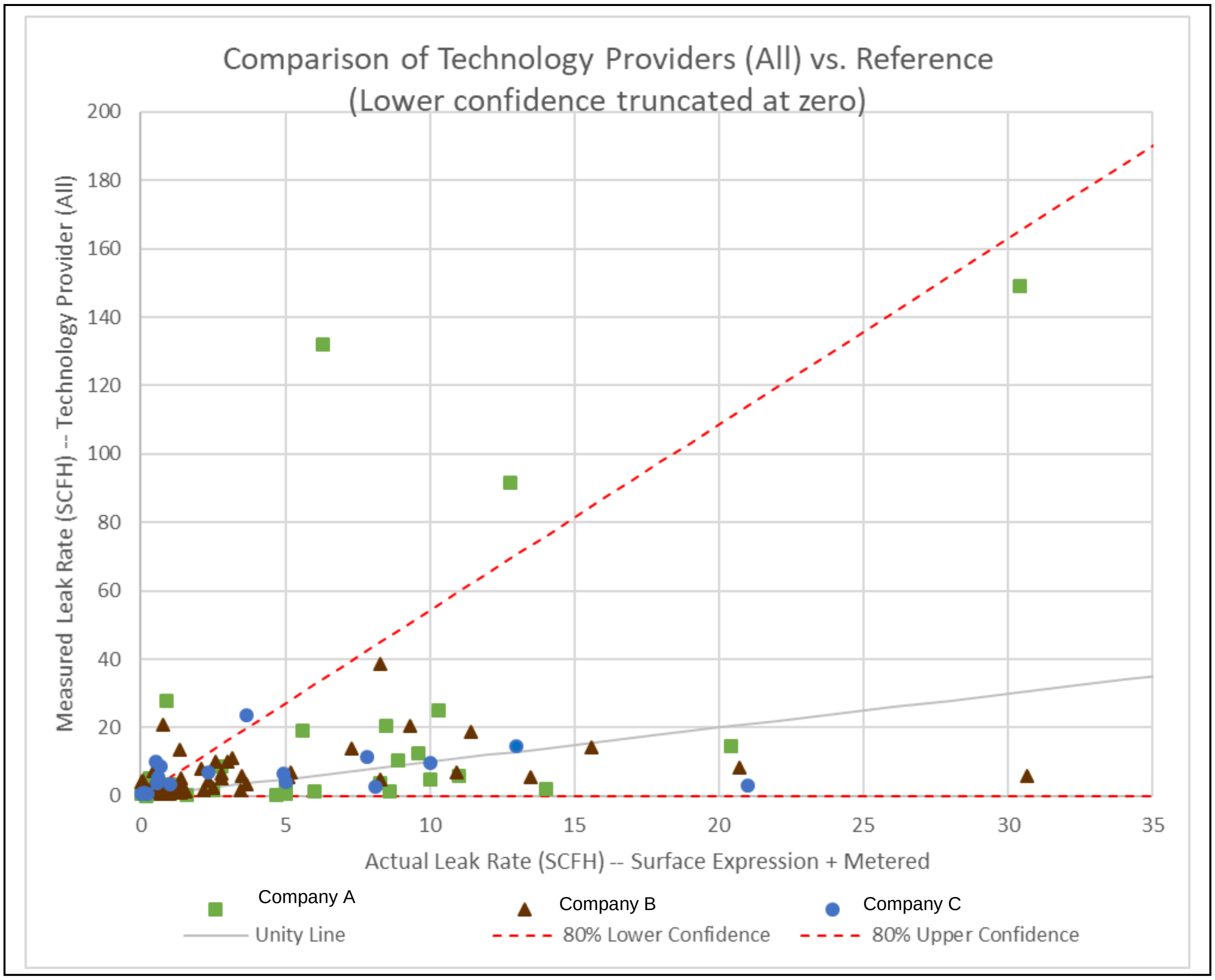
From Graph 1, it is evident that the surface expression measurements are mainly in close agreement with the metered releases (i.e. within the ±41.5 percent of a 95 percent confidence interval or ±27.1 percent of an 80 percent confidence interval). There is only 1 (of 34) value outside of the 95 percent confidence limits. Within the emission quantification categories, refer to Table 3, the specific range of leak detection of interest mainly between 0.2 SCFH through greater than 10 SCFH. Based on the calculations performed, there is 95 percent confidence that surface expression measurements for leaks at 2 SCFH will be within ±0.83 SCFH; at 5 SCFH will be within ±2.08 SCFH; and at 10 SCFH will be within ±14.15 SCFH.

Methane Leak Rate (True)	Calculated Uncertainty	Absolute Uncertainty	Lower 95% Limit	Upper 95% Limit
2 SCFH	41.5 %	± 0.83 SCFH	1.17 SCFH	2.83 SCFH
5 SCFH	41.5 %	± 2.08 SCFH	2.92 SCFH	7.08 SCFH
10 SCFH	41.5 %	± 4.15 SCFH	5.85 SCFH	14.15 SCFH

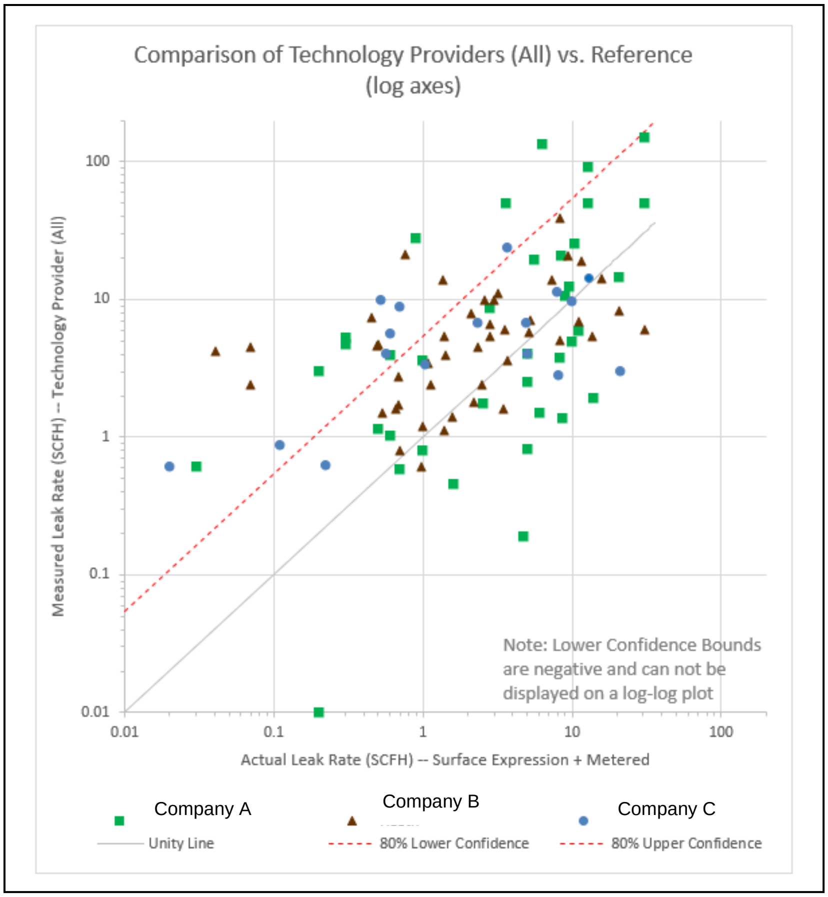
Table 2: *Validation with 95% Confidence Limits for Surface Expression Measurements within Emission Quantification Categories.*

Combined Data for all Tested Technologies

Combining all the technology providers data into one data set reveals the overall results of the tests. The confidence lines illustrated on Graph 2a – 1:1 Unity and Graph 2b – Log-Log provide a rough estimate of the expected range within quantification measurements that could occur for a given actual emission rate.



