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Project Summary

Standard Test Procedures for Evaluating Leak Detection Methods: Pipeline Leak Detection Systems

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This report presents a standard test procedure for evaluating the performance of leak detection systems for use in the pipelines associated with underground storage tanks. The test procedure is designed to evaluate these systems against the performance standards of the U.S. Environmental Protection Agency's (EPA's) underground storage tank (UST) regulations (40 CFR Part 280, Subpart D), which cover an hourly test, a monthly monitoring test, and an annual line tightness test. The test procedure can be used to evaluate any type of system that is attached to the pipeline and that monitors or measures either flow rate or changes in pressure or product volume. This procedure can be used to evaluate leak detection systems that can relate the measured output quantity to leak rate (in terms of gallons per hour) and systems that use an automatic preset threshold switch. The test procedure can be used to evaluate systems used to test pressurized pipelines or suction pipelines that are pressurized for the test. The test procedure offers five options for collecting the data required to calculate performance. The results of the evaluation are reported in a standard format on forms provided in the appendices of the report summarized here.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory in Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The EPA's regulations for underground storage tanks require owners and operators to check for leaks on a routine basis using one of a number of detection methods (40 CFR Part 280, Subpart D). To ensure the effectiveness of these methods, the EPA has set minimum performance standards for equipment used to comply with the regulations. Deciding whether a system meets the standards has not been easy, and the EPA will not test, certify, or approve specific brands of commercial leak detection equipment. Instead, the EPA has developed and published a series of standard test procedures that describe how equipment should be tested to prove that it meets the standards. Each document on a type of system or method explains how to conduct the test, how to perform the required calculations, and how to report the results. The results from each standard test procedure provide the information needed by tank owners and operators to determine whether the method meets the regulatory requirements. The final report summarized here is part of the series published by the EPA.

The performance results are reported in terms of leak rate (in gallons per hour), probability of detection (P_D), and probability of false alarm (P_{FA}). The protocol addresses the performance of these leak detection systems for the leak rates, P_D, and P_{FA} specified in the EPA regulation. The protocol covers all of the *internal* EPA release detection options for piping but does not cover the *external* leak detection options (those for vapor and groundwater monitoring). Separate protocols have been developed for these external systems. Common types of leak detection systems that can be evaluated with the protocol summarized here include systems that measure pressure, volume, or flow-rate changes in the pipeline. Both pressurized and suction piping systems are addressed, and if release detection is required for a suction system, it is assumed that the line will be pressurized for the test.

The EPA regulation requires two types of leak detection tests for underground pressurized piping containing petroleum fuels. First, underground piping must be equipped with an automatic line leak detector that will alert the operator to the presence of a leak by restricting or shutting off the flow of the regulated substance through the piping or by triggering an auditory or visual alarm. The automatic line leak detector must be capable of detecting leaks of 3 gal/h defined at a line pressure of 10 psi within an hour of the occurrence of a leak and with a P_D of 95% and a P_{FA} of 5%. The test is designed to detect the presence of very large leaks that may occur between regularly scheduled checks with the more accurate monthly monitoring tests or annual line tightness tests. Many of these systems use a preset-threshold switch.

Second, the regulation also requires either an annual line tightness test or a monthly monitoring test. The annual line tightness test must be capable of detecting a leak as small as 0.1 gal/h (defined at a pressure that is 150% of the operating pressure of the line) with a P_D of 95% and a P_{FA} of 5%. The monthly monitoring test evaluated by this protocol must be capable of detecting leaks as small as 0.2 gal/h (defined at the operating pressure of the line) with a P_D of 95% and a P_{FA} of 5%. This monthly monitoring test can be satisfied by the use of any type of pipeline leak detection system (line pressure monitor, automatic shutdown line leak detector, etc.) that conducts a precision test on the pipeline system and that can satisfy the performance requirements.

