Alternative Test Procedures for Evaluating Leak Detection Methods: For Bulk Field-constructed Tanks

Prepared for General Use by Ken Wilcox Associates, Inc.
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Part 1
Alternative Test Procedures for Evaluating Mass Measurement Leak Detection Methods: For Bulk Field-constructed Tanks

Revised November 2000

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DISCLAIMER

Some of the procedures described in this document are different than those in EPA's Standard Protocols. 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.

Users should feel free to copy or modify this protocol without restriction in any way that is acceptable to the cognizant regulatory agency.

ACKNOWLEDGMENTS

Ken Wilcox Associates prepared this document for use by anyone who wishes to leak test large, field-constructed tanks. The effort was funded entirely by KWA. Helpful input was obtained from KWA staff, other third-party evaluators, test method developers, and many local, state, and federal regulators. Particularly helpful discussions were obtained from Shahla Farahnak, California State Water Resources Control Board, Mr. Russ Brauksieck, State of New York, Ms. Beth DeHaas, State of Maine, Mr. Randy Nelson, USEPA Region 7, and Dr. Wen Young, Universal Sensors and Devices. Their assistance is gratefully acknowledged.

The protocol was revised in April 1999 to include averaging and the scaling of performance to tank sizes other than the size in which the method was originally evaluated. In addition to the above named persons, Mr. Jon Reeder, Florida Department of Environmental Protection, and Dr. Joe Maresca, Vista Research, offered valuable statistical assistance to the averaging and scaling procedures.

FOREWORD[1]

The US Environmental Protection Agency recognizes three distinct ways to prove that a particular vendor or leak detection equipment meets the federal performance standards:

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

1. Some leak detection systems cannot be evaluated using procedures described in the EPA Standard Methods for Evaluating Leak Detection Methods.
2. For some types of equipment (e.g., interstitial monitors) there is no EPA protocol available.
3. The costs to conduct an evaluation to the exact letter of an existing EPA protocol may be prohibitive. Less costly approaches may be available that will meet the requirements for alternative evaluations.

Two important factors have been considered by KWA in developing alternative procedures to meet specialized test requirements: First, the EPA criteria for alternative test procedures deemed equivalent to EPA's; and second, the guidelines established by the American Society for Testing and Materials (ASTM) in their standard practice 1546E - 1993. The EPA guidelines are as follows:

[1]Some material has been excerpted and adapted from the Foreword that appears at the front of each of the EPA Evaluation Protocols.

Alternative Test Procedures Deemed Equivalent to EPA's

The following general criteria must be met for an alternative procedure to be considered acceptable.

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 ATG systems, for example, this will mean testing under both 0.0-gallon per hour and 0.20 gallon per hour leak rates. In the case of ground water monitoring, this will mean testing with a 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 ATGS testing, the test should include a temperature difference between the delivered product and that already present in the tank, as well as the deformation of the tank 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.

National Consensus Code or Standard (ASTM 1526E - 1993)

This ASTM Practice provides general guidelines for performing evaluations on leak detectors designed for use on underground storage tanks. There are no specific requirements defined such as the number of tests to be conducted or specific variable such as temperature that should be included in the evaluation. None-the-less, the practice does prove a useful framework for developing alternative techniques.

Ken Wilcox Associates, Inc. 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 include summaries of the test procedures, descriptions of the leak detection systems, and a full disclosure of the test results obtained from the testing. Questions regarding these procedures should be addressed to Ken Wilcox, President, Ken Wilcox Associates, Inc., (816) 443-2494.

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Part 1 Mass Measurement Systems

1.0 INTRODUCTION

1.1 Background

This document provides an evaluation procedure that may be used for leak detection systems conducting tests on very large, vertically walled, underground storage tanks containing petroleum products. Tank sizes may range from 50,000 gallons to 4,000,000 gallons or larger. Since there is no official protocol for testing large field-constructed tanks, it has been necessary to develop an alternate protocol, incorporating as many of the features as possible from the EPA protocols for evaluating leak detectors for smaller tanks.

1.2 Applicability

This protocol is intended to be applied to large field-constructed tanks. Leak detection systems intended for use on tanks smaller than 50,000 gallons should be evaluated using standard EPA protocols.

Because the procedures for testing mass measurement devices are different from those for volumetric methods, the protocol has been separated into two parts. Part 1 of the protocol applies only to systems that are based on mass measurement methods that are not affected by temperature variation. Part 2 applies to volumetric methods based on level and temperature.

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 the maximum leak that can exist for a 5% false alarm rate. 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.

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. This protocol should specify requirements for safe installation and use of the device or method. This safety protocol will be supplied by the vendor to the personnel involved in the evaluation. In addition, each institution performing an evaluation of a leak detection device should have an institutional safety policy and procedure that will be supplied to personnel on site and will be followed to ensure the safety of those performing the evaluation.

Since the evaluations are performed on actual underground storage tanks, the area around the tanks should be secured. As a minimum, the following safety equipment should be available at the site:

- Two class ABC fire extinguishers
- One eyewash station (portable)
- One container (30 gallons) of spill absorbent
- Two "No Smoking" signs.

Personnel working at the underground storage tank facility should wear safety glasses when working with product and steel-toed shoes when handling heavy pipes or covers. After the safety equipment has been placed at the site and before any work can begin, the area should be secured with signs that read "Authorized Personnel Only" and "Keep Out."

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, product compatibility, etc., are considered. The evaluating organization should check to see what safety testing has been done before the equipment is used for testing to ensure that the test operation will be as safe as possible.

