Alternative Test Procedures for Evaluating Leak Detection Methods:

Mass-Based Leak Detection Systems for Aboveground Storage Tanks Larger than 50,000 gallons

Prepared for General Use by Ken Wilcox Associates, Inc.
Revision Date: November 2002

Copies of this protocol may be obtained at: http://www.kwaleak.com

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Prepared by:

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DISCLAIMER

The procedures described in this document have been based on those in the EPA's standard evaluation procedures for evaluating leak detection methods for underground storage tanks.[1] This protocol was developed by modifying the “Alternative Test Procedures for Evaluating Leak Detection Methods: Mass-Based and Volumetric Leak Detection Systems for Bulk Field-constructed Tanks”, Ken Wilcox Associates, November 2000.

Users are cautioned that although this alternative protocol may have been reviewed and accepted by some regulatory agencies, this does not mean that all agencies will necessarily find it acceptable. All regulatory agencies within the geographic area of application should be contacted prior to testing to assure that the results will be acceptable. KWA, Inc. makes no statement regarding the applicability, acceptability, or quality of results that may be obtained by other users, nor do we guarantee that any individual regulator or agency will accept the results.

Ken Wilcox Associates prepared this document for use by anyone who wishes to evaluate mass-based leak detection systems for aboveground storage tanks larger than 50,000 gallons. The effort was funded entirely by KWA. Users should feel free to copy or modify this protocol without restriction in any way that is acceptable to the cognizant regulatory agency.

[1] "Standard Test Procedures for Evaluating Leak Detection Methods," EPA/530 UST-90/001-7, March to October 1990. Seven different procedures were developed for different leak detection methods and released between March and October 1990.

PEER REVIEW AND ACKNOWLEDGMENTS

A peer review committee was organized to review this protocol prior to its public release. Members of the committee were familiar with leak detection regulations and AST operations. They reviewed the protocol and provided valuable technical input to the development of this protocol. The committee members consisted of the following individuals:

- Richard Bradley, HSE Coordinator & ASA Trainer, BP Products North America, Inc.
- Jack Quigley, Professor Emeritus, Department of Engineering Professional Development, University of Wisconsin-Madison
- Bill Trussler, Shell Canada

An appendix describing the use of multiple tests to improve the performance of leak detection systems is also included as part of this protocol. This appendix was taken directly from the Bulk Tank Evaluation Protocol.[2] Mr. Jon Reeder, Florida Department of Environmental Protection, and Dr. Joe Maresca, Vista Research, offered valuable statistical assistance to the scaling procedures and the use of multiple tests.

Development of this test protocol was funded entirely by KWA. The protocol was prepared by Jeffrey K. Wilcox and H. Kendall Wilcox, Ken Wilcox Associates, Inc.

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2 "Alternative Test Procedures for Evaluating Leak Detection Methods: Mass-based and Volumetric Leak Detection Systems for Bulk Field-constructed Tanks", Ken Wilcox Associates, Inc., November 2000.

FOREWORD

The purpose of this document is to provide the details for an evaluation procedure developed and utilized by Ken Wilcox Associates, Inc. There are several reasons why it has been necessary to develop these procedures. These include the following:

1. The federal EPA does not require leak detection for Aboveground Storage Tanks and there is not therefore a procedure for evaluating leak detection equipment designed for Aboveground Storage Tanks. This evaluation protocol has been developed in an effort to bring standard methods of testing to ASTs so that users can compare leak detection methods based on reliable testing techniques.

2. Vendors and users of leak detection equipment for Aboveground Storage Tanks can use the results of evaluations conducted according to this protocol to determine the effectiveness of equipment.

KWA EVALUATION PROCEDURES

Ken Wilcox Associates, Inc. is an independent, internationally recognized third-party evaluation laboratory. The procedures described in this document are based on operating experience, recognized scientific and engineering practices, and the guidelines provided by the EPA and ASTM. Existing procedures have been adopted when practical. Alternatives have been developed as necessary to meet the specialized requirements of leak detection systems that are not covered by the existing protocols. The complete reports or evaluations conducted by Ken Wilcox Associates, Inc. include summaries of the test procedures, descriptions of the leak detection systems, and a full disclosure of the test results obtained from the testing.

For more information about KWA evaluation procedures, please contact Ken Wilcox Associates, Inc. at (816) 443-2494.

Table of Contents

1.0 INTRODUCTION

1.1 Background

This document provides an evaluation procedure that may be used for mass-based leak detection systems designed for Aboveground Storage Tanks (ASTs). There is not an official federal protocol for testing AST leak detection equipment. The procedures described in this document have incorporated many of the procedures contained in the EPA protocols for evaluating leak detectors for smaller underground storage tanks.

1.2 Applicability

This protocol applies to mass-based leak detection equipment designed to conduct leak detection testing on vertically walled ASTs with volumes larger than 50,000 gallons. The performance parameters of volumetric methods are not adequately addressed in this protocol. This protocol does not address temperature variations related to product transfers and diurnal conditions, which will affect volumetric methods. Although leak detection systems intended for use on tanks smaller than 50,000 gallons might be adequately evaluated using the procedures described in this protocol, other evaluation procedures should be considered.

This protocol does not define the performance necessary to achieve regulatory compliance. It does provide data necessary for calculating the minimum leak rate that can be detected with a probability of 95% or greater and a probability of false alarm of 5% or less. The issue of compliance is left to the cognizant regulatory agency. Persons using this protocol should check with the appropriate agency to determine if the method is satisfactory.

Leak detection methods being evaluated should be complete and representative of the actual equipment that will be installed or sold to the end user. Use of this protocol for testing prototype equipment with an objective of third-party certification is discouraged.

1.3 Safety

This discussion does not purport to address all the safety considerations involved in evaluating leak detection equipment and methods for underground storage tanks. The equipment used should be tested and determined to be safe for the products it is designed for. Each leak detection system should have a safety protocol as part of its standard operating procedure, which specifies requirements for safe installation and use of the device or method. Vendors should supply their safety protocol to the personnel involved in the evaluation. All safety procedures appropriate for the product in the tanks should be followed. In addition, any safety procedures required for a particular set of test equipment should be followed.

