CARNEGIE
MELLON
RESEARCH
INSTITUTE
a division of Carnegie Mellon University

Advanced Devices and Materials Group
4400 Fifth Avenue Pittsburgh, PA 15213-2683
(412) 268-3495 FAX: (412) 268-3101

Test Procedures for Third Party Evaluation of Leak Detection Methods: Cable Sensor Liquid Contact Leak Detection Systems

Cable Sensors: Accuracy & Response Time
Cable Sensors: Specificity
Cable Sensors: Lower Detection Limit

Final Report
November 11, 1991

prepared for

W. L. Gore and Associates, Inc.	Phoenix, AZ 85076-0699
In-Situ, Inc.	Laramie, WY 82070
PermAlert ESP	Niles, IL 60648-3491
Raychem Corp., TraceTek Products	Menlo Park, CA 94025-1164

prepared by

Marc Portnoff & Margaret Nasta, Ph.D.

CMRI Contract 1-41224

Abstract

Presently there are no EPA approved methods or procedures for third party evaluation of liquid contact leak detection systems using cable sensors. These cable sensors are commonly used for detecting the presence of fuel products that collect in the ground or within the interstitial space of double-walled underground storage tanks or pipes.

These procedures were developed to satisfy the EPA criteria for third party testing of accuracy and response time, specificity, and the lower detection limit for liquid contact cable sensors. The tests were designed to yield results that could be related to the performance of liquid contact cable sensor leak detection systems at actual underground storage tank sites.

Test Procedures for Third Party Evaluation of Leak Detection Methods:

Cable Sensor Liquid Contact Leak Detection Systems

TABLE OF CONTENTS

Abstract	i
1.0 Introduction	1
2.0 Test Chamber	4
3.0 General Procedure	5
3.1 Procedure for Testing Accuracy and Response Time	6
3.2 Procedure for Testing Specificity	7
3.3 Procedure for Testing Lower Detection Limit	8
4.0 Calculations	9
4.1 Calculations for Testing Accuracy and Response Time	9
4.2 Calculations for Testing Specificity	10
4.3 Calculations for Testing Lower Detection Limit	10
5.0 Equations	11
6.0 Symbols	12
7.0 Disclaimers	13
Table 1. 2.5% t Values	14
Table 2. One-Sided Tolerance Limit Factors	15
Figure 1c. Test Chamber for Cable Sensor	15
Appendix 1 -- EPA Documents: Foreword	16
Appendix 2 -- Example Calculations	21
Appendix 3 -- Excerpts from EPA Document: Preparation of Synthetic Gasoline	22
Appendix 4 -- Definitions	24
Appendix 5 -- Referenced Documents	26
Appendix 6 -- Reagents	27
Appendix 7 -- EPA Document Review Letter	28
Appendix 8 -- Qualitative Liquid Contact Cable Sensor Results Form	30
Appendix 9 -- Quantitative Liquid Contact Cable Sensor Results Form	33

Test Procedures for Third Party Evaluation of Leak Detection Methods:

Cable Sensor Liquid Contact Leak Detection Systems

1.0 Introduction

These test procedures describe methods to determine the accuracy, response time, specificity, and lower detection limit for liquid hydrocarbon leak detectors that consist of a monitor and one or more cable sensors. These devices are used to detect leaks of fuels or solvents that occur in the ground or within the interstitial (annular) space of double-walled pipes or tanks.

The Federal Register [1] states that a new method of detection can be used if it can detect a release rate of 0.2 gal/hour or 150 gallons within a month with a probability of detection of 95% and a probability of false alarm of 5%. Test procedures to determine if sensors can meet this criteria have been established with the March 1990, EPA manual, "Standard Test Procedures for Evaluating Leak Detection Methods: Liquid-Phase Out-of-Tank Product Detectors" [2].

The foreward of this March 1990, EPA manual (Appendix 1), contains a section titled "Alternative Test Procedures Deemed Equivalent to the EPA's". This section details guidelines for an independent lab to develop equivalent third party tests for those protocols already approved by the EPA. The design of these test procedures follows the guidelines presented in this foreward. They also go one step further in that they are designed as third party testing procedures for liquid phase product sensor/monitors for which the EPA has no approved protocols. Therefore, changes have been made to accommodate the detection mechanisms unique to liquid contact cable sensors. For example, many of these cable sensor systems will not only detect a hydrocarbon leak, but they are capable of determining the location of that leak. Thus, the procedures direct that data for distance to the leak be collected and evaluated.

It should be noted that where possible, text from the EPA Standard Test Procedures has been used to provide for consistency in developing a parallel test procedure.

The procedures and the test apparatus are meant to be simple, yet flexible. The procedures use common laboratory equipment or other apparatus that can be easily fabricated. The test chamber should fit easily in a standard fume hood. It should also be possible to run several tests at the same time. The testing procedures can be adapted to the wide variety of cable sensors and monitors that are on the market. In addition, although this document is intended for cable sensors that detect non-viscous hydrocarbons such as gasoline, the procedures can be easily modified for testing cable sensors that detect waste oils, water, water-based solutions, etc. This will enable comparisons to be made among the many types of cable sensor/monitor systems that are on the market.

The cable sensor/monitor systems are tested by forming a length of cable into a coil around a solid core and suspending it in a non-reactive cylindrical container, such as a glass beaker. The beaker should be just slightly larger than the coil diameter. This will minimize the amount of the test liquid that is used, an important consideration when combustible materials are being tested. The container is also fitted with a cover that will minimize the evaporation of volatile liquids.

The test liquid, commercially available, unleaded gasoline, is added to the chamber at a constant rate of flow for all of the tests, to maintain a constant increase in height of 2 mm/minute. The sensor is monitored to determine if it will activate in the presence of the test liquid. If the sensor activates, the response time is measured as well as the height of test liquid added. If the monitor measures the location of the leak, this distance is recorded. Finally, if the sensor can be reused, recovery time is also measured.

Four liquids were selected for use in the specificity tests. Diesel fuel and heating oil were selected because of their occurrence in documented large scale UST spills [3]. Synthetic Gasoline [4], was selected as a standard since gasoline and diesel fuels vary in chemical composition. Finally, water was selected because it has the potential of coming into contact with the cable sensors.