2.0 GENERAL APPROACH

In general, the procedures described in this document are those contained in the EPA protocols for volumetric tank tightness testing and automatic tank gauging systems. Two major changes, both related to the large size of the tank have been incorporated into this protocol: First, since the capability to control product temperature differences for these tanks is virtually impossible, the product temperature differences for fuel transfers are not specified; second, the induced leak rates have been adjusted to reflect the leak rate target set by the vendor. The test procedure recommends testing at product levels of 90-95% of capacity until a total of 12 valid tests have been completed. Product transfers between each pair of tests must be conducted during the testing.

3.0 TANKS AND TEST EQUIPMENT

3.1 Tanks

The use of this protocol has been restricted to field-constructed vertical-wall tanks 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.

Because the leaks are induced using a pump, the presence of a water table outside the tank is not a factor for the evaluation. Water table information should be recorded, however, if it is available. Product levels and temperature changes may be achieved either by transfer back and forth using a second tank or by transferring the fuel to another source followed by delivery of product of a different temperature or by any other method that produces a significant temperature differential.

3.2 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 for monitoring product level or mass and for compensating for temperature. It will typically include 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 shall operate the equipment after the requisite training by the vendor or manufacturer.

4.0 LEAK SIMULATION EQUIPMENT

The induced leak procedures are identical to those described in the standard EPA protocols for ATG and volumetric systems. A peristaltic pump or equivalent method is used to remove product from the tank at a uniform rate. 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.

5.0 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. Highly viscous materials such as motor oil should not be used unless the leak detector is designed to test that product.

The vendor must specify 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.

6.0 EVALUATION PROCEDURES

Except for control of the temperature differentials and leak rates, all of the procedures described in the standard protocol for volumetric methods[2] are applicable to field-constructed bulk tanks. Only 12 tests are required for bulk tanks rather than the 24 tests required for a standard volumetric tank tightness test evaluation. The experimental design is indicated in Table 1 for an evaluation conducted under conditions where the tank is filled to 90-95% capacity. This matrix applies to tanks with straight, vertical walls where the horizontal surface area does not vary with product height.

A trial run is required before beginning the evaluation to assure that the test tank has no operational problems. Failure to address and correct operational problems related to the test tank may result in a degradation of the test results.

2 Standard Test Procedures for Evaluating Leak Detection methods: Volumetric Tank Tightness Testing Methods"

Table 1. Standard Testing Matrix - Product Volume, Leak Rate, and Temperature Differential Test Schedule

Test Description**	Test No.	Pair No.	Set No.	Nominal leak rate (gallon per hour)	Nominal temperature differential* (degree F)
Trial run	-	-	-	0.00	0
Empty to 50% full (if applicable)					
Refill to 90-95%	1	1	1	LR1	T1
	2	1	1	LR2	T1
Empty to 50-60%					
Refill to 90-95%	3	2	1	LR4	T2
	4	2	1	LR3	T2
Empty to 50-60%					
Refill to 90-95%	5	3	2	LR1	T3
	6	3	2	LR4	T3
Empty to 50-60%					
Refill to 90-95%	7	4	2	LR2	T4
	8	4	2	LR3	T4
Empty to 50-60%					
Refill to 90-95%	9	5	3	LR4	T5
	10	5	3	LR1	T5
Empty to 50-60%					
Refill to 90-95%	11	6	3	LR3	T6
	12	6	3	LR2	T6

*Note: Although the temperature cannot be controlled, these temperatures should be recorded on the appropriate data sheets. The temperature differential is calculated as the temperature of the product added minus the temperature of the product in the tank.

** empty/fill cycles that include adding product of a different temperature are required for mass systems.

A brief description of the procedures is as follows.

1. The leak detector is installed in the tank per the vendors instructions

2. A trial test is conducted to determine that the equipment and tank are behaving as expected.

3. The tank is emptied to 50-60% of capacity and refilled to 90-95%.

4. Product temperature is determined and reported for each test. The temperature differential is determined by measuring the relative difference in the temperature of the product in the tank and the incoming product temperature.

5. The tank is allowed to stabilize prior to the test for the time period or other criteria specified by the vendor.

6. The first test is conducted according to the vendors' criteria at the rate specified in the test matrix.

7. A second test is conducted immediately after the first with no addition or removal of product between the two tests.

8. The product is lowered to the 50-60% level and refilled to the 90-95% of capacity and steps 3 through 7 are repeated for a minimum of six empty/fill cycles. For mass based systems at least two of these transfers must use product of a different temperature than that already in the tank.

9. The data for each test are recorded on individual test log forms provided in Appendix B.

6.1 Induced Leak Rates

The leak rates induced during the testing are those indicated in Table 2. They are based on the target leak rate set by the equipment vendor, based on their expectations of performance. The actual leak rates will need to be calculated for each leak detection test. Three tests should be conducted for each nominal rate until 12 valid tests have been completed. The actual 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.

Table 2. Example Induced Leak Rates for Two Target Leak Rates

Leak No.	Rate (gal/hr)	Example Target Leak Rates 0.5 gal/hr	2.0 gal/hr
LR1	zero leak	0 gal/hr	0 gal/hr
LR2	½ x target leak rate	0.25 gal/hr	1 gal/hr
LR3	1 x target leak rate	0.5 gal/hr	2 gal/hr
LR4	2 x target leak rate	1 gal/hr	4 gal/hr

6.2 Temperature Differentials

For mass based systems, at least two of the six product deliveries must have product of a different temperature than that already in the tank. For product transfers between tests, some uncontrolled temperature variations may be present. Temperature should be measured at the best available access port into the tank. Temperature measurements should be conducted at different levels, by installing an array of sensors. The average product temperature is then determined by averaging (with volume weighting) the measured temperatures. The following temperature measurements should be taken.