Graph 2a: *Combined technology providers data, Unity (1:1) Actual methane quantification (scfh) vs Measured quantification (scfh) with 80% confidence limits*



Graph 2b: *Combined technology providers data, Log-Log Actual methane quantification (scfh) vs Measured quantification (scfh) with 80% confidence limits*

The observed standard deviations for the measurement deviations (measured – actual) for the technology providers are summarized in Table 3:

Technology Provider	Number of Observations	Minimum Deviation	Maximum Deviation	Standard Deviation	Observed Accuracy (80% confidence)
Company A	19	-96.0 %	+1993 %	482 %	±617 %
Company B	21	-60.4 %	+840 %	206 %	±264 %
Company C	4	-85.8 %	+10.0 %	43 %	±54 %
All (combined)	44	-96.0 %	1,993 %	346 %	±443 %

Table 3 – *Observed variation within each technology providers results*

The observed standard deviation for the surface expression method was 21%, substantially lower than all the technology provider methods. Repeating these graphs considering 95 percent confidence intervals (i.e. 95% calculated by 1.96 times the standard deviation instead of 80% calculated by 1.28 times for 80 percent confidence) yields wider confidence intervals.

Technology Provider Performance Relative to Stated Accuracy and Confidence

Prior to the field testing the technology providers submitted estimates of the capabilities of their technology, specifically the expected accuracy of the measurements with an associated confidence level, refer to Table 4.

Technology Provider	Stated Accuracy	Stated Certainty
Company A	+/- 2x actual	Not stated
Company B	+/- 5 percent	80 percent
Company C	+/- 60 percent	Not stated

Table 4: *Technology providers validation statements*

The findings of the unity 1:1 graphs for each of the technology providers indicate, refer to Table 4. Based on the stated accuracy from each of the technology provider, comparative measurements within and outside the stated accuracy are determined and provide an observed accuracy based on a desired 80% confidence.

Conclusions

Development and application of the new validation guideline (provided in Attachment A), specification and test plan have verified that any technology provider's innovation to perform methane emission quantification can be evaluated within a controlled process. The statistically-derived methods that were developed in this project and with the new guideline can reveal the actual accuracy, precision and certainty of the technology provider's measurement data.

Basing the validation process of methane emission quantification on the established API-1163 and converting API-1163 to a guideline specific to methane emissions measurements for LDCs proved to be effective and applicable.

The next steps for this validation guideline are to approach a national organization, such as the American Gas Association (AGA) or a standards organization such as the American Society for Testing and Materials (ASTM), or to prepare and publish a validation standard that would be recognized by LDCs and potential technology providers.

Attachment A: Methane Emissions Quantification System Qualification Guidelines

Methane Emissions Quantification System Qualification Guidelines

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U.S. Department of Transportation
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Cooperative Research Project

"Technology Evaluation & Test Program for Quantifying Methane Emissions Related to Non-Hazardous Leaks"

June 28, 2017

Legal Notice

Methane Emissions Quantification
System Qualification Guidelines

1 Introduction

1.1 GENERAL

These guidelines provide requirements for qualification of methane emissions quantification systems used for gas distribution pipeline systems. This document goes beyond leak identification and establishes bases for system qualification of quantifying methane emissions.

The purpose of these guidelines is to provide a qualification process to enable operators to collect valid methane emission flow rates. The flow rates can be used to estimate methane emissions, evaluate changes over time at a particular location to identify changes particularly in Grade 3, monitored, leaks. The flow rates can also be used in a leak management system as input to leak repair, to estimate methane emissions and pipeline replacement prioritization, or other applications.

Detection of leaks is not a part of the processes within these guidelines as detection of methane emission is typically conducted in a separate survey. These guidelines address quantification.

These guidelines assure the following:

g. Users make clear, uniform, and verifiable statements describing methane emissions quantification system performance.
h. Users select a methane emissions quantification system suitable for the conditions under which the survey will be conducted. This includes, but is not limited to, the pipeline operating conditions, operating environment, wind speed, temperature, humidity, area type (urban, suburban, rural, industrial), time of day and atmospheric stability among others.
i. The methane emissions quantification system operates properly under the conditions specified.
j. Survey procedures are followed, before, during and after the survey.
k. Methane emissions indications are described using a common nomenclature, as described in these guidelines.
l. The reported data and results provide the expected accuracy and quality in a consistent format.

Users of these guidelines should be aware that further or differing requirements might be needed for some applications. Nothing in these guidelines is intended to inhibit the use of survey systems or engineering solutions that are not explicitly covered by the guidelines. This may be particularly applicable where there is innovative developing technology. Where an alternative is offered, the guidelines may be used, provided any and all variations from the guidelines are identified and documented.

1.2 GUIDING PRINCIPLES

These guidelines are an umbrella document covering all aspects of methane emissions quantification. The guidelines are not technology specific. They are intended to accommodate present and future technologies.

The guidelines are performance-based and provide requirements for qualification processes; i.e., “what to do”. They do not, however, define “how” to meet those requirements.

The guidelines define the documentation of processes for methane emissions quantification. They ensure traceability and reproducibility.

An objective of these guidelines is to foster continuous improvement in the quality and accuracy of measurement and foster the development of new technologies.

Wherever possible, these guidelines utilize existing terms and definitions from other applicable work and research. Section 4 provides definitions of terms.

The use of a methane emissions quantification system requires close cooperation and interaction between the provider of the service (technology provider) and the user of the service (operator)[1]. The guidelines provide requirements that will enable technology providers and operators to clearly define the areas of cooperation required and thus ensure the satisfactory outcome of the methane emissions quantification process. While technology providers have the responsibility to identify the system capabilities, their proper use, and application, operators bear the ultimate responsibility to:

a. Identify the basis for methane emissions quantification; volumetric quantification, etc. A range is an acceptable alternative.
b. Choose the proper methane emissions quantification technology.
c. Maintain operating conditions within performance specification limits.
d. Confirm survey results.

Following the guidelines provides a consistent means of identifying, quantifying, and verifying results from a system such that acceptable methane emissions rate results are obtained.