These procedures have been developed so that test results can be used to determine how a device would perform at an underground storage tank (UST) site. They also call for testing the cable sensor/monitor systems at the design limits specified by the manufacturer. Instead of testing the cables at a particular length; e.g., 700 ft, they are tested at the maximum effective range that is specified for the product.

As an example, a 5000 gallon UST with 3 inch interstitial spacing will be used. The UST tank's shape is rectangular for ease of modeling (Appendix 2). The model shows that a leak rate of 0.2 gal/hr will cause the level of the product to rise at a rate of 0.2 inches/hour. The test results of a given cable sensor demonstrate that when 1 inch of product has accumulated in the beaker (2 feet of wetted cable), the sensor activated. With this information, it could be determined that it would take 5 hours for the cable sensor to activate for a leak of 0.2 gal/hr into the UST's interstitial space.

A relationship between the test procedures and the behavior of leaking underground fuel systems into the ground can be determined by assessing EPA documents [5,6] and others [7] describing hydrocarbon dispersion rates.

The calculations and manner in which the test results will be presented are again based, in general, on the March 1990, EPA manual [2]. Changes have been made to accommodate the unique properties of these cable sensor leak detector systems.

A list of equations and symbols follows the sections on calculations.

The report ends with the Reporting Forms, summarizing the test results, which have been designed under the guidelines set forth in the "Alternative Test Procedures Deemed Equivalent to the EPA's". The Reporting Forms follow the same general format and information presented in the EPA standard results sheet.

2.0 Test Chamber

The cable sensor tests should be performed using a non-reactive cylindrical container, for example, a glass beaker or graduated cylinder. It is convenient to have a transparent container so that the liquid level can be observed. The test chamber can also be constructed from stainless steel, Teflon, or any other material that is not sensitive to the test liquids. The solid core, used for wrapping the cable sensor, should also be be made from materials not sensitive to the test liquids (Figure 1c).

NOTE: If the test chamber is made from metal, care should be taken to ground both the chamber and the cover. The test chamber and other apparatus should be anchored securely to prevent tipping. For example, the beaker can be clamped to a ring stand. The tests should be conducted in a properly operating fume hood.

The test chamber should have a diameter of approximately 5 inches. The cable sensor is wound around a solid inner core with a circumference of 1 foot (about 3.75 inches in diameter) and suspended in the test chamber. This design will minimize the amount of flammable test liquid that is used for each trial. The test chamber should be about twice the height of the coiled cable sensor. A height of 8 to 10 inches should accommodate most types of sensors.

The container must have a cover to prevent the evaporation of the volatile test liquids. For example, a cover can be made from a sheet of Viton that does not react with hydrocarbons with small slits made to admit the cable sensor wires, etc.

The test liquid can be added by means of a mechanical pump or by gravity flow from a separatory funnel. The separatory funnel should have a narrow stem to control the direction of the flow and a Teflon stopcock to eliminate the chance of contamination from lubricants. (For example, a Pyrex separatory funnel is available with an offset PTFE plug stopcock. A knob operates the plug against the valve seat, allowing precise control of flow.)

3.0 General Procedure

Care should be taken to minimize or eliminate conditions that would contribute to poor precision in the data. For example: The test chamber should be kept level and covered until all of the data for a particular trial are recorded. Tests should be conducted at constant, normal laboratory temperatures. All of the apparatus and test liquids should be at normal laboratory temperatures (± 2°C) before the start of testing.

Equipment such as the thermometer, data collection systems (i.e., chart recorder, lab timers, data acquisition system), and test monitor, should be calibrated before use. The diameter of the sensor cable should be measured at several points along the cable and an average reading obtained. The product delivery system should also be calibrated so that the liquid flow rate maintains the liquid rate of rise to be approximately 2 mm/min or 1 mm every 30 sec. This would represent a leak rate of 0.17 gal/hr, assuming an empty test chamber.

The cable sensor should be tested at the maximum effective range (MER) given by the manufacturer, unless it is otherwise specified in the procedures. The length of sensor cable to be tested is specified in the procedures. Care should be taken to coil the cable evenly along the inner core starting from a set position on the core. The sensor should be connected to the monitor in a manner similar to the way that it would be installed in the field. Consult the manufacturer's directions.

Some variations in test results can be expected because of the sensor cable structure (i.e. porous, solid, etc.) and how uniformly the cable can be coiled. It is also important to carefully measure the product flow rate and rate of rise for each test. The average and standard deviation for each of these variables for the test procedures should be reported.

3.1 Procedure for Testing Accuracy and Response Time

The monitor/cable sensor system is tested with a single test liquid: unleaded gasoline. The cable sensor should be tested six times at the maximum effective range specified by the manufacturer. If the detector is quantitative, measuring distance to the leak, then the system should also be tested six times at approximately $^1/_3$ and $^2/_3$ of that distance.

The length of sensor cable to be tested is based upon manufacturer data regarding the minimum length of sensor cable that needs to be wetted to activate an alarm signal, at its maximum effective range. With this information, the length of cable to be tested would then be 120% of the minimum sensitive length rounded to the next higher foot. For example, if the minimum sensitive length of sensor cable were 10 feet, the cable test length would be 12 feet. If the minimum sensitive length were 9.5 feet, then 120% rounded to the next higher foot would still be 12 feet.

Before the analysis, perform a blank test by recording the monitor output for 30 minutes while the test container is empty. For quantitative monitors, check to insure that the system is stable before each measurement.

The test liquid should be added near the side of the test chamber and should not flow directly over the cable sensor. The liquid should be absorbed from the bottom of the cable upward. The flow rate should be adjusted so that the liquid level in the test chamber rises at the rate of 2 mm/min or 1 mm every 30 sec. Flow should continue until the monitor is activated or until the cable test length is covered. If the monitor has not become activated by the time that the liquid has reached this point, the flow of the liquid should be stopped, and the system allowed to stand. End the test if the monitor has not become activated after waiting an additional two hours.

Some sensors can only be used once and must be replaced after each test. Other sensors can recover to the original signal level when removed from the hydrocarbon and may be used again. If the sensor mechanism permits repeated usage, then the sensor should be removed from the test liquid, and the time needed to recover from the activation level should be recorded. The test should be ended after one hour if the signal has not recovered.

Depending on the sensor mechanism, the same cable sensor may be able to be cleaned, reset and used again within a reasonable length of time. Otherwise, the cable sensor must be replaced after each test run.