- Product temperature at the start of a test
- Product temperature at the end of the test
- Product temperature in the tank prior to a delivery
- Product temperature in the tank after completion of a delivery

Temperature differences are not expected to affect mass-based systems. However the temperature differences should be documented so that this can be verified. These temperatures are to be recorded on the individual test logs.

The difference in temperature between the delivered product and that already in the tank can be determined using thermal balance procedures. If the temperature of the delivered product is available it should be recorded and the difference between the average temperature before transfer and the temperature of the incoming product calculated directly.

6.3 Randomization

The leak simulation rates LR_1 through LR_4 must be kept blind to method vendor. The randomization considerations (except for temperature) are identical to those in the standard protocol.

6.4 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.

6.5 Minimum Stabilization Time

The stabilization time between the last significant delivery or removal from the tank is normally specified by the vendor. The criteria for determining when the tank has reached sufficient stability for testing should be specified by the vendor in a form that will allow the evaluator to determine when the criteria have been met during the evaluation. The stabilization times used for the tests immediately after the tank was filled (typically the odd-numbered tests in Table1) will be recorded and the average used as the minimum stabilization time required for the method. The median stabilization time may be used as the average instead of the mean if there are atypical stabilization times.

7.0 WATER SENSOR EVALUATION (if applicable)

Some systems may not include water sensors as part of their monitoring system. If water leaks do occur, either in or out, they will be detected as level or mass changes. The tank owner would then be alerted that a problem of some type exists.

For systems that include a water sensor, the evaluation procedures are identical to the standard protocol. The equipment used to evaluate water sensors is the same as that described in the standard protocol. Testing is conducted under controlled laboratory conditions. The results of the tests are then applied to the geometry of the tanks being tested. The calculations for the minimum detection time for a water leak to be detected would be based on the tank size and the target leak rate for the leak detection system.

8.0 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.
- groundwater above the tank bottom
- any other condition that might influence the test results

9.0 CALCULATIONS

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

All of the statistical calculations described in the standard EPA test protocol for volumetric systems apply to evaluations conducted on large bulk tanks. 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.

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

$$D_i = L_i - IL_i. \qquad (9\text{-}1)$$

The bias is estimated by the mean of the differences:

$$B = \Sigma\, D_i/N, \qquad (9\text{-}2)$$

where N is the number of tests (usually 12) in the evaluation and the summation is over all differences. The variance of the differences is found using the formula

$$V = \Sigma\,(D_i - B)^2/(N-1). \qquad (9\text{-}3)$$

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

$$t = (N)^{1/2}\, B/S, \qquad (9\text{-}4)$$

which is compared to the two-sided value from a t-distribution with N-1 degrees of freedom. For N=12, the appropriate value from the t-table is 2.201. 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.

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.

Probability of False Alarm

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

$$P_{FA} = P[t > (C - B)/S]. \qquad (9\text{-}5)$$

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 11 degrees of freedom. A table of the t-distribution is used to find the probability that a t-statistic with 11 degrees of freedom exceeds the computed value.

Probability of Detection

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

$$P_D = P[t > (C - R - B)/S]. \qquad (9\text{-}6)$$

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 11 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 PFA of 5% is desired, use the t-table to determine that the probability is 5% that a t-statistic with 11 degrees of freedom will exceed 1.796. To choose C, set

$$(C - B)/S = 1.796 \qquad (9\text{-}7)$$

and solve for C to get

$$C = (1.796)(S) + B \qquad (9\text{-}8)$$

which reduces to

$$C = (1.796)(S) \qquad (9\text{-}9)$$

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 11 degrees of freedom will exceed –1.796. Set

$$(C - R - B)/S = -1.796 \qquad (9\text{-}10)$$

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

$$MDL = C - B + 1.796\,(S) \qquad (9\text{-}11)$$

The value of R that satisfies the previous equation using the threshold for a 5% PFA 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.

9.2 Averaging of Test Results (if applicable)

Averaging more than one test result to achieve better performance is a recognized statistical technique. This protocol addresses some of these statistical processes in Appendix C. They are not however included as a part of this protocol. It is left up to individual regulators and agencies to determine the acceptability of averaging for compliance purposes.

9.3 Water Detection Mode (if applicable)

The calculations for a bulk tank water detector are identical to those described in the standard ATGS protocol. The results must be applied to each particular tank geometry for which the method is used.

9.4 Tank Size Limitations

Differing tank sizes and geometry's 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 for mass based systems. See Table 3 below for applying the evaluation to tanks of differing sizes.

Table 3. Tank Size Limitations

Mass Based Systems			
	Product Surface Area	Product Volume	Leak Rate Scaling
Scaling Limits	Maximum 2.5 X Area (No minimum) *See Note Below	50,000 gallon Minimum, No Maximum	Yes, but not below 0.2 gal/h
* Extrapolation beyond this surface area requires 6 additional tests in larger tanks using the same test procedures and parameters. The surface area limitation will then be equal to the surface area of the tank used in the confirmatory tests.			