This test procedure only addresses the issue of the system's ability to detect leaks. It does not address testing the equipment for safety hazards. The manufacturer needs to arrange for other testing for construction standards to ensure that key safety hazards such as fire, shock, intrinsic safety, and product compatibility are considered.

2.0 TANKS AND TEST EQUIPMENT

2.1 Tanks

The use of this protocol has been restricted to vertical-wall ASTs with nominal volumes of 50,000 gallons or larger. Operating tanks may be used to conduct the evaluations described in this protocol as long as they can be taken out of service for the time necessary to conduct the testing. The test tank should be known to be tight and not have a history of problems. The use of tanks with problems can seriously compromise the test results and may result in a degradation of the performance of the system under evaluation.

2.2 Fixed vs. Floating Roofs

ASTs can be constructed with fixed-roofs or floating-roofs. This protocol does not require that leak detection methods be tested on both fixed and floating roof tanks. End-users are cautioned that floating-roofs may affect leak detection equipment if there is uneven movement of the roof along the circumference of the tank. It is expected that if the roof does not stick that the results on floating-roof tanks would be similar to those of fixed-roof tanks.

2.3 Test Equipment

The vendor or manufacturer will supply the equipment for each tank test method. In general, the test equipment will consist of some method of monitoring the amount of product in the tank and any changes that occur over time. Equipment typically includes instrumentation for collecting and recording the data and for using the data to calculate a leak rate.

If the test equipment is to be installed permanently and left to the tank owner to be operated, the evaluating organization personnel may operate the equipment after undergoing training from the vendor.

3.0 LEAK SIMULATION EQUIPMENT

Product is typically removed from the tank at a uniform rate using a small pump or orifice device. The volume of product removed from the tank over a specified time period is used to determine the induced leak rate. The volume of product removed during the test can be determined volumetrically or gravimetrically with conversion to volume using the fuel density.

4.0 PRODUCT

Any hydrocarbon product of grade number 2 or lighter may be used. Acceptable products include gasoline, no. 2 diesel fuel, aviation fuel, Jet-A, JP-4, JP-5, and kerosene. Other products may also be acceptable but some limitations could result from a poor choice of liquids used in the evaluation. Highly viscous materials such as motor oil should not be used unless the leak detector is designed to test viscous products.

The vendor must specify on the results forms (included in Appendix A) how the procedures account for or compensate for the variations in volatility of different fuel types because product volatility may affect the test method and the associated test results.

5.0 EVALUATION PROCEDURES

5.1 Evaluation Summary

A summary of the evaluation is as follows:

1. The vendor installs the leak detection equipment in the evaluation tank.
2. The third-party evaluator installs leak simulation equipment in the evaluation tank.
3. Leaks are introduced into the tank by the third-party evaluator.
4. The leak detection equipment is programmed to initiate a leak detection test.
5. The third-party evaluator maintains leak conditions for the duration of the testing.
6. Results of the leak tests are collected by the third-party from the leak detection equipment or the leak detection vendor.
7. Steps 2 through 6 are repeated until a minimum of 24 tests have been completed.
8. The reported results are compared to the induced leak rates and a report detailing the results of the analysis is prepared.

5.2 Induced Leak Rates

A minimum of 24 tests should be conducted. A minimum of 6 tests must be conducted with actual induced leaks present. If 24 tests are conducted, up to 18 of the 24 tests may be conducted without an induced leak (zero leak tests). The actual induced leak rates and the vendor's reported leak rates will need to be recorded for each leak detection test. The threshold for the method to produce a P_{FA} of 5% or less and a P_D of 95% or greater will be determined from the test results.

In general, the leak rates induced during the testing are those indicated in Table 1. The rates in Table 1 are based on the target leak rate set by the equipment vendor, based on their expectations of performance. The rates are to be used as a guideline, however, and variations in leak rates from Table 1 should not affect the results of the evaluation. The important parameter that is determined during the evaluation is the difference between the rate reported by the vendor and the actual induced leak rate.

Table 1. Example Induced Leak Rates for Two Target Leak Rates

		Example Target Leak Rates		**Suggested Number of Tests**
Leak No.	**Rate (gal/h)**	**1.0 gal/h**	**2.0 gal/h**	
1	Zero leak rate	0.0 gal/h	0.0 gal/h	Maximum of 18
2	½ x target leak rate	0.5 gal/h	1.0 gal/h	Minimum of 2
3	1 x target leak rate	1.0 gal/h	20 gal/h	Minimum of 2
4	2 x target leak rate	2.0 gal/h	4.0 gal/h	Minimum of 2

5.3 Zero Leak Rates versus Induced Leak Rates

The evaluation allows for the majority of tests to be zero leak tests, assuming that blind test conditions can be maintained. A majority of zero leak tests is allowed for several reasons. Zero leak tests can be conducted without personnel present, which will make an evaluation more economically feasible. Leak simulation equipment will not be required for zero leak tests, which is one of the main requirements of having personnel present. Since testing large ASTs will likely require 24 hours or more per test, the economic costs of conducting an evaluation during which personnel must be present for all 24 tests would likely be prohibitive. In many cases, personnel do not have to be present to start and stop tests or to record results. Most current systems include some form of communication that allows for electronic downloading of test results and for tests to be started and stopped remotely.

If more zero leak tests are conducted without personnel present, it may be possible to schedule several leak tests immediately following tank fills that occur as part of normal fueling operations. The logistics and costs involved with moving large volumes of fuel in and out of these tanks makes simulating tank fills very difficult for an evaluation. This protocol recommends that at least one test be conducted immediately following a tank fill to demonstrate that the leak detection method is capable of conducting testing without adverse affects following tank fills. If the tank fill affects the leak detection method adversely, a minimum of 3 additional tests following tank fills will be required for the evaluation (i.e. - a minimum total of 4 tank fills will be required).