The following quantities should be recorded: temperature of the test liquid, rate of addition of the test liquid, volume of test liquid added, height of the test liquid at activation, response time, and recovery time. For quantitative detectors, record the output measuring the distance to the leak for each test.

3.2 Procedure for Testing Specificity

To test for specificity, the monitor/cable sensor system is tested three times with four test liquids: heating oil, diesel fuel, synthetic gasoline (Appendix 3), and water. The cable sensor should be tested at the maximum effective range specified by the manufacturer.

The length of sensor cable to be tested is based upon manufacturer data regarding the minimum length of sensor cable that needs to be wetted to activate an alarm signal, at its maximum effective range. With this information, the length of cable to be tested would then be 120% of the minimum sensitive length rounded to the next higher foot. For example, if the minimum sensitive length of sensor cable were 10 feet, the cable test length would be 12 feet. If the minimum sensitive length were 9.5 feet, then 120% rounded to the next higher foot would still be 12 feet.

Before the analysis, perform a blank test by recording the monitor output for 30 minutes while the test container is empty. For quantitative monitors, check to insure that the system is stable before each measurement.

The test liquid should be added near the side of the test chamber and should not flow directly over the cable sensor. The liquid should be absorbed from the bottom of the cable upward. The flow rate should be adjusted so that the liquid level in the test chamber rises at the rate of 2 mm/min or 1 mm every 30 sec. Flow should continue until the monitor is activated or until the cable test length is covered. If the monitor has not become activated by the time that the liquid has reached this point, the flow of the liquid should be stopped, and the system allowed to stand. End the test if the monitor has not become activated after waiting an additional two hours.

Some sensors can only be used once and must be replaced after each test. Other sensors can recover to the original signal level when removed from the hydrocarbon and may be used again. If the sensor mechanism permits repeated usage, then the sensor should be removed from the test liquid, and the time needed to recover from the activation level should be recorded. The test should be ended after one hour if the signal has not recovered.

Depending on the sensor mechanism, the same cable sensor may be able to be cleaned, reset and used again within a reasonable length of time. Otherwise, the cable sensor must be replaced after each test run.

The following quantities should be recorded: temperature of the test liquid, rate of addition of the test liquid, volume of test liquid added, height of the test liquid at activation, response time, and recovery time. For quantitative detectors record the output measuring the distance to the leak, for each test.

3.3 Procedure for Testing Lower Detection Limit

The lower detection limit for cable sensors can be calculated from the data for the accuracy and response time measurements for unleaded gasoline. These tests are conducted at the maximum effective range where most cable sensors have reduced sensitivity.

4.0 Calculations

The calculations for these test procedures are based, in general, on the Standard Test Procedures for Evaluating Leak Detection Methods: Liquid-Phase Out-of-Tank Product Detectors [2]. Changes have been made to accommodate the unique properties of the cable sensor leak detector systems. A list of equations and symbols follows the sections on calculations.

4.1 Calculations for Testing Accuracy and Response Time

Calculate and report for **unleaded gasoline** at the cable ranges tested:

- **Detection Accuracy** (Equation 1)
- **Product Activation Height** as the Average Observed Value (Equation 2) with Standard Deviation (Equation 3)
- **Detection Length** (Equation 4) as the Average Observed Value (Equation 2) with Standard Deviation (Equation 3)
- **Response Time** (Equation 5) as the Average Observed Value (Equation 2) with Standard Deviation (Equation 3)
- **Recovery Time** (Equation 6) as the Average Observed Value (Equation 2) with Standard Deviation (Equation 3)

For Quantitative Detectors

Calculate and report for all three cable ranges tested:

- **Distance to Leak** as the:
  - Average Observed Value (Equation 2) with Standard Deviation (Equation 3)
  - Relative Accuracy (Equations 7, 8, and 9)
  - Coefficient of Variation (Equation 10)
  - Bias (Equation 11)

4.2 Calculations for Testing Specificity

For heating oil, diesel fuel, synthetic gasoline, and water
Calculate and report at the cable range tested:

- **Detection Accuracy** (Equation 1)
- **Product Activation Height** as the Average Observed Value (Equation 2) with Standard Deviation (Equation 3)
- **Detection Length** (Equation 4) as the Average Observed Value (Equation 2) with Standard Deviation (Equation 3)
- **Response Time** (Equation 5) as the Average Observed Value (Equation 2) with Standard Deviation (Equation 3)
- **Recovery Time** (Equation 6) as the Average Observed Value (Equation 2) with Standard Deviation (Equation 3)

- **Specificity** (Equation 12) for the:
  - **Detection Accuracy**
  - **Detection Length**

  [Use unleaded gasoline as the reference point.]

For Quantitative Detectors
Calculate and report at the cable range tested:

- **Distance to Leak** as the:
- Average Observed Value (Equation 2) with Standard Deviation (Equation 3)

- **Specificity** (Equation 11) for **Distance to Leak**
  [Use unleaded gasoline as the reference point.]

4.3 Calculations for Testing Lower Detection Limit

Report the calculated lower detection limit (Equations 13, 14) for the height of the test liquid needed to activate the monitor. Use the data collected for unleaded gasoline at the maximum effective range for the cable being tested.

5.0 Equations

$$\text{detection accuracy, \%} = \frac{r_p}{n} \times 100 \qquad (1)$$

$$\text{average observed value } (\overline{V_o}) = \frac{1}{n} \sum_{i=1}^{n} V_i \qquad (2)$$

$$\text{standard deviation of n values (s)} = \sqrt{\frac{\sum_{i=1}^{n} V_i^2 - n\left(\overline{V_o}\right)^2}{n - 1}} \qquad (3)$$

$$\text{detection length} = \frac{H_a}{D_c} \times C_{core} \qquad (4)$$

$$\text{response time} = T_{activation} - T_{initial} \qquad (5)$$

$$\text{recovery time} = T_{recovery} - T_{activation} \qquad (6)$$

$$\text{confidence coefficient (c c)} = t_{0.975} \times \frac{s}{\sqrt{n}} \qquad (7)$$

$$\text{mean difference } (\overline{d}) = \frac{1}{n} \sum_{i=1}^{n} d_i \qquad (8)$$

$$\text{relative accuracy (RA), \%} = \frac{|\overline{d}| + |c\,c|}{V_r} \times 100 \qquad (9)$$

$$\text{coefficient of variation, \%} = \frac{s}{\overline{V_o}} \times 100 \qquad (10)$$

$$\text{bias, \%} = \frac{\overline{V_o} - V_r}{V_r} \times 100 \qquad (11)$$

$$\text{specificity, \%} = \frac{\overline{V_o}}{V_r} \times 100 \quad (12)$$

$$\text{absolute bias, B} = \left| \overline{V_o} - V_r \right| \quad (13)$$

$$\text{lower detection limit} = 2 \; (K \times s) + B \quad (14)$$

====================

6.0 Symbols

B = absolute bias

c c = 2.5% error confidence coefficient (one-tailed)