The evaluation protocol requires that the performance characteristics of the instrumentation be estimated and that the performance in terms of leak rate, P_D, and P_{FA} be determined for the specified pipeline configuration and a wide range of product temperature conditions. The probability of false alarm is estimated at the threshold used by the manufacturer (the threshold being the value at which a leak is declared), and the probability of detection is estimated at the leak rate specified in the EPA regulation. With one slight difference, the same procedure is used to evaluate the performance of the monthly monitoring test, the annual line tightness test, and the hourly automatic line leak detection test. For the monthly monitoring test, the probability of detection is estimated at a leak rate of approximately 0.2 gal/h, while for the line tightness test the probability of detection is estimated at a leak rate of approximately 0.1 gal/h; a 3-gal/h leak is used in the hourly test.

Options for Estimating Performance

A complete specification of system performance requires a statement of the P_D at a defined leak rate, a statement of the P_{FA}, and an estimate of the uncertainty of the P_D and P_{FA}. The performance estimate should be made over the range of conditions under which the system will actually be used. They can be made from a performance model based on the histograms of the noise and the signal-plus-noise. The actual calculations will be made with another representation of the histogram called the cumulative frequency distribution.

To estimate the performance of a pipeline leak detection system, one must develop histograms of the noise and the signal-plus-noise. Each histogram generated according to this protocol requires a minimum of 25 independent tests. This number ensures that an estimate of the P_D of 95% and the P_{FA} of 5% can be made directly from the data and that the uncertainty in the estimate of the P_D and P_{FA}, as measured by the 95% confidence intervals, is approximately 5%.

This protocol provides five options for generating the data necessary to develop noise and signal-plus-noise histograms. The first option is to conduct the evaluation at an instrumented test facility specifically designed to evaluate pipeline leak detection systems, and the second is to do it at one or more operational UST facilities that are specially instrumented for the evaluation. Both of these options require that the data be collected under a specific set of product temperature conditions, which are measured as part of the test procedure, and on a pipeline system that has defined characteristics. The instrumentation is minimal and does not require that temperature sensors be placed inside the pipeline. The next two options require that data be collected over a period of 6 to 12 months, either at 5 operational UST facilities where the integrity of the pipeline systems has been verified, or at 10 or more operational UST facilities. The stations should be geographically located so as to represent different climatic conditions. Each of the operational UST facilities selected should receive a delivery of product to the tank at least once per week. Options 3 and 4 should provide approximately the same range of temperature conditions specified in Options 1 and 2 because of seasonal variations in the temperature of the ground and the temperature of the product delivered to the tank. In the fifth option, a simulation is used to estimate the performance of the leak detection system. This simulation is developed from experimentally validated mathematical models of all the sources of noise that affect the performance of a particular system.

Generating the Noise Histogram

The primary source of noise for a pipeline leak detection system is the thermal expansion and contraction of the product in the line. Thus, the performance of most pipeline leak detection systems is controlled primarily by temperature changes in the product that is in the line. These changes are present unless no product has been pumped through the pipeline for many hours. To take these changes into account, the protocol requires that all leak detection systems be evaluated under a wide range of temperature conditions.

The range of temperature conditions used in this protocol is based on the results of an analytical study of the climatic conditions found throughout the United States. The study estimated the average difference in temperature, ΔT, between the product in the tank and the temperature of the ground around the pipe. The results indicated that values of ±25°F would cover a wide range of conditions. All systems will be evaluated in accordance with their own test protocols under the matrix of temperature conditions given in Table 1. The protocol in this document describes specifically how to create these conditions.

Table 1 summarizes the number of tests that must be done for each of the nominal conditions for which histograms must be generated. A temperature condition is generated by circulating product for 1 h or longer at one temperature through a pipeline system surrounded by backfill and soil at another temperature. It is assumed that the temperature conditions within the range of each 10°F increment will be as uniformly distributed as possible. This is particularly important for the conditions centered on 0°F; about half of the conditions should be positive and about half should be negative.