From a statistical point, it does not matter if a leak is present or not to determine the P_D and the P_{FA} of a leak detection method. The difference between the actual induced leak rate and the reported leak rate is the important parameter in determining the P_D and the P_{FA} of a leak detection method. Assuming the induced leak rates are measured correctly, this difference should be independent of the rate of the leak and therefore the number of induced leak tests versus the number of zero leak tests is not important. The calculations do include a requirement for performing an F-Test comparison to determine if there is a statistical difference between the leak tests and the zero leak tests. If the F-test comparison fails, the evaluator will review the test data for accuracy and the larger standard deviation of the leak and non-leak tests will be used to calculate the P_D and the P_{FA} of a leak detection method.

5.4 Minimum Testing Time

Each test method requires a minimum test time to obtain its performance accuracy. All tests under evaluation will meet the minimum test time specified by the equipment vendor. The minimum test time requirement shall be used during the evaluation. The minimum test time will become part of the vendor’s standard test procedure and will be used for all subsequent field-testing using that method. The test times used in the evaluation will be recorded and the average test time reported as the minimum test time required by the method. Any reasons for the unusual test durations should be documented. Leak tests must be conducted for at least the average test time, irrespective of tank size. Scaling down of test times is not permitted.

5.5 Tank Fills (Product Deliveries)

One tank fill is recommended for this evaluation to demonstrate that the leak detection method is capable of conducting testing without adverse affects following tank fills. The tank fill may be done prior to the start of the evaluation or during some other point of the evaluation. Due to the economic and operational difficulties associated with filling very large tanks, this protocol does not specify the amount of the product transferred and the timing of the transfer. The evaluator and the vendor should work with the tank operator in scheduling the tank fill.

More than one tank fill is not required for several reasons:

- This protocol has been written for mass-based systems, which are not affected by product temperature changes that are the result of product deliveries.

- It is expected that most leak detection equipment evaluated using this protocol will be designed for ASTs that are 1-million gallons or larger. Simulating deliveries for tanks this large is not practical from an economic and operational perspective.

As mentioned in the Section 5.3, if more zero leak rate tests are conducted, it may be possible to schedule several leak tests immediately following tank fills that occur as part of normal fueling operations.

6.0 ENVIRONMENTAL DATA RECORDS

The following environmental data should be recorded. Weather station data may be used if available.

- Ambient temperatures during the testing
- Barometric pressure during the testing
- Special weather conditions occurring during the testing that might alter the test results such as rain, high winds, storm fronts, cloudy or sunny conditions, etc.
- Any other condition that might influence the test results

The above information should be recorded for each test on the individual test logs included in Appendix B.

7.0 CALCULATIONS

All of the statistical calculations described in the standard EPA test protocol for volumetric systems apply to evaluations conducted on ASTs. The threshold and MDL to obtain a probability of detection (P_D) of 95% and probability of false alarm (P_{FA}) of 5% are to be reported for the evaluation. Procedures for determining the P_D, P_{FA}, and MDL are contained in the standard EPA test protocol for volumetric systems[3] and are summarized below.

7.1 Basic Statistics

Form the differences between the leak rates reported by the system, L_i, and the induced leak rates, IL_i,

$$D_i = L_i - IL_i \, . \qquad (7\text{-}1)$$

The bias is estimated by the mean of the differences:

$$B = \Sigma\, D_i/N, \qquad (7\text{-}2)$$

where N is the number of tests in the evaluation and the summation is over all differences. The variance of the differences is found using the formula

$$V = \Sigma\, (D_i - B)^2/(\, N-1). \qquad (7\text{-}3)$$

The standard deviation, S, is the square root of the variance. A test of whether the bias is zero is based on the statistic

$$t = (N)^{1/2}\, B/S, \qquad (7\text{-}4)$$

which is compared to the two-sided value from a t-distribution with N-1 degrees of freedom for a level of significance of 5%. For N=24, the appropriate value from the t-table is 2.069. If the absolute value of t is less than the value from the t-table, then B is negligible. This means that zero is substituted for B in the following equations.

7.2 F-Test Comparison of Zero Leak Tests versus Induced Leak Tests

A two-sample F test should be done to compare the zero leak tests with the induced leak tests. To make this comparison, divide the data records into two groups. One group should include the zero leak tests and the other group should contain the induced leak tests. Calculate the mean and standard deviation separately for the two

[3] Standard Test Procedures for Evaluating Leak Detection methods: Volumetric Tank Tightness Testing Methods", pages 28-33 describe procedures for calculating the P_D, P_{FA}, and MDL.

groups. Use a two-sample F test to test whether the variances of the two groups are equal. Calculate

$$F = (S_1/S_2)^2 \qquad (7\text{-}5)$$

where S_1 and S_2 are the standard deviations calculated from the two groups. In forming the F ratio, use the standard deviation with the larger calculated value in the numerator. Compare the calculated value of F to the 95th percentile of an F-distribution with (n_1 - 1) degrees of freedom in the numerator (corresponding to S_1) and (n_2 - 1) degrees of freedom in the denominator (corresponding to S_2). The sample sizes are n_1 and n_2, respectively.

If the calculated value of F is less than the tabled value, there is no significant evidence that the two population variances are different. If the calculated value of F exceeds the tabled value, the two variances are significantly different at the 5% significance level.

If the F-test shows that the results of the zero leak tests and the induced leak tests are not significantly different from each other, the standard deviation of the combined data sets should be used to calculate the P_D and the P_{FA}. If the F-test shows that the results are significantly different, the largest standard deviation of the two groups should be used to calculate the P_D and the P_{FA}. The evaluator will also review the test data for accuracy.