$\overline{d}$ = arithmetic mean of the difference of a data set

C_{core} = circumference of the solid chamber core

d_i = measured response - theoretical response

D_c = sensor cable diameter

H_a = product activation height

K = one-sided tolerance limit factor for a 5% beta error at a 95% confidence level [3.707 for n=6] (Table 2)

n = number of tests in the data set

r_p = number of positive responses

s = standard deviation of n values (n-1 degrees of freedom)

$t_{0.975}$ = one-sided 2.5% t value [2.447 for n–1=5; 3.182 for n-1=2] (Table 1)

$T_{activation}$ = time when monitor becomes activated

$T_{initial}$ = time when liquid is first added to the test container

$T_{recovery}$ = time when monitor recovers to 95% of the original signal

V_i = the individual response to the test product

$\overline{V_o}$ = the average observed value

V_r = the reference or theoretical value

Disclaimers

These procedures involve hazardous materials, operations, and equipment. This document does not purport to address all of the safety problems associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use. There is no intent to endorse any commercial products that may be mentioned in these procedures.

TABLE 1. 2.5% t Values

n - 1	$t_{0.975}$
0	12.708
1	4.303
2	3.182
3	2.776
4	2.571
5	2.447
6	2.365
7	2.306
8	2.262

CRC Mathematical Tables, 28th. edn., CRC Press, Inc., Boca Raton, FL, 1987.

TABLE 2. One-Sided Tolerance Limit Factors for a 5% Beta Error at a 95% Confidence Level

n	Tolerance Limit Factor (K)
3	7.655
4	5.145
5	4.202
6	3.707
7	3.399
8	3.188

Experimental Statistics, M. G. Natrella, National Bureau of Standards Handbook 91, U. S. Department of Standards, Stock Number 003-003-00135-0, 1963, Reprinted 1966.

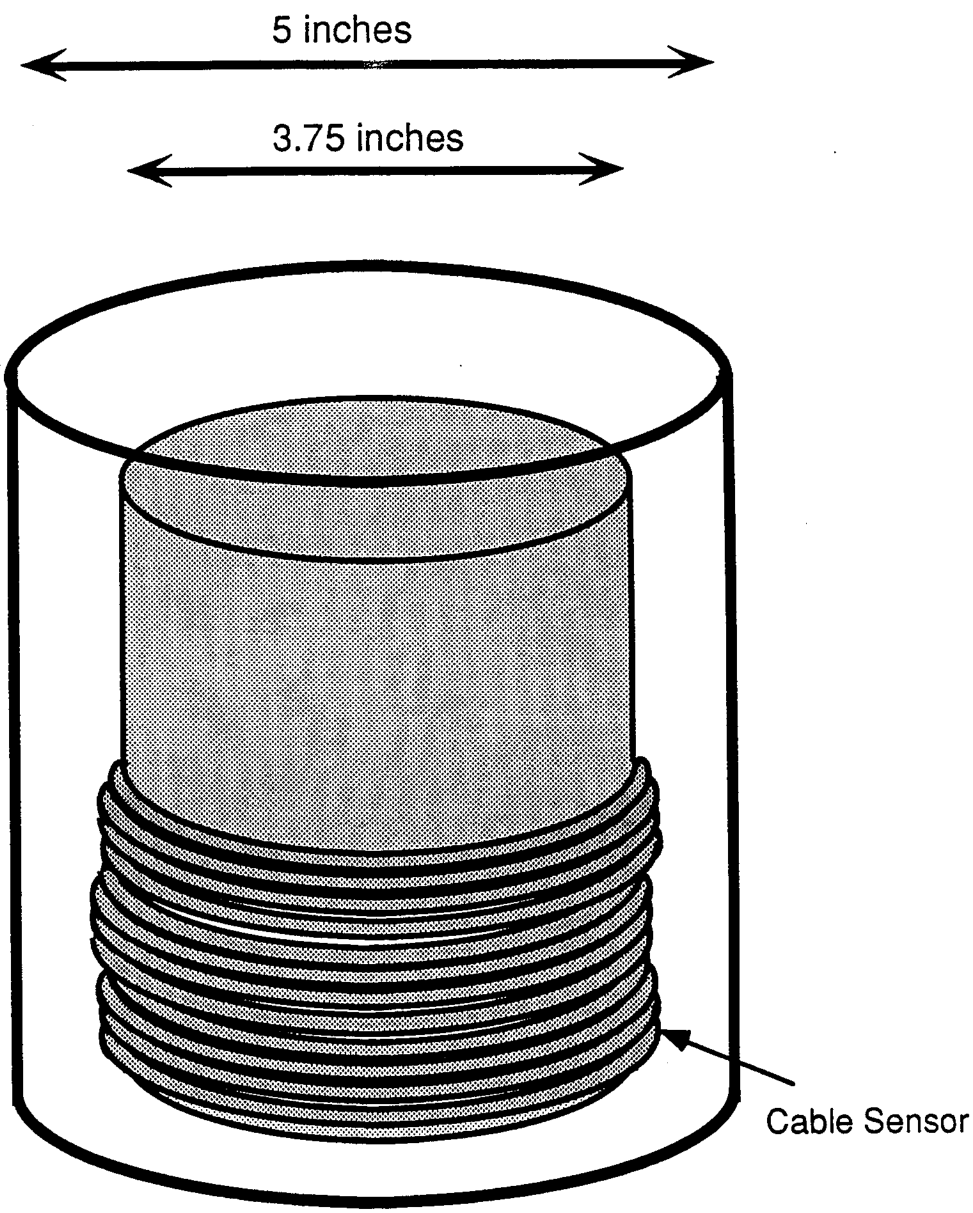

FIGURE 1c: TEST CHAMBER FOR CABLE SENSOR

(not to scale)

Appendix 1 -- EPA Documents: Foreword

Standard Test Procedures for Evaluating Leak Detection Methods: Liquid-Phase Out-of-Tank Product Detectors, EPA/530/UST-90/009 March 1990

Foreword

How to Demonstrate that Leak Detection Methods Meet EPA's Performance Standards

The Environmental Protection Agency's (EPA'S) regulations for underground storage tanks require owners and operators to check for leaks on a routine basis using a number of detection methods (40 CFR Part 280, Subpart D). In order to ensure the effectiveness of these methods, EPA set minimum performance standards for equipment used to comply with the regulations. For example, after December 22, 1990, all tank tightness testing methods must be capable of detecting a 0.10 gal/hr leak rate with a probability of detection of at least 95% and a probability of false alarm of no more that 5%. It is up to tank owners and operators to select a method of leak detection that has been shown to meet the relevant performance standard.