9.5 Rate and Threshold

The test data are used to calculate the basic statistics as described in Section 9.1. Once the data are available and the statistics have been calculated the following results are to be reported.

- The standard deviation
- The threshold for declaring a leak
- The minimum detectable leak rate
- The target leak rate
- The PFA and PD for the target leak rate

The test developer is allowed to select any target leak rate and threshold as long as the results are within the specifications of the regulatory agency. 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 false alarm rate or improve the probability of detecting a small leak. The PD and PFA are assumed to remain constant for the purpose of scaling the results to other tank sizes.

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. Some regulatory agencies may choose to reject one or more of the calculations based on the applicable regulatory standards.

9.6 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

$$S_2 = S_1 \times A_2/A_1 \qquad (9\text{-}12)$$

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 be field constructed.
2. It must be a vertical wall tank.
3. Leak rates may not be scaled below 0.2 gal/h.
4. The 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 PD 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, but scaling to target rates smaller than 0.2 gal/hr is not permitted.

When scaling the results, the appropriate standard deviation for the test tank should be used. This is the standard deviation calculated from the test data using equation (9-3) 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.

9.7 Temperature Differences

The difference in temperature between the product in the tank and that added to fill the tank should be determined for the first test conducted after each time the tank is filled using the data described in Section 6.2. For mass-based systems, the evaluator should plot the differences between the measured and induced leak rates as a function of the temperature differences. No relation is expected for mass-based systems. The evaluator must investigate any apparent relation to determine whether any limitations based on temperature differences are necessary. The temperature differences are calculated and the test conditions are reported on the results form to document the test conditions, even if no limitation is needed.

The difference in temperature between the product in the tank and that added to fill the tank should be determined for the first test conducted after each time the tank is filled using the data described in Section 6.2. The following calculations are required with the temperature differences.

Let $T_{p,i}$ denote the temperature of the product in the tank before the i^{th} delivery. Let $T_{d,i}$ denote the temperature of the delivered product during the i^{th} delivery. Then the difference in temperature for the i^{th} delivery is given by

$$T_i = T_{p,i} - T_{d,i} \quad (9\text{-}13)$$

The average temperature difference is given by

$$M_T = \Sigma\, T_i/N, \quad (9\text{-}14)$$

where N is the number of deliveries (usually 6) in the evaluation and the summation is over all temperature differences. The variance of the temperature differences is found using the formula

$$V_T = \Sigma\, (T_i - M_T)^2/(N-1). \quad (9\text{-}15)$$

The standard deviation of the temperature differences, S_T, is the square root of the variance. The minimum temperature difference, the maximum temperature difference and the standard deviation are reported on the results form.

If the temperature differences cannot be achieved between added product and product already in the tank during deliveries then the change in product temperature between the start and end of each test shall be calculated. The range of these values shall be recorded on the results form.

9.8 Minimum Stabilization Time

The stabilization time after filling the tank is obtained from average time between completion of the filling operation and the beginning of data collection for first test of each pair of tests. This can range from near zero to several hours, depending on the system. This process is expressed mathematically as equation 9-6.

$$\frac{\sum_{n-1}^{n-6}(endtransfe\,r - starttest\,)}{6} \qquad (9\text{-}16)$$

Most vendors will have a preset stabilization time that is the default value. Because of testing or other limitations the start time may be delayed beyond the normal start time. The evaluator should determine if these events are anomalous and use the median instead of the mean if this is the case. The reason for the delay in the start time should be documented on the log sheets.

The second test of a pair will have an additional stabilization time equal to the duration of the first test. The evaluator shall compare the results for the two stabilization times using the methods in the EPA Volumetric test protocol.[4]

9.9 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.

4 "Standard Test Procedures for Evaluating Leak Detection Methods: Volumetric Tank Tightness Testing Methods." US EPA March 1990.

10.0 REPORTING OF RESULTS

Any procedures used to either compensate for the presence of a water table or to account for fuel volatility must be stated in the report. The evaluator must agree that these approaches are reasonable for the method under evaluation.

Individual test report forms must be filled out for each test conducted including the trial test. These forms are provided in Appendix B.

Appendix A is designed to be the framework for a standard report. There are three parts to Appendix A. The first part is the Results of U.S. EPA Alternative Evaluation form. This is basically an executive summary of the findings. It is designed to be used 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.

The second part of the standard report consists of the Description of the Bulk Field-Constructed Tank Leak Detection Method. A description form is included in Appendix A and should be completed by the evaluating organization assisted by the vendor.

The third part of the standard report contains a Reporting Form for Leak Rate Data, also described in Appendix A. This table summarizes the individual test results and contains the information on starting dates and times, test duration, leak rate results, etc.

Appendix B contains a blank Individual Test Log. This form 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.

The limitations on the results of the evaluation are to be reported on the Results of U.S. EPA Alternative Test Procedures form. The intent is to document that the results are valid under conditions represented by the test conditions. Section 9 describes the summary of the test conditions that should be reported as limitations on the Results form. These items are also discussed below.

One practical limitation of the results is based on the surface area of the fuel in the tank. Most tests generally perform less well as the size or surface area of the tank increases. Consequently the results of the evaluation may be applied to field constructed tanks smaller than the test tank down to a volume of 50,000 gallons. Mass-based systems may be used on tanks with a product surface area up to 2.5 times larger than the test tank.

A second limitation on the results may be based on the temperature differential between the product added to the tank and that of the product already in the tank. This is generally not used for mass-based systems. However, if the evaluator determines that temperature changes during the testing may impact the test results, additional testing according to Part 2 (Volumetric Measurement Systems) may be necessary.