These guidelines provide requirements and processes for the qualification of methane emissions quantification systems, including the sensor technology, their algorithms and software, as well as the personnel to operate the systems and analyze the results.

2 Scope

These guidelines cover the qualification of methane emissions quantification systems for gas distribution pipelines. These guidelines apply to both existing and developing technologies. They are an umbrella document that provides performance-based requirements for methane emissions quantification systems, including procedures, personnel, equipment, and associated software.

3 References

[To be compiled as document is revised].

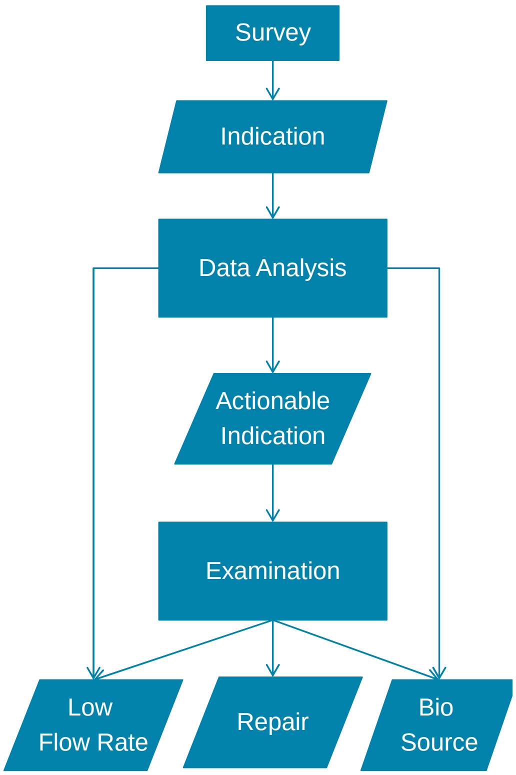
4 Terms and Definitions

[To be compiled as document is revised].

4.X actionable indication: Indications that may exceed predefined limits based on the data analysis (see Figure 1).

[1] The term "user" is also used within this document where either an operator or technology provider can perform the task or activity.

4.X examination: A direct physical measurement of methane emissions rate at an indication by a person, which may include the using specified examination techniques.



Redrafting figure to change "low flow rate" to "no leak found"
Figure 1 – Methane emissions Quantification Terminology

4.X indication: A peak of methane flow rate [concentration] as detected by a methane emissions quantification system. (See Figure 1).

4.X operator: A person or organization that owns and/or operates pipeline facilities.

4.X qualification (personnel): The process of demonstrating skills and knowledge, along with documented training and experience required for personnel to properly perform the duties of a specific job.

4.X qualification (system): The process of validating, through tests and analysis, the performance specifications of a methane emissions quantification system meeting predefined objectives.

4.X technology provider: An organization providing methane emission quantification technology, services or both.

4.X user: Persons, including an operator or technology provider applying these guidelines.

5 Systems Qualification Process

5.1 GENERAL

Section 5 describes the processes and personnel qualification requirements for the activities involved in quantifying methane emissions. The requirements are grouped according to the section of these guidelines that defines or governs each activity.

A description is given for each activity, and an activity sequence is illustrated in Figure 2—Methane emissions Quantification Systems Process Flow Diagram.

The process of successfully performing methane quantification begins with the operator defining survey goals, objectives and the pipeline system characteristics to technology providers. Based on this information, the technology provider recommends specific methane emissions quantification systems and procedures to meet the operator's requirements. Section 6 of these guidelines provides the details of the process required to select an appropriate methane emissions quantification system or systems. Section 7 describes the processes that users shall use to determine the performance specifications of a family of systems that have identical essential variables. These performance specifications define what types of leaks can be quantified as well as the associated survey precision and accuracy of measurements. Section 8 describes the requirements for preparing systems prior to physically performing surveys. It also describes the activities that shall be performed by the user during the survey. Section 9 describes processes that shall be used for verifying whether or not the system meets the performance specifications. It also describes what shall be done if the performance specifications are not met. Section 10 provides reporting requirements for the results of the surveys performed. These guidelines provide the information and processes to enable operators and technology providers to perform methane emissions quantification with greater consistency and accuracy.

5.2 PERSONNEL QUALIFICATION

The personnel operating the methane emission quantification systems and the personnel taking, reducing, analyzing and reporting the resultant data shall be qualified.

5.3 OPERATOR & TECHNOLOGY PROVIDER RESPONSIBILITIES

Representatives from the pipeline operator and the technology providers should discuss and agree upon the goals and objectives of methane emissions quantification and match relevant facts known about the pipeline and expected anomalies with the capabilities and performance of the methane emissions quantification system.

Pipeline operators shall provide relevant parameters and characteristics of the pipeline section to be surveyed. Operators should also provide access to piping and appurtenances to be surveyed, including permission from land and structure owners.

The roles of the operator and technology provider should be defined for all aspects of the work from implementation to delivery of the final report. The various stages of reporting and payment schedules associated with milestones should be established. Factors such as the implications of reruns, scheduling changes, and service interruptions should be addressed.

6 Methane Emissions Management System Selection

6.1 GENERAL

This section covers the selection of a methane emissions quantification system. When selecting a system, both the methane emissions quantification system capabilities and the pipeline operational and physical characteristics, as well as the environment in which the pipeline is situated shall be considered.

The process of selecting a methane emissions quantification system requires:

a. Defining the goals, objectives and required accuracies of the survey;
b. Considering the physical and operational characteristics and constraints of the pipeline, including mains, services and appurtenances; as well as the area characteristics and weather conditions for the survey; and
c. Selecting an appropriate methane emissions quantification system based on the requirements of the survey and performances capabilities of the methane emissions quantification system.

6.2 SURVEY GOALS AND OBJECTIVES

The goals and objectives of a methane emissions quantification system shall be defined. Goals and objectives shall include, but are not limited to, characteristics of leak indications to be detected, identified, and sized and the required accuracies.

6.3 PHYSICAL, OPERATIONAL AND ENVIRONMENTAL CHARACTERISTICS AND CONSTRAINTS

The physical, operational and environment characteristics and constraints shall be documented. The operator shall provide information on physical characteristics and constraints of the pipeline system, as well as its environment and its operation conditions to the technology provider, which is typically done through a pipeline system questionnaire.

Characteristics of the pipeline that shall be provided for assessing the compatibility of the methane emissions quantification system with the survey goals and objectives shall be documented. They include:

1. Physical properties of the pipeline section, such as length, diameter, joining type (welded steel, plastic, cast iron, mechanical couplings, etc., valves, known physical restrictions, …
2. The specific pieces of equipment that may be leaking such as meter set assemblies, regulation stations, etc.
3. Operational characteristics and constraints such as pressure.
4. Constraints posed by the environment in which the pipeline is located such as physical barriers such as pavement or structures and vegetation
5. The type of areas to be surveyed: urban, suburban, rural, industrial
6. The expected weather conditions: dominant wind directions, atmosphere stability, precipitations, temperature, solar radiation, etc.