Table 1. *Number of Tests Required for Each Range of Temperature Conditions*

Number of Tests	Percentage of Tests	Range of Temperature Differences ΔT (°F)
1	4	$\Delta T < -25$
4	16	$-25 \leq \Delta T < -15$
5	20	$-15 \leq \Delta T < -5$
5	20	$-5 \leq \Delta T < +5$
5	20	$+5 \leq \Delta T < +15$
4	16	$+15 \leq \Delta T < +25$
1	4	$\Delta T \geq +25$

The pressure and volume changes produced by the thermal expansion or contraction of any trapped vapor in the line also affect the performance of most detection systems; in some instances, a leak detection device will simply not work if vapor is trapped in the line. It is assumed in this protocol that the leak detection system being evaluated would require that the line be tested for vapor and, if vapor were found to be present, would either cancel the test or require that the trapped vapor be removed before the test was begun. Because the protocol makes this assumption, evaluators should ensure that, when the evaluation is conducted at an instrumented test facility (i.e., Options 1, 2, and 5), all vapor has been removed from the pipeline for all tests used in estimating performance. To assess the sensitivity of the system to trapped vapor, this protocol requires a minimum of three tests with a small volume of trapped vapor in the line. The results of these three tests will not be included in the performance estimates but will be presented in the evaluation report so that the manufacturer's claims about the effects of trapped vapor on the test results can be better assessed.

Generating the Signal-plus-noise Histogram

A histogram of the signal-plus-noise is a requirement for estimating the P_D for each leak rate of interest. The threshold value is used to determine the P_D directly from the histogram of the signal-plus-noise for a given leak rate. A separate histogram of the signal-plus-noise is required for each signal (i.e., leak rate) for which the performance in terms of P_D is desired. For each leak rate of interest, the histogram of the signal-plus-noise must be developed over the same temperature conditions and pipeline configurations used to generate the noise histogram. This protocol requires, at a minimum, that the P_D be estimated against the leak rate specified in the EPA regulation for the type of leak detection system being evaluated (i.e., 0.1, 0.2, or 3.0 gal/h).

Generating the signal-plus-noise histogram may be simple or may involve significant effort. There are two options. The *direct* approach is to develop the histogram by generating a leak in the line and conducting a large number of leak detection tests under the same conditions used to develop the histogram of the noise. This direct approach can be used regardless of whether the leak detection system uses a preset threshold or measures the flow rate directly. Noise and signal-plus-noise histograms are required for each temperature condition. In this approach, the histogram of the signal-plus-noise is measured directly for the leak rate at which the P_D is desired, and thus the relationship between signal and noise is determined directly. If the leak detection test is short, the data necessary to develop the noise and signal-plus-noise histograms can be acquired by conducting two tests in succession. The direct approach is most beneficial when a P_D is required for only a few leak rates; otherwise, the time required to collect the data can be excessive. This approach is easy to implement when data are collected at an instrumented test facility or one or more instrumented operational UST facilities, but it is cumbersome if the data must be collected over an extended period at many noninstrumented operational UST facilities. If there is a large number of leak rates, each requiring an estimate of the probability of detection, or if the test duration is sufficiently long that only one leak detection test can be conducted for a given temperature condition, the second approach would be more logical.

The second approach is to develop a signal-plus-noise histogram from the histogram of the noise by developing a theoretical relationship between the signal and the noise. An experimentally validated model that gives the relationship between the signal and each source of noise must be developed. With this model and the histogram of the noise, the signal-plus-noise histogram can be developed for any leak rate, and an estimate of the P_D can also be made for any leak rate. This relationship must be valid over the range of test conditions and pipeline configurations covered by the evaluation. It can be used with all five of the options for data collection. It is particularly useful for evaluating the performance of leak detection systems that require long tests or long waiting periods or that acquire the noise data at many operational UST facilities over a long period of time.

General Features of the Evaluation Protocol

The general features of the evaluation protocol, including how the pipeline configuration affects performance and the 13 steps required to conduct the evaluation, are summarized below.

Pipeline Configuration

There is a wide range of pressurized pipeline systems that must be tested periodically for leaks, and leak detection systems must comply with the EPA regulation. The performance of many pipeline leak detectors, especially pressure detection systems, will vary according to the configuration of the pipeline system. The magnitude of the signal as well as that of the noise will be affected. This occurs because the overall compressibility characteristics of the pipeline system are influenced by the choice of material (fiberglass or steel), the use of flexible hosing (and its length), and the presence of appurtenances on the line. This interaction between the pipeline and the performance of the leak detection system presents a challenging problem: the same leak detection system can perform very well on one pipeline system and poorly on another. Fortunately, the compressibility characteristics of the line can be described by the bulk modulus of the pipeline system. Two pipelines may have different configurations but may have the same compressibility characteristics. In this protocol, the bulk modulus, which can be readily measured, is used to characterize the pipeline used in the evaluation.