A third limitation is related to the stabilization time required by the vendor. The average time between the fill of the tank and the start of the first test will be calculated. (In the case of anomalous times, the stabilization time may be reported as the median stabilization time. The average stabilization time will be reported as a minimum stabilization time. If statistically significant differences between the first and second test results conducted after filling are noted, additional stabilization time limitations may be imposed.

A fourth limitation applies to the test duration. In general, longer tests produce better results. An average test time will be determined and reported by the evaluator. All subsequent testing, irrespective of tank size must be conducted for at least the average test time. Scaling down of test times is not permitted.

Part 2 Volumetric Measurement Systems

1.0 INTRODUCTION

1.2 Background

Same as Mass Measurement Systems (Part 1)

1.2 Applicability

Same as Mass Measurement Systems (Part 1)

1.3 Safety

Same as Mass Measurement Systems (Part 1)

2.0 GENERAL APPROACH

Same as Mass Measurement Systems (Part 1)

3.0 TANKS AND TEST EQUIPMENT

Same as Mass Measurement Systems (Part 1)

4.0 LEAK SIMULATION EQUIPMENT

Same as Mass Measurement Systems (Part 1)

5.0 PRODUCT

Same as Mass Measurement Systems (Part 1)

6.0 EVALUATION PROCEDURES

The general procedures are the same as for the mass-based leak detection methods. This section details the modifications that must be made for testing volumetric leak detection methods for field-constructed bulk tanks. Only those sections where different procedures or analyses are required are included here.

Table 1 has the experimental design for testing volumetric systems. The only difference in the experimental design is that for volumetric systems, four empty/fill cycles that include adding product of a different temperature are required (compared to only two for mass-based systems). Temperature is expected to be a more important factor with volumetric systems. Consequently, the temperature differences are more important. Limitations for use based on temperature differences will be included.

Table 1. Standard Testing Matrix - Product Volume, Leak Rate, and Temperature Differential Test Schedule

Test Description**	Test No.	Pair No.	Set No.	Nominal leak rate (gallon per hour)	Nominal temperature differential* (degree F)
Trial run	-	-	-	0.00	0
Empty to 50% full (if applicable)					
Refill to 90-95%	1	1	1	LR1	T1
	2	1	1	LR2	T1
Empty to 50-60%					
Refill to 90-95%	3	2	1	LR4	T2
	4	2	1	LR3	T2
Empty to 50-60%					
Refill to 90-95%	5	3	2	LR1	T3
	6	3	2	LR4	T3
Empty to 50-60%					
Refill to 90-95%	7	4	2	LR2	T4
	8	4	2	LR3	T4
Empty to 50-60%					
Refill to 90-95%	9	5	3	LR4	T5
	10	5	3	LR1	T5
Empty to 50-60%					
Refill to 90-95%	11	6	3	LR3	T6
	12	6	3	LR2	T6

*Note: Although the temperature cannot be controlled, these temperatures should be recorded on the appropriate data sheets. The temperature differential is calculated as the temperature of the product added minus the temperature of the product in the tank.

** Four empty/fill cycles that include adding product of a different temperature are required for volumetric measurement systems.

6.1 Induced Leak Rates

Same as Mass Measurement Systems (Part 1)

6.2 Temperature Differentials

For volumetric based systems, at least four of the six product deliveries must have product of a different temperature than that already in the tank. For conditions that allow product transfers between tests, some uncontrolled temperature variations may be present. Temperature should be measured at the best available access port into the tank. Temperature measurements should be conducted at different levels by installing an array of sensors. The average product temperature is then determined by averaging (with volume weighting) the measured temperatures. The following temperature measurements should be taken.

- Product temperature at the start of a test
- Product temperature at the end of the test
- Product temperature in the tank prior to a delivery
- Product temperature in the tank after completion of a delivery

Temperature differences are expected to affect volumetric-based systems. The temperature differences should be documented so that the ability of the system to adequately compensate for temperature can be verified. These temperatures are to be recorded on the individual test logs.

The difference in temperature between the delivered product and that already in the tank can be determined using thermal balance procedures. Alternatively, if the temperature of the delivered product is available it should be recorded and the difference between the average temperature before transfer and the temperature of the incoming product calculated directly.

The product temperature at the start and end of each test is also recorded in order to determine the change in temperature over the course of each test.

6.3 Randomization

Same as Mass Measurement Systems (Part 1)

6.4 Minimum Testing Time

Same as Mass Measurement Systems (Part 1)

6.5 Minimum Stabilization Time

Same as Mass Measurement Systems (Part 1)

7.0 WATER SENSOR EVALUATION (if applicable)

Same as Mass Measurement Systems (Part 1)

8.0 ENVIRONMENTAL DATA RECORDS

Same as Mass Measurement Systems (Part 1)

9.0 CALCULATIONS

The basic calculations described in equations 9-1 through 9-11 remain the same. Additional calculations for temperature are given in Section 9.7.

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

Same as Mass Measurement Systems (Part 1)

9.2 Averaging of Test Results (if applicable)

Same as Mass Measurement Systems (Part 1)

9.3 Water Detection Mode (if applicable)

Same as Mass Measurement Systems (Part 1)

9.4 Tank Size Limitations

The performance of volumetric systems is affected by the temperature and the product volume as well as the product surface area. The application of volumetric methods to tank sizes other than the one on which the method was evaluated is accordingly more restricted than for mass-based systems. Systems may not be used to evaluate tanks smaller than 50,000 gallons.