7.3 Probability of False Alarm (P_{FA}), Probability of Detection (P_D), Threshold, and Minimum Detectable Leak (MDL)

<u>Probability of False Alarm</u>
The probability of a false alarm, P_{FA}, is the probability that the measured leak rate will exceed the threshold for declaring a leak when the testing is done on a tight tank. If the threshold is denoted by C, then the probability of a false alarm is estimated from

$$P_{FA} = P[t > (C - B)/S]. \qquad (7\text{-}6)$$

This probability is calculated by computing the term (C – B)/S using the specified threshold C and the bias, B, and standard deviation, S, computed from the test results. The result is used with a t-distribution with 23 degrees of freedom (assuming 24 tests were conducted). A table of the t-distribution is used to find the probability that a t-statistic with 23 degrees of freedom exceeds the computed value.

<u>Probability of Detection</u>
The probability of detecting a leak depends on the specific leak rate. For a leak rate of size R, the probability of detection, P_D, is given by

$$P_D = P[t > (C - R - B)/S]. \quad (7\text{-}7)$$

In the formula, the threshold, C, is specified as before, the leak rate for which the P_D is calculated is R, and B and S are calculated from the test data as before. The term (C – R – B)/S is computed. A t-distribution with 23 degrees of freedom is used to look up the probability that a t-statistic exceeds the calculated value.

Setting the Threshold

The threshold, C, may be set to give a specified probability of false alarm. For example, if a P_{FA} of 5% is desired, use the t-table to determine that the probability is 5% that a t-statistic with 23 degrees of freedom will exceed 1.714. To choose C, set

$$(C - B)/S = 1.714 \quad (7\text{-}8)$$

and solve for C to get

$$C = (1.714)(S) + B \quad (7\text{-}9)$$

which reduces to

$$C = (1.714)(S) \quad (7\text{-}10)$$

if B is zero.

Here B and S have been calculated from the test data.

Finding the Minimum Detectable Leak Rate.

For a specified threshold C, the smallest leak rate that can be detected with a specified probability, e.g. 95%, can be determined as the minimum detectable leak rate, MDL. This is accomplished by using a t-table to find the probability that a t-statistic with 23 degrees of freedom will exceed –1.714. Set

$$(C - R - B)/S = -1.714 \quad (7\text{-}11)$$

The value of R that solves the above equation is the MDL for the threshold C.

$$MDL = C - B + 1.714\,(S) \quad (7\text{-}12)$$

The value of R that satisfies the previous equation using the threshold for a 5% P_{FA} is the MDL for a 5% P_{FA} and a 95% P_D. This is the smallest leak rate that is detectable with 95% probability using the threshold C. Note if the bias is not statistically significantly different from zero it is taken to be zero.

7.4 Tank Size Limitations

Differing tank sizes and geometries can affect the quality of testing. The parameters that affect the relationship between the noise in a test and the tank size are not always well understood and may be a function of the specific type of technology that is under evaluation. Possible sources of variability include tank volume and surface area. It is probable that both are always present. For this protocol, tank size limitations have been based on surface area because the methods being evaluated are mass-based. The results of an evaluation may be applied to tanks smaller than the test tank down to a volume of 50,000 gallons. The evaluation results may be used on tanks with a product surface area up to 2.5 times larger than the test tank. Table 2 summarizes applying the evaluation results to tanks of differing sizes.

Table 2. Tank Size Limitations

	Product Surface Area	Product Volume
Scaling Limits	Maximum 2.5 X surface area, no minimum	50,000 gallon minimum, no maximum

7.5 Target Leak Rate and Threshold

Once the data are available and the statistics have been calculated the following results are to be reported on the official results forms.

- Standard deviation
- Threshold for declaring a leak
- Minimum detectable leak rate
- Target leak rate
- P_{FA} and P_D for the target leak rate

The evaluator and the vendor may select any target leak rate and threshold. Target leak rates and thresholds should also meet the specifications of the regulatory agencies located in areas that the leak detection method is expected to operate in. In general, the results must show that the system is capable of detecting the target leak rate with a probability of detection of 95% or greater and a probability of false alarm of 5% or less. The threshold can be adjusted within these limits to either reduce the probability of false alarm or improve the probability of detection or both. The threshold can also be adjusted to reduce the target leak rate without changing the P_D or P_{FA}.

The vendor may choose to report the test results using more than one target leak rate and threshold. A different version number should be used for the results with different target leak rates. A separate results form must be prepared for each different target leak rate.

7.6 Leak Rate and Threshold Scaling

A simple technical approach to developing scaling performance of mass measurement systems to other tank sizes has been taken. The relative surface area of two tanks is considered to be the largest contributor to performance variability between tank sizes. The standard deviation of the reference tank is multiplied by the ratio of the surface areas of the size of tank to which the evaluation results are to be applied. This can be expressed mathematically by the equation

$$S_2 = S_1 \times A_2/A_1 \qquad (7\text{-}13)$$

where S_1 is the population standard deviation obtained from the evaluation test data using a reference tank, S_2 is the population standard deviation to be used to predict performance on a tank of a different size, A_1 is the surface area of the evaluation reference tank, and A_2 is the surface area of the new tank.

The scaling is limited by the following restrictions.

1. The tank must have vertical walls.
2. Leak rate scaling is based on the product surface area.

The maximum size tank that may be tested is determined by consideration of the performance of the method as measured by the standard deviation. The standard deviation is scaled up using equation 1. A new minimum leak rate for a P_D of 95% must then be calculated for the larger tank. For example, to apply a method that has been evaluated on a tank with a surface area of 2,000 sq. ft. with a measured standard deviation of 0.5 gal/h to a tank with a surface area of 3,000 sq. ft, a new minimum detectable leak based on a standard deviation of 0.75 gal/h would be used.

The maximum tank size to which the method may be applied is limited to not more than 2.5 times the surface area of the tank used for the evaluation. Scaling to smaller tanks is allowed.

When scaling the results, the standard deviation of the results obtained during the evaluation should be used for S_1 in equation (7-13). This is the standard deviation calculated from the test data using equation (7-3) if the results are based on a single test.