Deciding whether a method meets the standard has not been easy, however. Until recently, manufacturers of leak detection methods have tested their equipment using a wide variety of approaches, some more rigorous than others. Tank owners and operators have been generally unable to sort through the conflicting sales claims that are made based on the results of these evaluations. To help protect consumers, some state agencies have developed mechanisms for approving leak detection methods. These approval procedures vary from state to state, making it their method nationwide. The purpose of this policy is to describe the ways that owners and operators can check that the leak detection equipment or service they purchase meets the federal regulatory requirements. States may have additional requirements for approving the use of leak detection methods.

EPA will not test, certify or approve specific brands of commercial leak detection equipment. The large number of commercially available leak detection methods makes it impossible for the Agency to test all the equipment or review all the performance claims. Instead, the Agency is describing how equipment should be tested to prove that it meets the standards. Conducting this testing is left up to equipment manufacturers in conjunction with third-party testing organizations. The manufacturers will then provide a copy of the report showing that the method meets EPA's performance standards. This information should be provided to customers or regulators as requested. Tank owners and operators should keep the evaluation results on file to satisfy EPA's record keeping requirements.

EPA recognizes three distinct ways to prove that a particular brand of leak detection equipment meets the federal performance standards:

1. Evaluate the method using the EPA's standard test procedures for leak detection equipment;

2. Evaluate the method using a national voluntary consensus code or standard developed by a nationally recognized association or independent third-party testing laboratory; or,

3. Evaluate the method using a procedure deemed equivalent to an EPA procedure by a nationally recognized association or independent third-party testing laboratory.

The manufacturer of the leak detection method should prove that the method meets the regulatory performance standards using one of these three approaches. For regulatory enforcement purposes, each of the approaches is equally satisfactory. The following sections describe the ways to prove the performance in more detail.

EPA Standard Test Procedures

EPA has developed a series of standard test procedures that cover most of the methods commonly used for underground storage tank leak detection. These include:

1. "Standard Test Procedures for Evaluating Leak Detection Methods: Volumetric Tank Tightness Testing Methods"
2. "Standard Test Procedures for Evaluating Leak Detection Methods: Non-Volumetric Tank Tightness Testing Methods"
3. "Standard Test Procedures for Evaluating Leak Detection Methods: Automatic Tank Gauging Systems"
4. "Standard Test Procedures for Evaluating Leak Detection Methods: Statistical Inventory Reconciliation Methods"
5. "Standard Test Procedures for Evaluating Leak Detection Methods: Vapor-Phase Out-of-Tank Product Detectors"
6. "Standard Test Procedures for Evaluating Leak Detection Methods: Liquid-Phase Out-of-Tank Product Detectors"
7. "Standard Test Procedures for Evaluating Leak Detection Methods: Pipeline Leak Detection Systems"

Each test procedure provides an explanation of 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 if the method meets the regulatory requirements.

The EPA standard test procedures may be conducted directly by equipment manufacturers or may be conducted by an independent third party under contract to the manufacturer. However, both state agencies and tank owners typically prefer that the evaluation be carried out by an independent third party in order to prove compliance with the regulations. Independent third parties may include consulting firms, test laboratories, not-for-profit research organizations, or educational institutions with no organizational conflict of interest. In general, EPA believes that evaluations are more likely to be fair and objective the greater the independence of the evaluating organization.

National Consensus Code or Standard

A second way for a manufacturer to prove the performance of leak detection equipment is to evaluate the system following a national voluntary consensus code or standard developed by a nationally recognized association (e.g. ASTM, ASME, ANSI, etc.). Throughout the technical regulations for underground storage tanks, EPA has relied on national voluntary consensus codes to help tank owners decide which brands of equipment are acceptable. Although no such code presently exists for evaluating leak detection equipment, one is under consideration by the ASTM D-34 subcommittee. The Agency will accept the results of evaluations conducted following this or similar codes as soon as they have been adopted. Guidelines for developing these standards may be found in the U.S. Department of Commerce "Procedures for the Development of Voluntary Product Standards" (FR, Vol. 51, No.118, June 20, 1986) and OMB Circular No. A-119.

Alternative Test Procedures Deemed Equivalent to EPA's

In some cases, a specific leak detection method may not be adequately covered by EPA standard test procedures or a national voluntary consensus code, or the manufacturer may have access to data that makes it easier to evaluate the system another way. Manufacturers who wish to have their equipment tested according to a different plan (or who have already done so) must have that plan developed or reviewed by a nationally recognized association or independent third-party testing laboratory (e.g. Factory Mutual, National Sanitation Foundation, Underwriters Laboratory, etc.). The results should include an accreditation by the association or laboratory that the conditions under which the test was conducted were at least as rigorous as the EPA standard test procedure. In general, this will require the following:

1. The evaluation tests the system both under the no-leak condition and an induced-leak condition with an induced leak rate as close as possible to (or smaller than) the performance standard. In the case of tank testing, for example, this will mean testing under both 0.0 gallon per hour and 0.10 gallon per hour leak rates. In the case of ground water monitoring, this will mean testing with 0.0 and 0.125 inch of free product.

2. The evaluation should test the system under at least as many different environmental conditions as the corresponding EPA test procedure.

3. The conditions under which the system is evaluated should be at least as rigorous as the conditions specified in the corresponding EPA test procedure. For example, in the case of volumetric tank tightness testing, the test should include a temperature difference between the delivered product and that already present in the tank, as well as the deformation caused by filling the tank prior to testing.