Pipelines constructed at special instrumented test facilities should simulate the important features of the type of pipeline systems found at operational UST facilities. This protocol assumes that the leak detection systems to be evaluated are intended for use on underground storage tanks that are typically 10,000 gal in capacity, where the diameter of the pipe is typically 2 in. and the length is usually less than 200 ft. If the leak detection system will be used on pipelines with larger diameters or longer lengths, the evaluator should use a proportionately larger pipeline in conducting the evaluation. Whether the evaluation is conducted at a special instrumented testing facility or at one or more instrumented operational UST facilities, the requirements are as follows.

- The pipeline, which can be constructed of either fiberglass or steel, must have a diameter of at least 2 in. ± 0.5 in.
- The pipeline must be at least 75 ft long.
- The pipeline system should have a bulk modulus of approximately 25,000 psi ± 10,000 psi.
- A mechanical line leak detector must be present within the line if the leak detection system being evaluated normally conducts a test with this device in place.
- There must be a way to pressurize the pipeline system.
- There must be a tank or storage container to hold product withdrawn from the line during a test.
- There must be a pump to circulate product from the storage container through the pipeline for up to 1 h. (At operational UST facilities and at most test facilities, this container will be an underground storage tank, and a submersible pump will be used to pressurize the pipeline and circulate product through it.)
- The pipeline must have valves that can be used to isolate it from the storage tank and the dispenser. These valves must be checked for tightness under the maximum operating pressure of the pipeline system.
- The pipeline must contain a petroleum product, preferably gasoline, during the evaluation.
- In addition, when an evaluation is done at a special test facility, there must be a unit to heat or cool the product in the storage container.

When the evaluation is done at five or more operational UST facilities that are geographically separated, it will suffice if only one of the facilities meets these criteria, with the exception of the bulk modulus criterion, which does not have to be met by any of the facilities.

The performance of some of the systems that can be evaluated with this protocol will decrease as the diameter and/or length of the pipeline increases. This is particularly true for volumetric measurement systems that are directly affected by thermal expansion or contraction of the product in the pipeline. The performance estimate generated by this protocol is considered valid if the volume of the product in the pipeline system being tested is less than twice the volume of product in the pipeline used in the evaluation. This is an arbitrary limitation because it does not take into account the type of system, the method of temperature compensation, or the actual performance of the system. It was selected to allow flexibility in the application of the system. Thus, in selecting the length of the pipeline to be used in the evaluation one should consider how the system will ultimately be used operationally. Because the limitation is arbitrary, this protocol also allows the manufacturer to present a separate written justification indicating why the method should be considered applicable to pipelines having twice the capacity, or more, of the one used in the evaluation. Concurrence with this justification must be given by the evaluator. Both the written justification and evaluator's concurrence must be attached to the evaluation report.

Conducting the Evaluation

A 13-step procedure is used to conduct an evaluation. The particulars of the evaluation procedure depend on

- which performance standard the system will be evaluated against (i.e., hourly test at 3 gal/h, monthly monitoring test at 0.2 gal/h, or line tightness test at 0.1 gal/h)
- whether the leak detection system measures the flow rate and uses it to determine whether the pipeline is leaking or uses an automatic preset threshold switch and does not directly measure and report flow rate.

The protocol can be used to evaluate systems that require multiple tests as well as those based on a single test.

Step 1—Describe the leak detection system. Specifying the important features of the leak detection system is important for three reasons. First, a brief description will identify the system as the one that was evaluated. Second, changes to the system may be made at a later date, but the manufacturer may not feel that the changes are important enough for him to rename the system. Such changes may affect the performance, either for better or worse. If the characteristics of the system have been specified in a brief descriptive statement, the owner/operator of an underground storage tank system will have a way to determine whether the detection system he is using is actually the one that was evaluated. Third, the owner/operator will be able to interpret the results of the evaluation more easily if he has this information.

The description of the leak detection system need not be excessively detailed, and proprietary information about the system is not required. The description should, however, include the important features of the instrumentation, the test protocol, and detection criterion. If the system requires multiple tests before a leak is declared, this should be clearly stated. (A summary sheet on which to describe the system is provided in the final report.)