The user shall define the constraints under which the methane emissions survey and quantification equipment will operate, such as:

a. Restrictions on temperature or pressure.
b. Maximum wind speed
c. Maximum humidity
d. Detection limits of methane
e. Cloud cover
f. Weather conditions
g. Obstructions such as pavement or vegetation

6.4 SELECTION OF A METHANE EMISSIONS QUANTIFICATION SYSTEM

Typically, the technology provider will recommend a methane emissions quantification system based on the operator's goals and objectives. Before making a recommendation, the technology provider shall evaluate and make available to the operator:

a. Expected performance of the methane emissions quantification system with regard to accuracy, and coverage capabilities for the pipeline to be surveyed.
b. Physical characteristics of the methane emissions survey and quantification equipment, including size, weight, power requirements and environmental limitations.
c. Methane emissions survey sensor type(s) to be used.
d. Acceptable survey conditions and procedures.
e. Sampling frequency.
f. Description of algorithm and data analyses to be used.
g. Reporting requirements.
h. Operational reliability of the survey equipment (history, operational success, etc.) – possible constraints on survey duration.
i. Additional operational constraints.

The operator shall select the appropriate methane emissions quantification systems that meet the goals and objectives established in 6.2. The operator may select multiple systems that, when used in combination, meet the goals and objectives of the survey.

6.5 PERFORMANCE SPECIFICATION

Prior to selecting a methane emissions quantification system, the technology provider shall provide the operator with a written performance specification for the survey. Based on the technology providers' review of the pipeline to be surveyed and existing conditions, (see 6.4), the technology provider shall state whether the chosen methane emissions quantification system can meet the performance specification for that pipeline under the existing operating and environmental conditions. Operators selecting the systems themselves shall state whether the chosen methane emissions quantification system can meet the performance specification for that pipeline and under the existing operating environmental conditions. Requirements for a performance specification are provided in Section 7.

7 Qualification of Performance Specifications

7.1 GENERAL

This section covers requirements for the qualification of performance specifications for a methane emissions quantification system. The requirements of this section shall be met prior to a survey.

The requirements in this section are written so that all concerned have a clear understanding of the methane emissions quantification system's capabilities as defined in a performance specification for a methane emissions quantification survey. Within this section, the party that is typically responsible for meeting a requirement may be identified. Nothing in this section should preclude technology providers and operators from agreeing that one party is responsible for activities or requirements that are typically performed by the other.

7.2 PERFORMANCE SPECIFICATIONS

Performance specifications shall define, through the use of statistically valid methods, the ability of the methane emissions quantification system when conducted on a specific pipeline to locate, detect, identify, and quantify methane emissions.

The performance specification shall define the capabilities of the methane emissions quantification system to locate, detect, identify, and quantify methane emissions and characteristics in terms of the following parameters:

a. The type of leaks or methane emission sources covered by the performance specification.
b. Detection thresholds,
c. Likelihood false positive detection
d. Expected accuracies and precision,
e. Localization accuracies.
f. Linear (distance) and orientation measurement accuracies.
g. Limitations.

These guidelines recognize that the capabilities listed above are interrelated. To provide uniformity and minimum requirements, these guidelines require individual value or values for each parameter be given and requires that all significant interactions be defined and addressed under "Limitations."

The performance specification shall state how the system will measure leak locations and how reference points will be utilized/required.

7.2.1 Detection Thresholds

The performance specification shall clearly state one or more detection thresholds that are statistically derived, for each type of indication or characteristic covered by the specification.

In all cases, both detection threshold(s) must be given. The detection threshold(s) must be statistically valid for the distribution of indication quantities reasonably expected for the survey to be conducted.

7.2.2 Sizing Accuracy

The performance specification shall clearly state the sizing accuracies for each type and range of indications covered by the Specification. A sizing accuracy refers to how closely the reported methane emissions flow rates agree with the true flow rates.

Sizing or characterization accuracies should include a tolerance (e.g., ± 5% or 10% on flow rate), a certainty (e.g., 80% or 90% of the time), and the confidence level (e.g.,95%).

7.2.3 Limitations

Physical and operational factors or conditions that limit the detection thresholds, and quantification accuracy shall be identified in the performance specification. Examples of physical and operational factors that can limit detection thresholds and quantification accuracy include:

a. Wind speed
b. Humidity
c. Solar radiation
d. Cloud cover
e. Weather conditions such as atmospheric stability, precipitation, etc.
f. Obstructions such as vegetation, pavement or structures
g. Type of areas: urban, suburban, rural, industrial

The following table is an example of how limitations may be reported. The change in detection threshold and quantification accuracy that results from operation outside the range of acceptable conditions should be provided in the performance specification. Alternatively, no detection threshold or quantification accuracy should be implied outside the range of acceptable conditions. Results for a survey (or portion of an survey) that are outside the range of acceptable conditions should be considered advisory.

7.3 QUALIFICATION REQUIREMENTS

Each performance specification shall be qualified by the user conforming with the requirements below.. The methodology used to qualify a performance specification shall be based on sound engineering practices, be statistically valid, and include a definition of essential variables (see 7.3.1) for the methane emissions quantification system.

The methodology used to qualify the performance specification shall be based on at least one of the following methods:

a. Verified historical data,
b. Large-scale tests from real or simulated leaks, and/or
c. Small-scale tests, modeling, and/or analyses.

7.3.1 Essential Variables

The performance specification shall define and document the essential variables for the methane emissions quantification system being qualified. Essential variables are characteristics or analysis steps that are essential for achieving desired results. Essential variables may include, but are not limited to:

1. Constraints on operational characteristics as defined in 6.3 including weather conditions, type of the survey area, vegetation.
2. Survey equipment design and physical characteristics, such as:
    - Survey parameters (e.g., sensor type)
    - Detection limits
    - Analysis algorithms (e.g., steps used in preprocessing, classification and characterization of signals).
3. Operation procedures defining the manner the technology is used, and
4. Goal of the quantification expressed in accuracy, precision and confidence level.

Changes to the essential variables of a system shall require a new performance specification and qualification.

7.3.2 Data and Analyses Requirements

The data and analyses used to qualify a performance specification shall cover the full range of each essential variable defined for the specification. Data and analyses that are not within the range of essential variables defined for a performance specification shall not be used to qualify the specification.

Data and analyses used to qualify a performance specification shall be selected to generate a representative distribution of indications, components, and characteristics reasonably expected for the survey to be conducted.

The analyses used to define the statistical quantities, such as detection thresholds and quantification accuracies, shall be in accordance with standard statistical analysis methods, and the confidence levels given shall be consistent with the amount of data used in the analyses. Data and analyses used to qualify a performance specification shall be documented and maintained. For indications, the data shall include values of the essential variables during the survey, survey conditions (e.g., pressure, velocity), reported indication characteristics, and verified indication characteristics.