4. The evaluation results must contain the same information and should be reported following the same general format as the EPA standard results sheet.

5. The evaluation of the leak detection method must include physical testing of a full-sized version of the leak detection equipment, and a full disclosure must be made of the experimental conditions under which (1) the evaluation was performed, and (2) the method was recommended for use. An evaluation based solely on theory or calculation is not sufficient.

APPENDIX 2:
Example Calculations Relating Product Leak Rate to Product Rate of Rise in an UST Interstitial Space.

Conversion Factors

1 ft^3 = 7.481 gal
1 in^3 = 0.00433 gal
1 gallon = 0.1337 ft^3
1 gallon = 231 in^3
1 ft^3 = 1728 in^3

Specifications

Tank Capacity = 5000 gal = 668 ft^3
Interstitial Spacing = 3 in
Leak Rate = 0.2 gal/hr = 46.2 in^3/hr

Assume: Double-walled UST with a capacity of 5000 gal or 668 ft^3 and an interstitial spacing of 3 inches. The cable sensor hangs vertically in the interstitial space on one end of the UST.

Assumed dimensions

Internal tank: 70 in. (width) X 236 in. (length) X 70 in. (height).
External tank: 76 in. (width) X 242 in. (length) X 76 in. (height).
Interstitial area (A) where the leaking product will accumulate:
76 in. X 3 in. or 228 in^2.

The UST is tilted so that all of the fluid accumulates in area A. If the product leak rate is 0.2 gal/hr or 46.2 in^3/hr, equation 1, then the product will rise at the rate of 0.2 in/hr, equation 2.

$$\text{Product Leak Rate: } 0.2 \text{ gal/hr} \times 231 \text{ in}^3\text{/gal} = 46.2 \text{ in}^3\text{/hr} \qquad (1)$$

$$\text{Rate of Product Rise} = \frac{\text{Product Leak Rate}}{\text{Interstitial Area}} = \frac{46.2 \text{ in}^3\text{/hr}}{228 \text{ in}^2} = 0.203 \text{ in/hr} \qquad (2)$$

If the Product Activation Height for a given point sensor is 1 in., then it will take at least 5 hrs. for enough product to accumulate to cause the sensor to activate and sound an alarm, equation 3.

$$\text{System Response Time} = \frac{\text{Product Activation Height}}{\text{Rate of Product Rise}} = \frac{2 \text{ in}}{0.203 \text{ in/hr}} = 5 \text{ hrs} \qquad (3)$$

Appendix 3

Excerpts from EPA Documents: Preparation of Synthetic Gasoline

Standard Test Procedures for Evaluating Leak Detection Methods: Liquid-Phase Out-of-Tank Product Detectors, EPA/530/UST-90/009 March 1990

X0004: Standard Practice for Preparation of Synthetic Gasoline

1. Scope

1.1 This practice covers preparation of a standard hydrocarbon mixture to be used for testing out-of-tank petroleum detectors. The mixture is intended to approximate commercially available automotive gasoline.

2. Summary of Test Method

2.1 An eleven-component mixture consisting of chemicals representing classes of chemicals found in automotive gasoline is mixed in standard proportions.

3. Significance of Use

3.1 The synthetic gasoline mixture is used as a standard for determining the performance of out-of-tank petroleum detectors. This mixture is provided because commercial gasoline compositions vary geographically, seasonally, and by manufacturer.

7. Procedure

7.1 Prepare 1-L of synthetic gasoline by mixing the identified volumes of hydrocarbon liquids listed in Table 1 in a glass container. The mixture should be prepared using glass graduated cylinders or burets, and the resulting mixture should be stored in a tightly sealed container as soon after preparation as possible to avoid loss of volatile components.

Table 1. Synthetic Gasoline Component Proportions and Volumes

Component	Proportion, wt%	Volume Per Liter, mL
2-methlybutane	10	119
n-pentane	10	118
n-hexane	5	56
2-methyl-2-butene	5	56
2,2,4-trimethylpentane	5	52
n-octane	20	211
cyclohexane	5	48
toluene	20	171
1,2,4-trimethylbenzene	8	68
benzene	2	17
xylene(s)	10	84

Appendix 4 -- Definitions

Activated -- refers to the state of a qualitative detector's response when indicating the presence of hydrocarbons.

Bias -- systematic error inherent in a method. It may be positive or negative.

Cable sensor -- a component of a leak detection system in which the sensor mechanism is a part of a continuous length of cable. It must come into contact with the hydrocarbon before a leak is detected.

Cable sensor test length -- the length of cable to be wrapped around the test chamber solid core. The length is calculated as 120% of the minimum sensitive length rounded to the next higher foot.

Detection -- refers to the activation of a leak monitor, indicating the presence of hydrocarbons.

Detection Accuracy -- the measure, in percent, of sensor response to the presence of a given test liquid.

Detection Length -- refers to the length of cable in contact with the liquid at the time of sensor activation.

Effective range -- same as maximum effective range.

Jumper cable -- a non-sensing cable which serves to connect other parts of a leak detection system.

Maximum effective range -- the maximum length of sensor cable and jumper cable that can be connected to form a leak detection network.

Minimum sensitive length -- length of sensor cable that must be wetted before the monitor is activated. Sensitivity can vary with the range of the leak detection network.

Non-activated -- refers to the state of a qualitative detector's response when indicating that no hydrocarbons are present.

Point sensor -- a component of a leak detection system which functions as a discrete location sensor. It must come into contact with the hydrocarbon before a leak is detected.

Precision -- the degree of agreement of repeated measurements of the same parameter. It reflects random error and is not affected by bias. Precision is defined as the percent coefficient of variation.

Product activation height -- the height of fuel product required to activate the sensor/monitor

Qualitative detector -- type of detector which responds only to the presence or absence of hydrocarbons without determining the distance to hydrocarbon leak.

Quantitative detector -- type of detector which responds to the presence or absence of hydrocarbons. It also determines the distance to hydrocarbon leak.

Recovery time -- the elapsed time from a detector's activated response until it reaches at least 95% of its original signal output or achieves a non-activated response.

Response -- detector's indication of the presence of petroleum hydrocarbons.

Response time -- the elapsed time from a detector's first contact with the test product until it reaches 95% of its predicted signal output or until it produces an activated response.