Step 2—Select an evaluation option. It must be determined which one of the five evaluation options will be used: test facility, one or more instrumented operational UST facilities, 6- to 12-month data collection effort at 5 operational UST facilities at which pipeline integrity has been verified, 6- to 12-month data collection effort at 10 or more operational UST facilities, or validated computer simulation.

Step 3—Select temperature and leak conditions for the evaluation. The temperature and leak conditions must be determined. If the evaluation is done at a test facility, at one or more instrumented operational UST facilities, or by computer simulation, the temperature conditions necessary to compile the noise histogram will be developed according to a test matrix, which is generated before the data collection begins, and will be verified by means of specific diagnostic ground and product measurements made immediately before the test. A matrix of leak conditions will also be generated so that a histogram of the signal-plus-noise can be compiled; the type of test matrix will depend on whether the leak rates are known *a priori* or whether a blind-testing procedure is used. The protocol is designed to minimize any advantages that the test crew might have because of its familiarity with the test conditions described in the protocol. Thus, the performance estimates should be identical regardless of whether the test conditions were known *a priori*. Two blind testing techniques are provided; these can be implemented most easily at an instrumented test facility.

If the data are collected at operational UST facilities over a period of 6 to 12 months, temperature conditions do not need to be artificially generated, but the relationship between the measured quantity and the flow rate that would be produced by a leak at the manufacturer's standard test pressure (i.e., the relationship between the signal and the noise) should be defined and provided by the manufacturer before the system is evaluated. This relationship is used to generate the signal-plus-noise histogram from the noise histogram at the EPA-specified leak rate. The relationship can be either a theoretical one that has been validated experimentally or an empirical one that has been developed through experimentation.

Step 4—Assemble equipment and diagnostic instrumentation. The protocol specifies certain equipment, apparatuses, and measurement systems to be used in the evaluation. Although these must be assembled and calibrated, none is particularly complex or sophisticated. A description of each is provided. The protocol allows for the use of other equipment not specified by this protocol provided it has the same functionality and performance as the equipment described.

Step 5—Verify the integrity of the pipeline system. Conducting a performance evaluation of a leak detection system requires a nonleaking pipeline. If the pipeline is not tight, the performance of the system being evaluated will be degraded. For all but one of the evaluation options presented in this protocol (Option 4), it is recommended, though not required, that the integrity of the pipeline be verified beforehand by means of a leak detection system whose performance is already known.

Step 6—Determine the characteristics of the pipeline system. It must be determined whether the pipeline system used in the evaluation meets the minimum specified conditions. The same pipeline configuration can be used regardless of whether the evaluation is done at a test facility, one or more instrumented operational UST facilities, or by the simulation approach. The compressibility of the pipeline system must be within a specified range; if it is not, a mechanical device can be used to modify the compressibility characteristics of the line for the test. An example of a device that can be used to modify the compressibility characteristics of the pipeline system is described in the final report.

Step 7—Evaluate the performance characteristics of the sensor subsystems. The resolution, precision, accuracy, and minimum detectable quantity of the measurement subsystems (instrumentation), as well as what the instrumentation is measuring (i.e., specificity), should be determined. Also, the flow rate at the threshold should be determined. Although this step is not actually required in order for an evaluator to estimate the performance of the system, it serves two important purposes. First, it indicates, before the evaluation is performed, whether the instrumentation is working according to the manufacturer's specifications. If the instrumentation is not performing properly or if it is out of calibration, the evaluation should not proceed until the problems are remedied. Second, the instrumentation will ultimately limit the performance of the leak detection system. If it is evident that the performance expectations of the manufacturer are more than the instruments will allow, the evaluation can be stopped before too much time has been invested or too much expense incurred. Furthermore, this step can be completed quickly.

Step 8—Develop (if necessary) a relationship between the leak and the output of the measurement system. If the relationship between the leak and the output of the measurement system (i.e., between the signal and the noise) is known or has been supplied by the manufacturer and no direct estimate of the signal-plus-noise histogram at the EPA-specified leak rate has been made as part of this protocol, experiments must be conducted to verify the relationship. This step is not necessary if the test matrix requires 25 tests at the EPA-specified leak rate (i.e., developing the signal-plus-noise histogram with the *direct* approach).