The qualification of a performance specification shall be considered valid for the range of essential variables defined for the Specification. If data indicates the methane emissions quantification system does not meet the performance specification for any values or combinations of essential variables, the essential variables must be redefined, or the performance specification must be restated.

7.3.3 Validation Based on Historic Data

Verification measurements from previous use of a methane emissions quantification system may be used to qualify performance characteristics that have been physically measured after indications have been validated.

7.3.4 Validation Based on Full-scale Tests

Data from full-scale verification tests on real or known indications may be used for qualification provided the data is correlated or calibrated to field data. An example of a full-scale test used for qualification is a high-volume sampler. The methods by which the data are correlated or calibrated shall be documented.

7.3.5 Validation Based on Small-scale Tests, Modeling, and Analyses

Data from small-scale tests, modeling, and/or analyses may be used to demonstrate that the performance of a system component, such as a type of sensor, is consistent with data used for qualifying performance specifications. Data from small-scale tests, modeling, and/or analyses must be correlated or calibrated with historical field data or full-scale test data. The methods by which the data is correlated or calibrated shall be documented. Data from small-scale tests, modeling, and/or analyses that are consistent with historical data and full-scale data may be used to qualify a change in system components and to extend the range of essential variables.

7.4 DOCUMENTATION AND OTHER REQUIREMENTS

The methodology and data used to qualify a performance specification shall be fully documented and available for review.

7.4.1 Detection Thresholds

Detection thresholds shall be based on historic or full-scale test data. If a statistically significant amount of historic or full-scale test data is not available, the detection thresholds shall be estimated using prior experience with other survey systems, provided the estimates are clearly identified as such in the performance specification.

7.4.2 Indication Accuracies

Accuracies shall be based on verification measurements from prior surveys or full-scale tests. If a statistically significant amount of historic or full-scale test data is not available, methane emission flow rate accuracy may be estimated using statistically homogeneous small-scale test data, modeling results, analyses, and/or prior experience with other survey systems, provided the estimates are clearly identified as such in the performance specification.

Sizing accuracies may be determined by comparing reported flow rates with verification measurements. Sizing accuracies should be determined using a linear or nonlinear regression analysis (e.g., a least-squares best fit) of reported and measured dimensions or characteristics with the reported ILI characteristics plotted as the independent variable (x axis) and field verified

characteristics plotted as the dependent variable (y axis) unless the alternative is known to be statistically valid.
Tolerances should be stated as the difference between a one-to-one relationship of the reported dimensions and verification measurements. Tolerances may be stated as an absolute value (e.g., ± 1 scf/h) or a relative value (e.g., ± 10% of the reported flow rate), a logarithm interval (e.g. within one order of magnitude) or a system of bins (e.g. <1scf/h, <10scf/h, >10scf/h)

- Certainties should be calculated based on the frequency with which the reported measurement is within tolerance. Certainties may include the frequency with which out-of-tolerance errors are over-predicted or under-predicted.
- The confidence level should be calculated as the statistical confidence level that applies to the tolerance or certainty.

Sources of differences between reported and measured methane emission flow rates should be identified, documented, and accounted for in the statistical analyses used to determine the tolerances, certainties, and confidence levels where practical.
Sources of errors include those due to the methane emissions measurement system, as well as those due to hands-on methane emission flow rate measurements made of a given characteristic. The tolerances and certainties required in these guidelines refer to errors due to the methane emissions quantification system only. These errors include, but are not limited to, systematic errors (errors that result from known, but unaccounted for causes, such as sources of variability), random errors (lack of repeatability and other errors with no identified cause), and indication-specific errors (error in detecting indications), such as local wind conditions.

7.4.3 Review and Revision Requirements

The qualification methodology shall be reviewed on an annual basis to ensure its continued validity. If the methodology is found to be no longer valid, any performance specifications that were validated by the methodology must be revalidated by an acceptable methodology. All reported significant errors in detection and identification shall be investigated. Significant errors are those that are outside the performance specification.

The root cause(s) of all reported significant errors shall be determined and used to modify, as necessary, the analysis procedures and future performance specifications.

8 System Operational Validation

8.1 GENERAL

This section defines requirements for validating that a methane emissions management system is prepared and conducted in the manner defined as necessary to achieve the performance specifications as outlined in Section 7. Four sets of requirements are given:

1. Project requirements.
2. Pre-survey requirements.
3. Survey requirements.
4. Post-survey requirements.

All methane emissions quantification project requirements, pre-survey, survey, and post-survey requirements and procedures shall be documented.

8.2 PROJECT REQUIREMENTS

Project requirements assure that the methane emissions quantification system and operating conditions are consistent with those required to achieve the performance specifications defined in Section 7.

Prior to the actual survey, the pipeline geometry and planned pipeline operating conditions shall be reviewed to ensure they are consistent with the information previously provided.

The user shall confirm that the methane emissions quantification system to be used for the survey is consistent with that used to define the required performance specifications.

The user shall verify that a qualified crew to operate the methane emissions quantification equipment is available to support the survey system.

8.3 PRE-SURVEY REQUIREMENTS

Pre-survey requirements are defined as the activities that are to be completed before beginning the survey.

8.3.1 Function Tests

The user shall define and document necessary steps to prepare and validate proper operation of the survey equipment prior to a survey. The steps shall include a function test to ensure the system is operating properly. Pre-survey function tests may include, but are not limited to:

a. Confirmation that an adequate power supply is available and operational.
b. Confirmation that all sensors, data storage, and other mechanical systems are operating properly.
c. Confirmation that adequate data storage is available.
d. Confirmation that all components of the methane emissions survey equipment are properly calibration and initialized.

Records of the pre-survey function tests should be made available to the operator, if requested.

8.3.2 Mechanical Checks

Prior to a survey, the methane emissions survey shall be checked visually to ensure that it is mechanically sound. The electronics shall be checked to make sure that they are properly functional as per manufacturers specifications.

8.4 SURVEY REQUIREMENTS

Survey requirements are intended to ensure a successful methane emissions quantification survey.

The pipeline operating conditions shall be monitored prior to the start of the survey, and while the methane emissions quantification survey is being conducted. Efforts shall be taken to ensure the operating conditions are consistent with those required to meet the performance specification. Variations from the required operating conditions shall be identified and documented.

8.5 POST-SURVEY REQUIREMENTS

Post-survey requirements cover activities that are to be completed, if required, on site after a survey has been completed. These activities are intended to validate that the equipment has operated correctly during the survey.

8.5.1 Function Tests
The user shall define and document steps necessary to validate the proper operation of the survey equipment after a survey inclusive of manufacturers specifications. These steps shall include a function test to ensure the system has operated properly during the survey. Tested functioning properly, calibrated properly,

Deviations from these function checks shall be noted, and their effects shall be included in the survey report.

8.5.2 Data Checks
The user shall define and document the steps necessary to check the quality and quantity of the data collected during the survey. These steps shall include but are not limited to:

a. Confirmation that a complete set of data was collected during the survey.
b. Confirmation that the data meets basic quality requirements.