Systems evaluated on product volumes less than or equal to 100,000 gallons may be used to test tanks where product surface area and volume are less than or equal to 1.5X the volume and the surface area used in the evaluation.

Systems evaluated on product volumes larger than 100,000 gallons capacity may not be used to test tanks where either the product volume or surface area exceed that used in the evaluation.

9.5 Rate and Threshold

Same as Mass Measurement Systems (Part 1)

9.6 Leak Rate and Threshold Scaling

A simple technical approach to developing scaling performance of volumetric 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 area of the size of tank to which the evaluation results are to be applied. This can be expressed mathematically by the equation

$$S_2 = S_1 \times A_2/A_1 \tag{9-12}$$

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 be field constructed;
2. It must be a vertical wall tank;
3. The scaling is based on product surface area:
4. Leak rates may not be scaled below 0.2 gph.
5. For tanks larger than 100,000 gallons capacity, scaling up is not permitted. (Scaling down is permitted).

For systems evaluated using product volumes larger than 100,000 gallons, performance of the method may be scaled down using equation 9-12. A new minimum leak rate for a PD of 95% must then be calculated for the smaller tank. For example, to apply a method that has been evaluated on a tank with a surface area of 14,300 square ft. (a nominal 2,000,000 gallon tank), with a measured standard deviation of 0.5 gal/h to a tank with a surface area of 7150 square ft. (a nominal 1,000,000 gallon tank), a new minimum detectable leak rate based on a standard deviation of 0.25 gal/h would be used. Scaling to target leak rates smaller than 0.2 gal/hr is not permitted.

For systems evaluated using product volumes up to and including 100,000 gallons, performance of the system may be scaled up or down using equation 9-12 (see above paragraph also). The system may not be applied to any tank where the surface area or the volume stored exceeds 1.5 times the surface area or product volume of the tank used in the original evaluation. Again, scaling to target leak rates below 0.2 gal/hr is not permitted.

9.7 Allowable Temperature Differences

The difference in temperature between the product in the tank and that added to fill the tank should be determined for the first test conducted after each time the tank is filled using the data described in Section 6.2. The following calculations are required with the temperature differences.

Let $T_{p,i}$ denote the temperature of the product in the tank before the i^{th} delivery. Let $T_{d,i}$ denote the temperature of the delivered product during the i^{th} delivery. Then the difference in temperature for the i^{th} delivery is given by

$$T_i = T_{p,i} - T_{d,i} \qquad (9\text{-}13)$$

The average temperature difference is given by

$$M_T = \Sigma\, T_i/N, \qquad (9\text{-}14)$$

where N is the number of deliveries (usually 6) in the evaluation and the summation is over all temperature differences. The variance of the temperature differences is found using the formula

$$V_T = \Sigma\, (T_i - M_T)^2/(\,N-1). \qquad (9\text{-}15)$$

The standard deviation of the temperature differences, S_T, is the square root of the variance. A limitation on the temperature differences for which the system has been shown to work is 1.5 times the standard deviation of the temperature differences. Experience has shown that it is frequently difficult to transfer product of a different temperature to the test tank. This makes it difficult to evaluate the performance of both the temperature detection hardware and the temperature compensation software. In this situation, the standard deviation of the temperature change that occurred between the start and finish of each test must be calculated. Multiply this number by a factor of +/- 1.5. This is the maximum temperature change that may occur from start to finish of a test. If the temperature change from start to finish exceeds this amount then the test is considered invalid.

9.8 Stabilization Time

Same as Mass Measurement Systems (Part 1)

9.9 Test Time

Same as Mass Measurement Systems (Part 1)

10. REPORTING OF RESULTS

Any procedures used to either compensate for the presence of a water table or to account for fuel volatility must be stated in the report. The evaluator must agree that these approaches are reasonable for the method under evaluation.

Individual test report forms must be filled out for each test conducted including the trial test. These forms are provided in Appendix B.

Appendix A is designed to be the framework for a standard report. There are three parts to Appendix A. The first part is the Results of U.S. EPA Alternative Evaluation form. This is basically an executive summary of the findings. It is designed to be used 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.

The second part of the standard report consists of the Description of the Bulk Field-Constructed Tank Leak Detection Method. A description form is included in Appendix A and should be completed by the evaluating organization assisted by the vendor.

The third part of the standard report contains a Reporting Form for Leak Rate Data, also described in Appendix A. This table summarizes the individual test results and contains the information on starting dates and times, test duration, leak rate results, etc.

Appendix B contains a blank Individual Test Log. This form 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.

The limitations on the results of the evaluation are to be reported on the Results of U.S. EPA Alternative Test Procedures form. The intent is to document that the results are valid under conditions represented by the test conditions. Section 9 describes the summary of the test conditions that should be reported as limitations on the Results form. These items are also discussed below.

One practical limitation of the results is based on the volume and surface area of the fuel in the tank. Most tests generally perform less well as the volume and surface area of the tank increases and vice versa. To compensate for this, scaling can be used. For systems evaluated using product volumes greater then 100,000 gallons the standard deviation may be scaled down to create a new MDL. For systems evaluated using product volumes less than or equal to 100,000 gallons the standard deviation may be scaled up or down but the systems may not be used to test tanks where the product volume or surface area exceed 1.5X the surface area or product volume used during the evaluation. Regardless of tank volume or surface area, a system may not be used to detect a leak of 0.2 gph or less..