Sensitivity -- a measure of the intensity of the monitor response with respect to the amount of sensor cable wetted. Sensitivity varies with the range of the leak detecting network.

Specificity -- the ability of a sensor to respond to various test liquids. It is measured by the percent difference between the average value for a series of tests and a reference value.

Test product -- commercial or synthetic gasoline used to characterize detector performance.

Other definitions relating to statistical calculations can be found in ASTM E456 -- Standard Terminology Relating to Statistics

Appendix 5 -- Referenced Documents

1. **Rules and Regulations**, Federal Register, Vol. 53, No. 185, Sept. 23, 1988, 37164-5

2. **Standard Test Procedures for Evaluating Leak Detection Methods: Liquid-Phase Out-of-Tank Product Detectors**, EPA/530/UST-90/009, March 1990.

3. **Leak Prevention and Corrective Action Technology for Underground Storage Tanks**, Gangadharan, et al., Noyes Data Corporation, Park Ridge, NJ (1988), pg. 21.

4. **Standard Test Procedures for Evaluating Leak Detection Methods: Liquid-Phase Out-of-Tank Product Detectors**, EPA/530/UST-90/009, including Method X0004 -- "Standard Practice for Preparation of Synthetic Gasoline."

5. **Modeling Vapor Phase Movement in Relation to UST Leak Detection**, prepared by Schreiber, Levy, Rosenberg, Camp Dresser and McKee, Inc., EPA Office of Underground Storage Tanks Contract No. 68-03-3409, Draft Copy.

6. **Modeling Liquid Phase Movement in Relation to UST Leak Detection**, prepared by Schreiber, Levy, Rosenberg, Camp Dresser and McKee, Inc., EPA Office of Underground Storage Tanks, Draft Copy still with the editors.

7. **Detection System Placement Parameters for Leaking Underground Fuel Systems**, Kreamer, David, Arizona State University, Prepared for W. L. Gore and Associates, July 1990.

8. **CRC Mathematical Tables**, 28th. edn., CRC Press, Inc., Boca Raton, FL (1987).

9. **Experimental Statistics**, M. G. Natrella, National Bureau of Standards Handbook 91, US Department of Standards, Stock Number 003-003-00135-0 (1963, Reprinted 1966).

10. **Handbook of Statistical Methods for Engineers and Scientists**, ed. H. M. Wadsworth, Jr., McGraw-Hill, New York (1990).

11. **ASTM D1125** -- Standard Test Methods for Electrical Conductivity and Resistivity of Water.

12. **ASTM E456** -- Standard Terminology Relating to Statistics.

Appendix 6 -- Reagents

Unleaded gasoline -- regular unleaded gasoline purchased at a retail outlet. The gasoline should contain less than 2% water-miscible substances.

Synthetic gasoline -- an eleven component mixture representative of automotive gasoline. It is prepared according to Method X0004, see Appendix 5.

Heating oil -- Fuel oil No. 2 purchased at a retail outlet. The fuel should contain less than 2% water-miscible substances.

Diesel fuel -- Automotive diesel fuel, grade 2, purchased at a retail outlet. The fuel should contain less than 2% water-miscible substances.

Water -- drinking water or other relatively pure water with an electrical conductivity of at least 50 µmho/cm. See ASTM D1125 -- Standard Test Methods for Electrical Conductivity and Resistivity of Water.

Appendix 7

EPA Document Review Letter

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OCT 31 1991

Marc Portnoff
Carnegie Mellon Research Institute
Advanced Devices and Materials Group
4400 Fifth Avenue
Pittsburgh, PA 15213-2683

OFFICE OF
SOLID WASTE AND EMERGENCY RESPONSE

Dear Mr. Portnoff:

This letter is in response to your request for documentation of our earlier conversations. Your draft reports entitled "Test Procedures for Third Party Evaluation of Leak Detection Methods: Cable Sensor Liquid Contact Leak Detection Systems" and "Test Procedures for Third Party Evaluation of Leak Detection Methods: Point Sensor Liquid Contact Leak Detection Systems" were reviewed by Joe Womack of EPA's Region VI and myself. These test procedures were developed for evaluation of certain leak detection systems for which there are presently no EPA methods or procedures.

Our review was done from the point of view of trying to determine whether or not EPA's intent for evaluation is achieved in these procedures. It does appear that the procedures were developed in a manner that will allow test results to be compared to EPA standards. Therefore, systems evaluated by these procedures would likely be acceptable both to industry and to state and local implementing agencies. We assume that appropriate data and reporting forms will be developed for inclusion in the final procedure.

Of course, I must note that EPA will neither test, certify, or approve specific brands of leak detection equipment, nor deem evaluation procedures equivalent to EPA's. I thank you for consulting EPA and keeping us informed, and I apologize for not responding in writing earlier. Please call me at (703)308-8877 if you have any questions.

Yours,

David R. Wiley
Office of Underground Storage Tanks

cc: Dave O'Brien
Joe Womack, Region VI

wiley\external

Appendix 8

Qualitative Liquid Contact Cable Sensor Results Form

Results of Third Party Standard Evaluation

Cable Sensor Liquid Contact Product Detectors

This form documents the performance of the cable sensor liquid contact leak detection system described below. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the Third Party Procedures developed according to the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Liquid-Phase Out-of-Tank Product Detectors."[1]

Tank owners using this leak detection system should keep this form on file to prove compliance with the federal regulations. Tank owners should check with state and local agencies to verify that this form satisfies their requirements.

Method Description

Name ______________________________

Version ______________________________

Vendor ______________________________

____

(street address)

____

(city) (state) (zip) (phone)

Detector output type: ___Qualitative

Detector operating principle: ___Electrical Conductivity ___Capacitance Change ___Interface Probe ___Product Permeable ___Product Soluble ___Thermal Conductivity ___Other ______________________

Detector sampling frequency: ___Intermittent ___Continuous

Evaluation Results

The detector described above was tested for its ability to detect test liquids in contact with the cable sensor. The following parameters were determined:

- Detection Accuracy - The measure of sensor response to the presence of liquids.
- Bias - Whether the method consistently over-estimates or under-estimates leak location. Not applicable to qualitative detectors.
- Detection Length - The length of cable in contact with liquid, when the sensor is activated.
- Response Time - Amount of time the detector must be exposed to liquid before it responds.
- Recovery Time - Amount of time that passes before the detector returns to its baseline reading after the test liquid is removed.
- Lower Detection Limit - The smallest liquid concentration that the detector can reliably detect.
- Precision - Agreement between multiple measurements of the leak location. Not applicable to qualitative detectors.
- Product Activation Height - The height of liquid to cause sensor activation.
- Specificity - Indicates the level of response, of the detector, to several different liquids.