Data checks are typically based on direct measurement data, data completeness, and data quality. Deviations shall be noted and their effects communicated to the operator and included in the report.

8.5.2.1 Direct Measurement Data
Direct measurement data may include critical parameters to making the calculation including but not limited to barometric pressure, wind speed, operating pressure, and technology-specific data. Direct measurement data is typically used to make general judgments about the basic operation of equipment during a survey. Such data shall be utilized as one of the post-survey data checks.

8.5.2.2 Data Completeness
The amount of data collected allows an initial assessment of data completeness. The amount of data collected is typically accessible after processing the recorded data. Completeness of data shall be checked after the initial processing of the data. This will be considered one of the data checks.

8.5.2.3 Data Quality
Data quality can be demonstrated using a variety of data integrity checks, such as verification that the data taken was within the operating ranges of the sensors used. Such data checks shall be included in the data checking process. Post survey data quality checks do not cover the interpretation of the obtained data.

9 System Results Verification

9.1 INTRODUCTION
This section describes the methods that shall be applied to verify that the reported survey results meet or are within the performance specification for the pipeline being inspected. Requirements for establishing a performance specification are given in Section 7.

Verification activities may require agreement between the pipeline operator and the technology provider as to the extent of verification work, such as verification surveys, and who will perform or be assigned to specific activities. Such assignments are not within the scope of these guidelines.

9.2 EVALUATION OF SYSTEM RESULTS

The process shown in Figure 4 shall be used to verify that the reported survey results have been met and are consistent with the performance specification for the pipeline being surveyed. The process shall include:

a. A process validation, and
b. A comparison with historic methane emissions quantification (cfh) data (if available) for the pipeline being surveyed, and/or
c. A comparison with historic data or large-scale test data from the system being used.
Based on these steps, verification measurements may be required. Not all surveys require verification measurements, as discussed later in this section.

The evaluation of system results should include

Pre-calibration and post-calibration results

Comparison to some other complimentary quantification system, such as:

- Mass flow controller reading
- Surface expression measurement
- Others

9.2.1 Process Validation

A process validation shall be conducted for all surveys. The process validation shall include (1) a confirmation of the data analysis processes, (2) a comparison of recorded data to previous data or that used to establish the performance specification, and (3) a comparison of reported locations and types
of pipeline components with the actual locations and types of components.

The process validation may include, but is not limited to:

a. A review of the pipeline route and operating conditions during the survey relative to those planned for the survey and the essential variables of the methane emissions quantification system.
b. A review of the set-up and operation of the survey equipment relative to that planned for the survey and the essential variables of the methane emissions quantification system.
c. A review of the processes used for:
  1. Bulk data handling, conditioning, and filtering.
  2. Automated analyses (categorization) (if used).
  3. Manual or other adjustments of data or categorization.
  4. Identification, evaluation, and integration of supplemental data relative to the processes required for compliance with the performance specification.

d. A review of any additional requirements for the survey, including any standards or codes applicable to the survey.
e. A review of the reported indication types and characteristics relative to the data used to establish the performance specification.

Appendix B gives an example of a quality assurance program used for process validation. Inconsistencies uncovered during the process validation shall be evaluated and resolved. If the inconsistencies cannot be resolved, the survey results are not verified. If the survey results are not verified, the performance specification may be restated or all or parts of the survey data may be rejected.

9.2.2 Comparison with Historical Information on Line/ Location Being Surveyed

After process validation, the reported survey results shall be compared to prior historical data on the pipeline being surveyed if such data is available. Types of prior historical data that can be used for comparisons may include, but are not limited to:

a. Prior methane emissions quantification results.

b. Results from prior field tests and measurements of indications similar to those covered by the survey.

c. Other data and analyses, when supported by sound engineering practices.

If prior methane emissions quantification data is available for the specific pipeline, the reported results can be considered verified if:

a. Differences in the reported locations, and characteristics of the leaks are within the tolerances, certainties and confidence levels stated in the performance specification, or

b. Differences in the reported locations, and characteristics are outside the tolerances stated in the performance specification but the differences can be explained using sound engineering practices (e.g., increase in methane emissions rate, advancements in system technology).

The reported results can also be verified by comparisons with results from prior field tests and measurements, provided,

1) the data from such field test and measurements represents the range of reported indication types and characteristics and

2) any differences are within the tolerances, certainties and confidence levels stated in the performance specification or can be explained using sound engineering practices.

If the reported results are not verified using comparisons with prior historic data, additional comparisons with other survey data (as defined below) or verification measurements are recommended. Alternatively, the performance specification can be restated or all or parts of the survey data can be rejected.

9.2.3 Comparisons with Other Data from the Same Survey System

When historic information on the line being surveyed is not available or the reported results are not verified by the comparisons with historic information, the reported results may be verified through comparisons with prior data from the survey system being used on other lines supplemented with data from large-scale tests as warranted. The reported results can be considered verified by comparisons with the results from prior validated surveys on other lines, provided (1) the prior data represents the range of reported indication types and characteristics, and (2) the prior essential variables match those used in the current survey.

If the reported survey results are not consistent with prior data, verification measurements are recommended as discussed below. Alternatively, the performance specification can be restated or all or parts of the survey data are not validated.

9.2.4 Verification Measurements

Verification measurements are a common method for evaluating methane emissions quantification results. Appendices C and D provide examples of verification measurement procedures [Note: may not need these]. When verification tests are performed, information from the measurements shall be given to the user to confirm and continuously refine the data analysis processes.

The information to be collected from the verification measurements and given to the technology provider shall be agreed upon by both the operator and the technology provider and shall include the measurement techniques used and their accuracies.
Information to be provided by the technology provider to the operator should include the measurement threshold, reporting threshold, and interaction criteria, if any. Appendix D lists types of information that should be provided to the technology provider.

Any discrepancies between the reported survey results and verification measurements that are outside of performance specifications shall be documented. The source of the discrepancies should be identified through discussions between the technology provider and the operator and through analyses of essential variables, the verification process, and data analysis process.

Based on the source and extent of the identified and analyzed discrepancies, one of the following courses of action may be taken:

a. The survey data may be reanalyzed taking into account the detailed correlations between indication characteristics and the survey data.
b. All or part of the survey results may be invalidated.
c. The performance specification may be revised for all or part of the survey results.

9.2.5 Other Methods
Other methods of evaluating reported survey results may be used if they are based on sound engineering practices and are statistically valid.

9.3 USING VERIFICATION MEASUREMENTS
When verification measurements are used, a comparison shall be made between reported and measured indication characteristics to verify the accuracy of the reported survey results and to demonstrate that the reported results are consistent with the performance specification. The comparison analysis shall be statistically valid and based on sound engineering practice. Listed below are examples of statistical analysis methods that may be used for verifications.