A second limitation on the results is based on the temperature differential between the product added to the tank and that of the product already in the tank. Volumetric-based systems are limited based on temperature differentials between the product in the tank and that of a new delivery. The limitation is 1.5 times the standard deviation of the temperature differentials found during the evaluation. If testing conditions do not allow adding product of a significantly different temperature to the test tank then a volumetric system may only be used to test tanks where the product temperature change between the start and end of the test does not exceed 1.5X the standard deviation of the product temperature differences which occurred between the start and end of the tests in the evaluation.

A third limitation is related to the minimum stabilization time required. The average time between the fill of the tank and the start of the first test will be calculated. This average stabilization time will be reported as a minimum stabilization time. (In the case of anomalous times, the minimum stabilization time may be reported as the median stabilization time). If statistically significant differences between the first and second test results conducted after filling are noted, additional stabilization time limitations may be imposed.

A fourth limitation applies to the test duration. In general, longer tests produce better results. An average test time will be determined and reported by the evaluator. All subsequent testing, irrespective of tank size must be conducted for at least the average test time. Scaling down of test times is not permitted.

APPENDIX A

REPORTING FORMS

Appendix A contains the following:

1. Results of U.S. EPA Alternative Test Procedures: Bulk Field-Constructed Tank Mass-Based Leak Detection Method - 4 pages

2. Results of U.S. EPA Alternative Test Procedures: Bulk Field-Constructed Tank Volumetric Leak Detection Method - 4 pages

3. Description Bulk Field-Constructed Tank Leak Detection Method - 6 pages

4. Reporting Forms for Testing Conditions and Leak Rate Data - Leak Detection Systems for Bulk Field-Constructed Tanks - 2 pages

Method Name and Version: ______________________________
Date of Certification: ______________________________

Results of U.S. EPA Alternative Test Procedures
Bulk Field-Constructed 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 a modification of the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Volumetric Tightness Testing Methods." 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 as required to comply with the applicable 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 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/hr.

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/hr.

The minimum water level (threshold) in the tank that the method can detect is ________ inches.

The minimum change in water level that can be detected by the method is _____ ______inches (provided that the water level is above the threshold).

Method Name and Version: ____

Date of Certification: ____

Test Conditions During Evaluation

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

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

The product used in the evaluation was _________.

The temperature differences between product added to fill the tank and product already in the tank ranged from ___________ deg F to _______________ deg F, with a standard deviation of _______ deg F.

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 is a field-constructed tank with vertical walls of constant cross section.
- The waiting time after adding any substantial amount of product to the tank is ______ hours ___ minutes.
- The total data collection time for the test is at least _____ hours ______ minutes.
- The maximum product surface area is no greater than ____ square feet.
- The minimum tank size is 50,000 gallons.
- 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.
- The detectable leak rate may not be scaled below 0.2 gal/h.
- Other limitations specified by the vendor or determined during testing:
- ____

  ____

  ____

Method Name and Version: ______________________________
Date of Certification: ______________________________

Procedural Information

State the procedures used to compensate for the presence of a water table above the bottom of the tank.

____

____

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

____

____

Temperature Variations were achieved by: (describe briefly)

____

____

Other Modifications: (describe briefly)

____

____

Method Name and Version: ________________________________

Date of Certification: ________________________________

Summary of Performance Estimates and Scaling

	Test Tank	Maximum Size Tank	Minimum Size Tank
Diameter			
Surface Area			
Standard Deviation			
Target Leak Rate			
Vendor's Threshold			
PFA			
PD(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)

Method Name and Version: ______________________________

Date of Certification: ______________________________

Results of U.S. EPA Alternative Test Procedures
Bulk Field-Constructed Tank
Volumetric 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 a modification of the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Volumetric Tightness Testing Methods." 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 as required to comply with the applicable 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 Leak Detection Method which declares tank to be leaking when the measured leak rate exceeds the threshold of _____ gallon per hour, has a probability of false alarm [P_{FA}] of ___% for tests conducted on tanks with surface areas of ____________ sq ft or less and volume of ___________ gallons 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/hr.

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/hr.

The minimum water level (threshold) in the tank that the method can detect is ________ inches.

The minimum change in water level that can be detected by the method is ______inches (provided that the water level is above the threshold).

Method Name and Version: ______________________________
Date of Certification: ______________________________

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 ________ in diameter or ( ) ___________ feet long, ___________ feet wide and ______ feet deep.

The tests were conducted with the tank product level _________ % full (________ gallons).

The product used in the evaluation was ________.

The temperature differences between product added to fill the tank and product already in the tank ranged from ____________ deg F to _______________ deg F, with a standard deviation of _______ deg F.

The maximum temperature change during the test was __________ deg F.

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

Limitations on the Results for Volumetric Systems

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 is a field-constructed tank with vertical walls of constant cross section.
- The waiting time after adding any substantial amount of product to the tank is ______ hours ___ minutes.
- The total data collection time for the test is at least _____ hours ______ minutes.
- The maximum product volume is no greater than _________ gallons.
- The minimum tank size is 50,000 gallons
- The temperature of the added product does not differ more than _____ deg. F from the product already in the tank.

Method Name and Version: ______________________________
Date of Certification: ______________________________

Limitations on the Results (continued)

- If temperature differences between added product and product already in the tank could not be achieved during deliveries then the temperature change during a test must not exceed ______ deg. F..
- The maximum surface area is no greater than ________ square feet.
- The detectable leak rate may not be scaled below 0.2 gal/h.
- Other limitations specified by the vendor of determined during testing:

____

____

____

Procedural Information

State the procedures used to compensate for the presence of a water table above the bottom of the tank.