The results form contains a table that lists the performance parameters for the test tank and for the maximum and minimum size tank for scaling. Additional tables representing results for other sizes of tanks may be included by the evaluator if the vendor so desires.

7.7 Minimum Test Time

The test time is measured from the start of data collection to the end of the data collection. Some systems will report a leak rate at this time, but others may require additional data processing off site. Test times for all tests shall be included in the average. Leak tests must be conducted for at least the average test time, irrespective of tank size. Scaling down of test times is not permitted.

7.8 Testing Following Tank Fills (Product Deliveries)

The results forms contain a space for the vendor to state any procedures used to determine when a tank is stable following tank fills. Any minimum required stabilization times following tank fills and any effects of testing following tank fills with temperature differentials are specified by the vendor. One tank fill will be done during the evaluation to verify that the test method is not adversely affected by deliveries. If the method is adversely affected, a minimum of three additional deliveries will be required.

7.9 Fuel Volatility

Any procedures used to account for fuel volatility must also be stated on the results forms. The evaluator must agree that these approaches are reasonable for the method under evaluation.

7.10 Using Multiple Tests (Averaging of Test Results)

Averaging more than one test result to achieve better performance is a recognized statistical technique. The procedures for averaging the results of several leak tests to improve the performance of a leak detection system are contained in Appendix C of this evaluation protocol. Averaging procedures were taken from the Bulk Tank protocol[4].

[4] "Alternative Test Procedures for Evaluating Leak Detection Methods: Mass-Based and Volumetric Leak Detection Systems for Bulk Field-constructed Tanks", Ken Wilcox Associates, November 2000.

8.0 REPORTING OF RESULTS

8.1 Certification Forms

Appendix A contains the certification forms, which are designed to be the framework for a standard report. There are three parts to Appendix A, each of which is describe below.

Results Forms
The “Results of Alternative Test Procedures” form is basically an executive summary of the findings. It is designed for use as a form that would be provided to each tank owner/operator that uses this method of leak detection. If the vendor chooses to report more than one set of performance criteria, the table attached to the results section must be completed for each set. The report should be structured so that this Results form can be easily reproduced for wide distribution.

Description Forms
The ”Description of the Aboveground Storage Tank Leak Detection Method” form contains details about the technology and operation of the leak detection method. This form should be completed by the evaluating organization assisted by the vendor.

Reporting Forms
The “Reporting Form for Leak Rate Data” summarizes the individual test results and contains information on starting dates and times, test duration, leak rate results, etc.

8.2 Individual Test Logs

Appendix B contains the individual test log sheets. The individual test logs should be reproduced and used to record data in the field. Copies of the completed daily test logs are to be included in the standard report. These serve as the backup data to document the performance estimates reported.

APPENDIX A

REPORTING FORMS

Appendix A contains the following:

1. Results of Alternative Test Procedures: Aboveground Storage Tank Mass-Based Leak Detection Method

2. Description: Aboveground Storage Tank Mass-Based Leak Detection Method

3. Reporting Form for Testing Conditions and Leak Rate Data: Aboveground Storage Tank Mass-Based Leak Detection Method

Results of Alternative Test Procedures
Aboveground Storage Tank
Mass-Based Leak Detection Method

This form describes the performance of the leak detection method described below. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the "Alternative Test Procedures for Evaluating Leak Detection Methods: Mass-Based Leak Detection Systems for Aboveground Storage Tanks Larger than 50,000 gallons", Ken Wilcox Associates, Inc., November 2002. The full evaluation report also includes a form describing the method and a form summarizing the test data.

Tank owners using this leak detection system should keep this form on file to provide compliance with any applicable state or federal regulations. Tank owners should check with State and local agencies to make sure this form satisfies their requirements.

Leak Detection Method Description

Name ____

Version number ____

Vendor ____

____
(street address)

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

Evaluation Results

This method ( ) does ( ) does not use multiple tests. If multiple tests are used, the results are based on _____ independent tests. The results apply only when ____ tests are performed and the estimated leak rates are averaged.

This Leak Detection Method which declares tank to be leaking when the measured leak rate exceeds the threshold of ______ gallons per hour, has a probability of false alarm [P_{FA}] of ___% for tests conducted on tanks with surface areas of ________ sq. ft or less.

The corresponding probability of detection [P_D] of a ____ gallon per hour leak is ___%.

The standard deviation of the test data results was__________ gal/h.

The smallest leak that can be detected with a probability of detection of 95% and a probability of false alarm of 5% (MDL) is _____ gal/h in a tank with a surface area of ______ sq. feet.

Test Conditions During Evaluation

The evaluation testing was conducted in a _________ gallon tank with a surface area of _______ sq. ft.

The tank was constructed of ( ) steel ( ) fiberglass ( ) concrete

( ) other (describe) ____

The tank geometry included vertical walls and was ( )_____ feet deep and _____ feet in diameter or ( ) _____ feet long, _____ feet wide and _____ feet deep.

The tank roof was ( ) fixed ( ) floating

( ) other (describe) ____

The tests were conducted with the tank product level ______ % full.

The product used in the evaluation was ________________.

The number of tank fills conducted during the evaluation was __________.

The system was operated as an automatic device. ( ) Yes ( ) No

Limitations on the Results

The performance estimates above are only valid when:

- The method has not been substantially changed.
- The vendor's instructions for installing and operating the Leak Detection Method are followed.
- The tank contains a product identified on the method description form.
- The tank has vertical walls of constant cross section.
- The maximum product surface area is no greater than ______square feet.
- The minimum tank size is 50,000 gallons.
- The total data collection time for the test is at least ______ hours ____ minutes.
- The waiting time after adding any substantial amount of product to the tank is ______ hours______ minutes.
- The threshold for declaring a leak is adjusted for different tank sizes by multiplying the ratio of the product surface area used in the evaluation, which was _______ square feet, and the product surface area in the tank being tested. The detectable leak rate is scaled up or down by multiplying in the same way.
- Other limitations specified by the vendor of determined during testing:

____
____

Procedural Information

State the procedures used to determine when the tank is stable.