---

[1] Carnegie Mellon Research Institute. Test Procedures for Third Party Evaluation of Leak Detection Methods: Cable Sensor Liquid Contact Leak Detection Systems: Final Report - November 11, 1991.

Liquid Contact Product Detector________________

Version________________

Evaluation Results (continued)

> **Compiled Test Results for Qualitative Detector** - **Cable Length** - ________

(Test Product Flow Rate:) **Cable tested at** ________

	Detection Accuracy	Product Activation Height	Detection Length	Response Time at a Flow Rate of	Recovery Time
Accuracy and Response Time Regular Unleaded Commercial Gasoline (6 tests)					
Specificity Synthetic Fuel (3 tests)					
Diesel Fuel (3 tests)					
Home Heating Oil #2 (3 tests)					
Water (3 tests)					

* **Specificity Reference: Regular Unleaded Commercial Gasoline**

Calculated Lower Detection Limit for 95% / 5% Condition	Product Activation Height	Detection Length
Regular Unleaded Commercial Gasoline		

> **Safety disclaimer:** This test procedure only addresses the issue of the method's ability to detect the presence of liquid product. It does not test the equipment for safety hazards.

Certification of Results

I certify that the cable sensor liquid contact product detector was operated according to the vendor's instructions and that the evaluation was performed according to the Third Party Procedures developed according to the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Liquid-Phase Out-of-Tank Product Detectors."[1] I also certify that the results presented above are those obtained during the evaluation.

________________ (printed name)

________________ (organization performing evaluation)

________________ (signature)

________________ (city, state, zip)

________________ (date)

________________ (phone number)

Appendix 9

Quantitative Liquid Contact Cable Sensor Results Form

Results of Third Party Standard Evaluation

Cable Sensor Liquid Contact Product Detectors

This form documents the performance of the cable sensor liquid contact leak detection system described below. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the Third Party Procedures developed according to the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Liquid-Phase Out-of-Tank Product Detectors."[1]

Tank owners using this leak detection system should keep this form on file to prove compliance with the federal regulations. Tank owners should check with state and local agencies to verify that this form satisfies their requirements.

Method Description

Name ____

Version ____

Vendor ____

____
(street address)

____
(city) (state) (zip) (phone)

Detector output type: ___Quantitative

Detector operating principle: ___Electrical Conductivity ___Capacitance Change ___Interface Probe ___Product Permeable ___Product Soluble ___Thermal Conductivity ___Other ________________________

Detector sampling frequency: ___Intermittent ___Continuous

Evaluation Results

The detector described above was tested for its ability to detect test liquids in contact with the cable sensor. The following parameters were determined:

- Detection Accuracy - The measure of sensor response to the presence of liquids.
- Bias - Whether the method consistently over-estimates or under-estimates leak location. Not applicable to qualitative detectors.
- Detection Length - The length of cable in contact with liquid, when the sensor is activated.
- Response Time - Amount of time the detector must be exposed to liquid before it responds.
- Recovery Time - Amount of time that passes before the detector returns to its baseline reading after the test liquid is removed.
- Lower Detection Limit - The smallest liquid concentration that the detector can reliably detect.
- Maximum Effective Range (MER) - The longest length of sensor cables and / or jumper cables that can be connected to form a leak detection network.
- Precision - Agreement between multiple measurements of the leak location. Not applicable to qualitative detectors.
- Product Activation Height - The height of liquid to cause sensor activation.
- Specificity - Indicates the level of response, of the detector, to several different liquids.

---

1 Carnegie Mellon Research Institute. Test Procedures for Third Party Evaluation of Leak Detection Methods: Cable Sensor Liquid Contact Leak Detection Systems: Final Report - November 11, 1991.

Liquid Contact Product Detector____________________

Version____________________

Evaluation Results (continued)

> Compiled Test Results for Quantitative Detector

Sensor Cable Maximum Effective Range (MER):__________

Test Product Flow Rate:__________

	Detection Accuracy %	Product Activation Height in (cm)	Detection Length ft (cm)	Response Time hr:min:sec	Recovery Time hr:min:sec
Accuracy and Response Time Regular Unleaded Commercial Gasoline (6 tests at each length) 1/3 MER Cable Test Length__________					
2/3 MER Cable Test Length__________					
MER Cable Test Length__________					
Specificity @ MER (3 tests for each liquid) Synthetic Fuel					
Diesel Fuel					
Home Heating Oil #2					
Water					

*** Specificity Reference: Regular Unleaded Commercial Gasoline**

Calculated Lower Detection Limit for 95% / 5% Condition	Product Activation Height in (cm)	Detection Length ft (cm)
Regular Unleaded Commercial Gasoline		

____

(signature) (date)

Liquid Contact Product Detector ____________________

Version ____________________

Evaluation Results (continued)

> **Compiled Test Results for Product Location Measurements.**

	Cable Test Length (1/3 MER) ________ ft	Cable Test Length (2/3 MER) ________ ft	Cable Test Length (MER) ________ ft
<u>**Product Location Accuracy**</u> Regular Unleaded Commercial Gasoline <u>(6 tests at each length)</u> **Average Observed Value**			
Standard Deviation			
Relative Accuracy			
Coefficient of Variation			
Bias			
<u>Specificity @ MER</u> <u>(3 tests for each liquid)</u> Synthetic Fuel			
Diesel Fuel			
Home Heating Oil #2			
Water			

* **Specificity Reference: Regular Unleaded Commercial Gasoline**

> **Safety disclaimer:** This test procedure only addresses the issue of the method's ability to detect the presence of liquid product. It does not test the equipment for safety hazards.

Certification of Results

I certify that the cable sensor liquid contact product detector was operated according to the vendor's instructions and that the evaluation was performed according to the Third Party Procedures developed according to the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Liquid-Phase Out-of-Tank Product Detectors."[1] I also certify that the results presented above are those obtained during the evaluation.

____________________ (printed name)

____________________ (organization performing evaluation)

____________________ (signature)

____________________ (city, state, zip)

____________________ (date)

____________________ (phone number)