1. Comparison of Verification Measurements with the Performance Specification. This is the simplest method of assessing survey results. Reported results are considered verified if the verification measurements meet the performance specification. If the reported results do not meet the performance specifications, further analysis shall be performed. The accuracy of the verification measurements must be considered in the comparison. (See Appendix D for an example.)
2. Comparison of a Population of Verification Measurements with Distributions. This method assesses whether the verification measurements are statistically consistent with the performance specification by determining the probability of meeting the performance specification through the use of distribution functions such as binomial or normal distribution functions. It becomes more accurate as the number of verification measurements increases. This method is attractive when there is a high confidence level on the tolerance and certainty given in the performance specification. If the test population can be considered representative and if an appropriate number of measurements are consistent with the performance specification, the results are considered verified. (See Appendix D for an example.)
3. Confidence Intervals. This method compares the range of certainties indicated by the verification measurements to the certainty level in the performance specification. Confidence intervals provide an estimate of the precision with which the true certainty is

known. This method is attractive when there is a low confidence level on the tolerance and certainty levels given in the performance specification. If the confidence interval reasonably bounds the stated certainty, the results are considered verified.
4. Other Methods of Assessing Verification Results. Other methods include combinations and modifications of the methods listed above.
Separate verification comparisons based on different types of metal loss geometries are permissible.

9.4 CONCLUSIONS ON USING VERIFICATION RESULTS

The methodologies available to assess verification results cannot, in general, guarantee the performance specification has been met unless every reported indication is verified. This is the case in all verifications in all industries. As a consequence, heavy emphasis must be placed on historic data, especially the data used to establish the performance specification.
(See Section 7 for details on establishing performance specifications.)

As the size of the databases used to establish performance specifications increases, the specifications themselves should become more accurate. Consequently, verification activities tend to concentrate on identifying situations where there are clear problems. For surveys under unusual conditions or conditions not before seen, it may be beneficial to use a larger number of comparisons.

10 Reporting Requirements

This section describes requirements for reporting methane emissions quantification system results after the analysis of data has been completed. Reports shall include indication or identification for which the performance specification has been qualified (Section 7) and also the results verified (Section 9). For consistency, the definitions provided in Section 4 should be utilized in all reports for clarity and comparisons from one survey to another. The following reporting requirements are provided to clearly tie the methane emissions quantification system qualifications to methane emissions quantification results.

10.1 METHANE EMISSION QUANTIFICATION SYSTEM PERFORMANCE SPECIFICATIONS

Performance specifications shall be included in each report.

10.1.1 Performance Specification

10.1.1.1 The performance specification to be reported shall include, as applicable, the capabilities of the methane emissions quantification system to locate, detect, identify, and quantify indications and characteristics (see 7.2):
Additional information may be provided about leaks that are not included in the performance specification, based on past experience, but these shall be qualified as “experience based” observations.

10.1.1.2 Also included are the essential variables (see 7.3.1) for the methane emissions quantification survey:

- a. Constraints on operational characteristics.
- b. Survey equipment design and physical characteristics, such as:
    - 1. Survey parameters (e.g., sensor types).
- c. Analysis algorithms (e.g., steps used in preprocessing,, and classification and characterization of signals).

10.1.2 Qualification Method

A description of the method used to qualify the performance specification shall be included in the report (see 7.4).

The description shall identify the source of data or analyses used for qualification:

a. Verified historical data,
b. Large-scale tests from real as well as non-pipeline emissions (e.g.-sewer gas), and/or
c. Small-scale tests, modeling, and/or analyses.

The description should also summarize the statistical techniques used to determine the performance specification.

10.1.3 Equipment Specifications

The report shall include any other parameters for which the methane emissions quantification system is qualified.

10.2 REPORT CONTENTS

10.2.1 Summary

The report should include an executive summary that includes:

a. Date of survey.
b. Methane emissions quantification data quality.
Any quality issues with the methane emissions quantification data, such a sensor malfunction, should be stated within the summary and described in the report.
c. Summary comments on the technology supplier initial validation information compliance.
d. Data analysis parameters.

Clear communication of data analysis parameters should be included. At a minimum, measurement threshold, reporting threshold, and interaction criteria should be included. (See Appendix D.)

The executive summary may also contain observations that, while exceeding the reporting requirements based on the system's performance specification, could be of interest to the operator.

10.2.2 Survey Results

The following information shall be provided for each indication reported in the report of the methane emissions quantification system results where appropriate or applicable:

a. Location (GPS coordinates, distance from curb or center of street or other marker).
b. Indication quantity or classification

10.3 REPORTING FORMATS

The following tables and plots should be included in the final report. These options are recommended to aid in the integration of survey results with pipeline integrity assessment programs.

10.3.1 A table of all indications should be included in the final report.

10.3.2 Summary and statistical data should be included.

11 Quality Management System

11.1 SYSTEM SCOPE

This section establishes the quality system standards that are required of organizations that perform the services used for methane emissions quantification systems, and methane emissions surveys utilizing those systems. An effective quality management system includes processes that assure consistent products and services are being delivered, that those processes are properly controlled to prevent delivery of unsatisfactory services, and that adequate measures are in place to ensure that the products and services provided continue to meet the needs of a pipeline operator.

11.1.1 Limitations and Inclusions

The quality management system shall apply to all activities involved in the design, testing, field operations, data analysis, and support services provided that specifically relate to the use of an methane emissions quantification as covered in the scope of this document.

Organizations that have an existing quality management system that meets or exceeds the requirements of this section can incorporate these requirements within their existing system. For those organizations without a quality management system, this section provides a basis for establishing a quality system to meet specific methane emissions quantification system needs.

11.1.2 Quality Management System Perspectives

The quality management system shall take into consideration regulatory, safety, and environmental requirements.

11.1.3 Requirements Review

The quality system shall include processes that review the specified requirements of an survey project, prior to and including the formal agreement between the pipeline operator and the organizations providing services within the scope of this document. As a minimum, this review shall, where applicable, include:

a. Identify which parties involved will be responsible for performing the specific tasks required for successful completion of the methane emissions quantification project.
b. A review of procedures to determine if they were followed during the entire survey process.
c. A review to ensure the pipeline operator's survey needs can be met by the organization providing the services.
d. A review of the pipeline data provided by the pipeline operator to ensure the free access for the survey.
e. A determination that survey capabilities of the specified methane emissions quantification survey meet the specific objectives of the pipeline operator.
f. Evaluation of the analysis requirements of the pipeline operator, [including any specific codes or standards used to ensure that the pipeline operator receives correct and accurate results from the methane emissions survey.

11.1.4 Communications and Interfaces

Throughout the methane emissions quantification process, procedures shall include provisions to establish the necessary communication interfaces at the organizational and functional levels of the pipeline operator and the technology provider(s) necessary to ensure any issues can be resolved in a timely manner.

11.2 QUALITY SYSTEM DOCUMENTATION

The organizations shall have a documented quality system for the scope of activities encompassed in these guidelines. The quality system documentation shall be made available to the pipeline operator upon request.

Records of qualification processes and procedures and personnel qualifications records shall be made available to the operator upon request.