____

____

State the procedures used to account for fuels of different volatility.

____

____

Other Information

Summary of Test Procedure Modifications

____

____

Other Modifications: (describe briefly)

____

____

Method Name and Version: ____
Date of Certification: ____

	Test Tank Size	Maximum Size Tank	Minimum Size Tank
Diameter			
Surface Area			
Standard Deviation*			
Target Leak Rate, TLR			
Vendor’s Threshold			
P_{FA}			
P_D(for target leak rate)			
MDL			

Note: Additional copies of this table for other tank sizes may be included as desired.

> **Safety disclaimer: This test procedure only addresses the issue of the Leak Detection Method’s ability to detect leaks. It does not test the equipment for safety hazards.**

Certification of Results

I certify that the Leak Detection Method was installed and operated according to the vendor's instructions and that the results presented on this form are those obtained during the evaluation.

______________________ (printed name)	______________________ (organization performing evaluation)
______________________ (signature)	______________________ (city, state, zip)
______________________ (date)	______________________ (phone number)

Description
Aboveground Storage Tank
Mass-Based Leak Detection Method

This section describes briefly the important aspects of the aboveground storage tank leak detection method. It is not intended to provide a thorough description of the principles behind the system or how the equipment works.

Method Name and Version

____

Product

> Product type

For what products can this Method be used? (check all applicable)

( ) gasoline

( ) diesel

( ) aviation fuel

( ) fuel oil #4

( ) solvents

( ) other (list) ____

> Product level

What product level is required to conduct a test?

( ) greater than 90% full

( ) greater than 50% full

( ) tests can be conducted at any level (explain briefly) ____________________

____

( ) other (specify) ____

Principle of Operation

What technique is used to detect leaks in the tank system?

( ) directly measure the volume of product change

( ) changes in head pressure

( ) changes in buoyancy of a probe

( ) other (describe briefly) ____

Temperature Measurement

How many temperature sensors are used to measure the product temperature?

( ) Product temperature not measured

( ) One sensor

( ) Two sensors

( ) Three sensors

( ) Four sensors

( ) Five sensors

( ) Other (describe briefly) ____

Where are temperature sensors located (product and non-product sensors)? (check all that apply)

( ) In the liquid

( ) On the tank shell

( ) Ambient temperature measurements

( ) Other (describe briefly) ____

What types of temperature sensors are used (product and non-product sensors)? (check all that apply)

( ) Temperature not measured

( ) Resistance temperature detector (RTD)

( ) Bimetallic strip

( ) Quartz crystal

( ) Thermistor

( ) Other (describe briefly) ____

If product temperature is not measured during a test, why not?

( ) The factor measured for change in level/volume is independent of temperature (e.g., mass)

( ) The factor measured for change in level/volume self-compensates for changes in temperature

( ) other (explain briefly)____
____

Data Acquisition

How are the test data acquired and recorded?

( ) manually

( ) by strip chart

( ) by computer

Procedure information

> Waiting times

What is the required waiting period between adding a large volume of product (i.e., a delivery) and the beginning of a test (e.g., filling from 50% to 90-95% capacity)?

______ Days _____Hours ____ Minutes

Additional Comments: ____

> Test duration

What is the required time for collecting data?

______ Days _____Hours ____ Minutes

Additional Comments: ____

What is the sampling frequency for the level and temperature measurements?

( ) more than once per second

( ) at least once per minute

( ) every 1-15 minutes

( ) every 16-30 minutes

( ) every 31-60 minutes

( ) less than once per hour

( ) variable (explain) ____

> Use of multiple tests

Does the procedure use the average leak rate from more than one test in reaching a conclusion?

( ) Yes (How many tests? _________)

( ) No

Does the procedure base its conclusion on the agreement of k out of n tests?

( ) Yes (A leak is indicated if ______ (specify k) out of _____ (specify n) tests indicate a leak.)

( ) No

> Interpreting test results

How are measured changes converted to volume changes (i.e., how is height-to-volume conversion factor determined)?

( ) actual measured changes observed when known volume is added or removed (e.g., liquid metal bar)

( ) theoretical ratio calculated from tank geometry

( ) interpolation from tank manufacturer's chart

( ) other (describe briefly)

( ) not applicable; volume measured directly

How is the leak rate (gallon per hour) calculated?

( ) average of subsets of all data collected

( ) difference between first and last data collected

( ) from data from last ____ hours of test period

( ) from data determined to be valid by statistical analysis

( ) other (describe) ____

What threshold value for product volume change (gallon per hour) is used to declare that a tank is leaking?

( ) 0.05 gal/hr ( ) 0.1 gal/hr ( ) 0.2 gal/hr

( ) 0.5 gal/hr ( ) 1.0 gal/hr ( ) 2.0 gal/hr

( ) Other ____________

Under what conditions are test results considered inconclusive?

( ) too much variability in the data (standard deviation beyond a given value)

( ) unexplained product volume increase

( ) other (describe briefly) ____

Exceptions

Are there any conditions under which a test should not be conducted?

( ) extremely high or low ambient temperature

( ) invalid for some products (specify) ________________________________

( ) harsh weather conditions (such as high wind or rain)

( ) other (describe briefly) ____

What are acceptable deviations from the standard testing protocol?

( ) lengthen the duration of test

( ) other (describe briefly) ____

( ) none

What elements of the test procedure are determined by personnel on-site?