Step 9—Develop a histogram of the noise. A histogram of the noise under the temperature conditions specified in Step 3 for the pipeline system specified in Step 6 must be developed. This histogram, which is needed to estimate the probability of false alarm, is generated from one or more pipeline tests, conducted according to the manufacturer's protocol, for each condition given in Step 3. If the system uses a multiple-test procedure, two histograms are required. The performance of the system, which includes the entire multiple-test sequence, is generated from the data obtained from the test that is used to determine whether the pipeline is leaking (in many instances these are the data from the last test in the sequence). Step 9 is the heart of any evaluation. Once the histogram of the noise is known and either the relationship between the signal and the noise is known or a histogram of the signal-plus-noise has been developed, the performance of the system can be estimated.

Step 10—Develop a histogram of the signal-plus-noise. A histogram of the signal-plus-noise for each leak rate at which the system will be evaluated and under the same conditions used to generate the noise histogram must be developed. If system uses a multiple-test procedure, two histograms are required. The performance of the system, which includes the entire multiple-test sequence, is generated from the data obtained from the test that is used to determine whether the pipeline is leaking (in many instances these are the data from the last test in the sequence). This histogram is needed to estimate the probability of detection. It may be a simple matter to generate the histogram, or it may involve significant effort. The histogram of the signal-plus-noise may be measured directly for each leak rate of interest by developing a histogram of the test results when a leak of a given magnitude is present. As an alternative, a model that gives the relationship between the signal and the noise may be developed and validated experimentally. If the relationship between the signal and noise is known, the noise histogram can be used to estimate the signal-plus-noise histogram. This relationship can be difficult to develop unless all sources of noise during the test are compensated for (or unless they are small). A model is required if one wants to know a system's performance at many leak rates that are different from those specified in the EPA regulation.

Step 11—Determine the system's sensitivity to trapped vapor. The sensitivity of the leak detection system to vapor trapped in the pipeline system must be determined. To this end, three special leak detection tests will be performed. In each test, a specific amount of vapor, unknown to the tester, will be introduced into the line by means of an apparatus especially designed for this purpose and described in the final report. These three tests will be intermixed with the other 25.

Step 12—Conduct the performance analysis. The performance of the system in terms of P_D at the EPA-specified leak rate and in terms of P_{FA} is then calculated. The protocol is designed so that the P_D and P_{FA} of the system are determined with the manufacturer's threshold at the leak rate and test pressure specified by the EPA regulation (i.e., 0.1, 0.2, or 3 gal/h). If the evaluation is not done at the pressure specified by the EPA, a method is given to calculate an equivalent leak rate at whatever pressure is used. The protocol provides a summary sheet to be used in reporting a variety of other performance estimates so that the performance can be compared to that of other leak detection systems. If a system uses a multiple-test procedure, the protocol requires a second performance estimate based on noise and signal-plus-noise data from the first test of the multiple-test sequence.

Step 13—Report the results. The final step is to report the results of the evaluation in a set of standardized forms found in an appendix to the final report. With the information provided in these forms, the evaluation can be independently reviewed and verified.

Reporting the Results

One of the appendices of the complete final report contains a standard form on which the results of the evaluation can be summarized. The performance characteristics of the instrumentation, the estimates of the system's performance in detecting leaks in the ambient environment, and the sensitivity of the system to trapped vapor are summarized in a set of tables. The test conditions and pipeline systems to which the detector is applicable are also presented. Seven attachments to the form give additional details about the system and the evaluation. With the data and information provided in these attachments, all of the results of the evaluation can be independently reviewed and verified. The seven attachments include:

- a description of the system
- a summary of its performance
- a summary of the configuration of the pipeline system(s)
- a summary of product temperature conditions
- a summary of leak tests
- a summary of trapped vapor tests
- a summary of test results used to check the relationship supplied by the manufacturer for combining the signal and the noise.

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The complete report, entitled "Standard Test Procedures for Evaluating Leak Detection Methods: Pipeline Leak Detection Systems," (Order No. PB91-106245/AS; Cost: $23.00, subject to change) will be available only from:
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