The Quality Management System manual shall be reviewed and approved by the organization as required in its delegation of authority.

11.2.1 Procedures and Work Instructions

Written procedures are required that describe the design, testing, contracting, field operations, data reduction and analysis processes as well as any support services necessary to successfully perform methane emissions surveys. Provisions shall be included for maintaining the quality of developed and utilized software applications. Software maintenance, configuration management and auditing should be performed in accordance with accepted industry practices. These procedures shall document the steps required to ensure that the individuals assigned to perform the task can perform the work in a consistent manner. The detail deemed necessary will depend on the task as well as the training and qualification requirements established by the supplying organization. Training and personnel qualifications requirements shall be specified in the procedures. Any procedure or work instruction that is required shall be available to the individual performing the work. Those procedures should also be available for review by the pipeline operator upon request. Procedures shall be reviewed and modified on a periodic basis.

11.2.2 Record-keeping

Each organization shall maintain adequate records of the methane emissions quantification relevant to their area of responsibility. Minimum record keeping-requirements shall be documented. These records shall include not only and calibration of a methane emissions quantification system and analysis software. These procedures shall include requirements for the identification of all equipment used, requirements of the individuals performing the task, and provisions for the calibration of applicable test equipment that is traceable.

11.2.3 Traceability

Each survey project performed shall be uniquely identified to ensure all information pertaining to that project can be referenced for future use without confusion with other projects.

The equipment used for the survey shall be uniquely identified to permit traceability. The use of serial numbers or other tracking references provides a history of equipment used and a way to monitor that equipment for changes in operation and functionality that may affect proper operation. If the historical information process is used for verifying survey results, the data collected for this purpose shall be matched to the traceability of the system utilized under this section.

Equipment traceability requirements shall extend to support equipment that directly affects the successful completion of a project when used in conjunction with the methane emissions quantification system.

11.3 QUALITY CONTROL

Quality control procedures shall be included in the quality system to ensure that the project requirements are being fulfilled. This shall include the checks required to ensure the proper equipment has been selected, qualified, properly calibrated, and successfully operated in the field. This shall also include the checks required to ensure that the data has been properly analyzed, and the date successfully delivered to the pipeline operator.

Quality control procedures shall also include those procedures necessary to demonstrate that all personnel are qualified in accordance with the requirements of these guidelines.

Procedures shall contain provisions for personnel to have the ability to interrupt the process when a quality control nonconformance is discovered and initiate immediate corrective action procedures to prevent further or more severe nonconformance. Records shall be maintained of these quality checks and retained in the record keeping system selected by the organization.

11.3.1 Personnel Qualifications

In accordance with these guidelines (Section 5) records of all personnel qualifications, including qualification levels, test scores and training records, shall be maintained for any individual performing the tasks identified in these guidelines. Qualification processes and procedures shall also be maintained as part of the Quality Management System.

11.3.2 Calibration and Standardization

To ensure consistent and accurate surveys, users shall have documented procedures for the qualification and calibration of an methane emissions quantification system and analysis software. These procedures shall include requirements for the identification of all equipment used, requirements of the individuals performing the task, and provisions for the calibration of applicable test equipment that is traceable.

11.3.3 Traceability

Each survey project performed shall be uniquely identified to ensure all information pertaining to that project can be referenced for future use without confusion with other projects.

Equipment traceability requirements shall extend to support equipment that directly affects the successful completion of a project when used in conjunction with the survey.

11.4 CONTINUOUS IMPROVEMENT

Provisions for continuous improvement shall be included in the quality system to facilitate the continuous improvement of the products and services provided to the pipeline operator.

Effective improvement requires feedback from employees and the pipeline operator, a review of new technology developments, and a continuous observation and measurement of the results of the output of the organization.

11.4.1 Process Measurement

The key to any improvement process is the ability to measure the effectiveness of that process through quantitative measures. The relevant organization will provide indicators of the success of their processes. Key measures of those indicators shall be established. The process measures selected shall include measures relevant to the products and services provided. Basic measures include:

a. The survey success percentage that measures the number of acceptable surveys made versus the total number of surveys made over a selected period of time.
b. A measure of the turn-around time of survey data as measured from completion of the fieldwork to the time of delivery of the report.
c. The accuracy of the survey results compared to verification surveys.
d. An analysis of the number and types of measurements outside of accuracy specifications over a period of time, for each type of survey system, based upon the stated performance specification or service requirement.

Other performance measures may be developed to further analyze the effectiveness of the processes being measured.

11.4.2 Corrective and Preventive Action

The quality system shall include procedures for correcting a nonconforming product or service. These procedures should include steps to prevent the nonconformance from recurring. This requires provision for adequate supervision commensurate with personnel experience and peer review crosscheck as necessary to assure accuracy of data. Processes to prevent nonconformance from initially occurring shall also be part of the quality system. These processes are often included in the research and development program.

11.5 QUALITY SYSTEM REVIEW

The organizations shall periodically evaluate the Quality Management System in place within their organization. These reviews are performed to ensure the overall effectiveness of the Quality Management System is maintained and continues to meet the goals of the organization.

11.5.1 Internal Audit

The quality management system shall include provisions to allow management to periodically evaluate the effectiveness of the procedures and processes within the quality system. Internal audits shall be performed at defined intervals, and the records of the audits shall be maintained. Records of any corrective actions taken shall also be maintained.

11.5.2 External Audit

A pipeline operator or an independent entity may perform an audit of a technology provider's quality system. Consideration may be given to parties that have no financial, competitive, or other incentive that may be in conflict with the financial, proprietary or intellectual nature of the organization being audited. Prior to performing the audit, the scope and procedure of the audit shall be clearly defined, discussed, and approved by the technology provider.

Records shall be maintained to the level that will allow the recreation of the system set up for survey system verification and validation purposes. Additional information may also be maintained as part of the survey record as determined between technology providers and the pipeline operator.

Survey records shall be retained for a time period no less than that required for legal or regulatory purposes. Adequate measures shall be taken to protect the records from loss or damage. When developing storage and regeneration procedures for survey data, changes in data collection technology should be considered.

11.5.3 Document and Revision Control

All documents that are a part of the quality system shall be controlled to ensure that the latest revisions are available to those performing the work. A revision control system shall include procedures for withdrawal of outdated information, including documents, files, forms, and software. Procedures shall also be in place to allow the user to be able to identify the revision level of the document being used. This includes documents and software internal to the organization as well as documents, files, and software released to the end-user.

11.5.4 Design Change Control

Procedures shall be established to document and record changes in the design of the electrical, mechanical, and software components of a methane emissions quantification system. These records shall sufficiently document the changes to allow an evaluation of the effects on the essential variables of the previous design.

The same procedures apply to the design of services provided to a pipeline operator. Service process changes shall also be documented to review the effectiveness of the change. Feedback from the pipeline operator should be a component of any design change procedure to be used when evaluating the effectiveness of changes to the design of either a methane emissions quantification system or service.