( ) product level when test is conducted

( ) when to conduct test

( ) waiting period between filling tank and beginning test

( ) length of test

( ) determination of "outlier" data that may be discarded

( ) other (describe briefly) ____

( ) none

Reporting Form for Testing Conditions and Leak Rate Data
Aboveground Storage Tank Mass-Based Leak Detection Method

Name and Version: ____

Tank Evaluation Period: from ________ to ________ (Dates)

Test No.	Date Test Began (m/d/y)	Time Test Began (m/d/y)	Date Test Ended (m/d/y)	Time Test Ended (m/d/y)	Test Time (hours)	Product Level (%)	Nominal Leak Rate (gal/h)	Induced Leak Rate (gal/h)	Measured Leak Rate (gal/h)	Meas.-Ind. Leak Rate (gal/h)
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										

APPENDIX B

INDIVIDUAL TEST LOGS

Test Number: ___________

Individual Test Log

Aboveground Storage Tank
Mass-Based Leak Detection Systems

Instructions:
Use one log for each test. Fill in the blanks and check the boxes, as appropriate.
Keep test log even if test is inconclusive.

1.0 Leak Detection Method Description

Name ____

Version number ____

Vendor ____

2.0 General Background Information

Product Type ____

Type of Tank ____

Tank Dimensions (nominal)

Diameter _________feet ________ inches

Height ___________feet ________ inches

Volume _____________________ gallons

If applicable, recommended stabilization period before test (per vendor SOP)

___________ Hours ___________ Minutes

Test Number: __________

3.0 Leak Detection Test Times

Start of test data collection _______________ Date ___________ military time

End of test data collection ________________ Date ___________ military time

4.0 Weather Information

	Temperature (deg F)	Barometric Pressure (mm or in Hg)	Wind Conditions (none, light, moderate, or heavy)	Precipitation (none, light, moderate, or heavy)	Sky Conditions (sunny, partly cloudy, cloudy, night)
Start of Test					
End of Test					

5.0 Leak Rate Data

Nominal Leak Rate (gal/h)	
Induced Leak Rate (gal/h)	
Vendor's Reported Leak Rate (gal/h)	
Difference (Reported minus Induced)	

6.0 Leak Detection Method's Result Printout

Attach a copy of the Leak Detection Method's results printout with the vendor's reported leak rate to this form (Attach additional pages if needed).

7.0 Additional Comments (Attach additional pages if needed)

APPENDIX C

USING MULTIPLE TESTS

Using Multiple Test Results

Averaging Test Results

The performance of a mass-based or volumetric leak detection system can be improved by averaging two or more test results together. Averaging reduces the uncertainty of the test results. The standard deviation of the mean test result, S_m, can be determined from

$$S_m = S / (n)^{0.5} . \qquad \text{(C-1)}$$

where S is the standard deviation of N individual tests obtained from a reference tank during an evaluation and n is the number of individual tests averaged together. Equation C-1 assumes that the noise is additive with the leak signal and that the individual tests are random and independent, which is a valid set of assumptions for mass-based (volumetric) tank leak detection systems. Once the S_m is determined, it can be used in the same way that S is used for computing performance as described in section 9.1 above and for scaling performance from one tank size to another as described in section 9.6.

The performance obtained when two or more tests are combined is described in more detail below.

Quantitative leak detection systems produce a measured leak rate. This measured leak rate is compared with some standard threshold to determine whether the measured value is evidence of a leak or is within the normal variability of the measurement process.

A possible modification of any quantitative leak detection method is to conduct multiple, independent tests on a system. The n independent test measurements are averaged to produce an estimated leak rate. The average leak rate is then used to make the comparison with a threshold to determine whether or not there is a leak. The advantage of this procedure is that it reduces the size of the leak that can be detected with a given PFA and PD. The procedure is based on the following statistical theory.

If X is a measured value that is a random variable, with a mean of μ and a standard deviation of σ, and if n, independent replications of the measurement are made, then the average (arithmetic mean) of the n measurements is given by:

$$m = \Sigma X_i/n \qquad \text{(C-2)}$$

and the average, m, is also a random variable. The random variable, m, has the same expected value, say, μ, as a single observation. However, m has a standard deviation of $\sigma/n^{1/2}$. That is, the standard deviation of the average is reduced by dividing it by the square root of the number of samples used to calculate the average.

These results imply that if a vendor conducts several independent tests, and averages the resulting leak rates, the result will have less variability than a single measurement. This, in turn, implies that use of the average would improve the performance of the method. The relationship of the performance based on the average to the performance based on a single test is as follows.

Suppose that the method compares the measured leak rate, L, to a threshold, C. In this discussion, the leak rate, L, is taken as a positive number. Evaluation testing of the method produced an estimate, S, of the standard deviation, σ, based on the number of evaluation tests, say N. The PFA of the method is given by

$$PFA = P(\ t > C/S), \qquad \text{(C-3)}$$

where the probability is calculated from the t-distribution with N-1 degrees of freedom. The probability of detecting a leak of size R is given by

$$PD(R) = P(\ t > (C-R)/S). \qquad \text{(C-4)}$$

with the probability again computed from the t-distribution with N-1 degrees of freedom.

If the average of n independent measurements of the leak rate is used in place of a single measurement, the standard deviation is divided by the square root of the number of measurements. Then the formulas for PFA and PD are modified by replacing the estimated standard deviation, S, with $S/n^{1/2}$. The revised formulas become:

$$PFA = P(\ t > n^{0.5}C/S), \qquad \text{(C-5)}$$

and

$$PD(R) = P(\ t > n^{0.5}(C-R)/S). \qquad \text{(C-6)}$$

Again, the probability is computed from the t-distribution. Since the evaluation testing covered a variety of test conditions, the standard deviation estimated from it applies to the set of conditions used in those tests. Consequently, it is generally taken for the value of the estimated standard deviation. The number of degrees of freedom, N-1, is based on the N tests run during the evaluation.

Once the PFA and PD for a given leak rate R is determined for a single test, the detectable leak rate R can be reduced by averaging without changing the PFA or PD by dividing the threshold T and the detectable leak rate R used for a single test by the square root of n. Thus,

$$R_m = R/(n)^{0.5} \ , \qquad \text{(C-7)}$$

where R_m is the detectable leak rate when n tests are averaged together, and R is determined from the evaluation of a single test. Equation (C-7) is valid for a normally distributed performance model because the R (and R_m) are multiples of S.

The minimum detectable leak rate (MDL) is a special case of R using PFA of 5% and PD of 95%. The MDL of the mean test result obtained by averaging n tests together can be computed from

$$MDL_m = MDL/(n)^{0.5}, \qquad \text{(C-8)}$$

where the MDL was determined from the evaluation of a single test.

Alternatively, the P_{FA} or P_D or both can be changed without changing the detectable leak rate. The P_{FA} or P_D can be averaged using S_m instead of S in equations C-3 and C-4.

Some caution needs to be exercised in applying this procedure. First, the time needed for testing using an average of n tests will be at least n times as long as for a single test. This might imply, for example, that tests are done on n successive nights. Secondly, the individual test results and times and dates of the test should be reported to document that n independent tests were actually done. For some systems, as prescribed by the vendor, it might be necessary for some time to elapse between the conclusion of one test and the start of the next to ensure that the tests are independent. All of the tests must be of the same duration and follow the same procedure.

Note that the averaging of test results is not affected by scaling. That is, if the results are scaled up to larger tank sizes either by the ratio of the surface areas (mass-based systems) or by the ratio of the tank volumes (volumetric systems), the scaling affects the standard deviation. The scaled standard deviation is used as above in the averaging process. The scaling of the standard deviation for different sized tanks can be applied to the original standard deviation and then the adjustment for averaging applied. The same results will be obtained if the adjustment for the averaging is made first and then the resulting standard deviation of the mean is scaled.

Combining Test Results for Qualitative Systems

Instead of averaging, one could use the pass or fail result from multiple tests to make a decision. This is necessary for qualitative systems, which only produce a pass or fail result. This approach also works equally well for quantitative systems once the threshold is used to make a decision about whether or not the tank passes or fails the test, since at that point the result is qualitative. Use of multiple tests involves defining the decision rule based on the results from a specified number of independent tests.

In contrast to averaging results, combining pass/fail results from multiple tests does not allow scaling up to larger tanks in a simple manner.

For example, one could specify that 2 tests would be done and a leak would be declared only if both tests indicated that a leak was present. The alternative with two tests would be to declare a leak if either test indicated a leak was present. With three or more independent tests used, the situation is more complicated. One could fail a system only if all three tests indicated a leak; a fail could be indicated if 2 out of the 3 tests indicated a leak; or a fail could be indicated if any of the three tests indicated a leak. The situation becomes even more complicated if a larger number of independent tests are used.

If a PFA and a PD (neither of which is equal to zero or one) have been established based on a single test, then a decision rule based on “k out of n” tests results in a binomial probability. That is, the overall PFA and PD based on multiple tests are related to the individual values through a binomial probability distribution. This is exemplified below.

Suppose that for a single test the probability of a false alarm is denoted P_1. Let the probability of detecting a leak of a fixed specified size be P_2. Then for a given decision rule based on multiple independent tests, the overall probability of false alarm, PFA, and the overall probability of detection, PD, can be determined from P_1 and P_2. The actual formula depends on the number of tests and the form of the decision rule. Some examples are given to illustrate this relationship.

Example 1. Two independent tests are used. A leak is declared only if both tests indicate a leak. Then,

$$PFA = P_1^2 \tag{C-9}$$

and

$$PD = P_2^2 \tag{C-10}$$

Example 2. Two independent tests are used. A leak is declared if either test indicates a leak. Then,

$$PFA = 1 - (1-P_1)^2 \tag{C-11}$$

and

$$PD = 1 - (1-P_2)^2 \tag{C-12}$$

Examples 1 and 2 are the only cases using two tests that change the PFA and PD. These cases can be generalized to the case where n independent tests are used and either all tests must indicate a leak for a leak to be concluded as in Example 1, or all tests must pass to conclude that the system is tight as in Example 2. The generalization is to replace the exponent of 2 in Example 1 or Example 2 with an exponent of n, the number of independent tests.

Example 3.

The situation becomes more complicated if n independent tests are used and k out of n test results must agree for the overall conclusion to be reached. With n=3 the reasonable decision rules are listed below.

- Conclude a leak if all 3 tests indicate a leak.
- Conclude a leak if at least 2 of the 3 tests indicate a leak.
- Conclude a leak if any of the 3 tests indicates a leak.

Number 3 is equivalent to concluding that the system is tight only if all three tests indicate a pass. Number 1 and Number 3 were considered in the generalization of Examples 1 and 2. The other case is Number 2.

If the system is judged to be leaking if at least 2 out of 3 tests indicate a leak, then the overall PFA is given by

$$PFA = 3P_1^2(1 - P_1) + P_1^3 \qquad \text{(C-13)}$$

Similarly, the overall PD is given by

$$PD = 3P_2^2(1 - P_2) + P_2^3 \qquad \text{(C-14)}$$

If the number of independent tests increases, the number of possible decision rules gets quite large. The overall PFA and PD can be computed for any specified n and decision rule. The advantage of a k-out-of-n approach is that the PFA or the PD can be greatly reduced.

Minimum Criteria when Using Multiple Test Results

If averaging or combining test results, the following criteria must be met:

I. Each test must be independent. (This implies that the data for each test comes from non-overlapping time periods.)

II. Tests to be averaged or combined must be completed within the time interval specified by the regulatory agency.

III. The averaging or combining procedures must be reviewed by the evaluator and found to be appropriate.

The evaluator must complete an attachment to the original results report that describes the averaging or combining procedures. For averaging, this attachment should indicate the number of tests to be averaged. For combining test results, this attachment should indicate the number of test results combined (e.g. 2, 3, 4, etc.) and the number of failing test results which will result in a leak being declared (e.g. 1 out of 2, 2 out of 2, 2 out of 3, etc.). Additional information regarding the Pd, Pfa, MDL, etc. should also be included for both averaging and combining procedures. If the information about averaging is included on the official results form, a separate attachment may not be necessary.