____

____

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

____

____

Temperature Variations were achieved by: (describe briefly)

____

____

Method Name and Version: ______________________________
Date of Certification: ______________________________

Other Modifications: (describe briefly)______________________________

____

Summary of Performance Estimates and Scaling

	Test Tank	Maximum Size Tank	Minimum Size Tank
Diameter			
Volume			
Standard Deviation			
Target Leak Rate			
Vendor's Threshold			
PFA			
PD(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
Bulk Field-Constructed Tank Leak Detection Method

This section describes briefly the important aspects of the bulk 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) ______________________________

> Water level

Does the Method measure inflow of water as well as loss of product (gallon per hour)?

( ) yes

( ) no

Does the Method detect the presence of water in the bottom of the tank?

( ) yes

( ) no

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

( ) mechanical level measure (e.g., ruler, dipstick)

( ) changes in capacitance

( ) ultrasonic

( ) change in level of float (specify principle, e.g., capacitance, magnetostrictive, load cell, etc.) ______________________________

( ) acoustical signal characteristics of a leak

( ) identification of a tracer chemical outside the tank system

( ) 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) ______________________________

What type of temperature sensor is used?

( ) Product 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)?
________Hours ______ Minutes

Additional Comments: ______________________________

> Test duration

What is the required time for collecting data?

______ 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) ______________________________

> **Identifying and correcting for interfering factors**

How does the Method determine the presence and level of the ground water above the bottom of the tank?

( ) level of ground water above bottom of the tank not determined

( ) observation well near tank

( ) information from USGS, etc.

( ) information from personnel on-site

( ) presence of water in the tank

( ) other (describe briefly) ______________________________

Does the method measure inflow of water as well as loss of product?

( ) yes

( ) no

Additional Comments: ______________________________

____

____

How does the Method correct for the interference due to the presence of ground water above the bottom of the tank?

( ) no action

( ) system tests for water incursion

( ) Maintain product level sufficient to produce ____p.s.i. pressure differential between the tank and it's environment.

( ) other (describe briefly) ______________________________

> **Interpreting test results**

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

( ) actual level 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 coefficient of thermal expansion (Ce) of the product determined?

( ) actual sample taken for each test and Ce determined from specific gravity

( ) value supplied by vendor of product

( ) average value for type of product

( ) other (describe briefly) ______________________________

____

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 ______________________________

Additional Comments: ______________________________

Under what conditions are test results considered inconclusive?

( ) ground water level above the bottom of the tank

( ) soil not sufficiently porous

( ) 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?

( ) ground water level above the bottom of the tank

( ) large difference between ground temperature and delivered product temperature

( ) extremely high or low ambient temperature

( ) invalid for some products (specify) ______________________________

( ) other (describe briefly) ____

What are acceptable deviations from the standard testing protocol?

( ) none

( ) lengthen the duration of test

( ) other (describe briefly) ____

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

Form 1. Testing Conditions
Leak Detection Systems for Bulk Field-Constructed Tanks

Name and Version: ______________________________

Tank Evaluation Period: from __________ to __________ (Dates)

Test No.	Date at Completion Of Last Fill (m/d/y)	Time at Completion Of Last Fill (m/d/y)	Wait Time (hours)	Product Level (%)	Product Temperature Differential (Deg F)	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)
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										

Form 2. Leak Rate Data
Leak Detection Systems for Bulk Field-Constructed Tanks

Name and Version: ______________________________

Tank Evaluation Period: from __________ to __________ (Dates)

Test No.	Wait Time (hours)	Product Level (%)	Product Temperature Differential (deg F)	Nominal Leak Rate (gal/h)	Induced Leak Rate (gal/h)	Measured Leak Rate (gal/h)	Meas.-Ind. Leak Rate (gal/h)	Product Temperature Start of Test (deg F)	Product Temperature End of Test (deg F)	Temperature Change (deg F)
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										

APPENDIX B

INDIVIDUAL TEST LOGS

Field Operator ______________________________ Test No. __________

Signature ______________________________ Test Date __________

Individual Test Log

Bulk Field-Constructed Tank 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 General Background Information

Product Type ______________________________

Type of Tank ______________________________

Tank Dimensions (nominal)

Diameter _________ inches Length/width ______/______ inches

Volume __________ gallons

Ground-water level _______ inches above tank bottom (if known)

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

______ Hours ______ Minutes

2.0 Leak Detection Test Times

Start of test data collection __________ Date ______________ military time

End of test data collection __________ Date ______________ military time

3.0 Product Level and Temperature Information

	Product Level (inches)	Product Volume (gallons)	Average Product Temp (deg F)	In-tank Water Level (inches)	In-tank Water Volume (gallons)
Before Adding Product					
After Adding Product					
Start of Test					
End of Test					

Field Operator ______________________ Test No. __________

Signature ______________________ Test Date __________

4.0 Product Delivery Information – Please complete Section 3.0 if product was added to the tank before testing.

Date and Time at Start of Delivery	
Date and Time at End of Delivery	
Amount of Product Added (gallons)	
Temperature of Product Added (deg F)	
Number of Tests Completed Since the Delivery Including This Test (e.g. – If this is the 2nd test following a delivery, write 2 in the table.)	

5.0 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					

6.0 Leak Rate Data

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

7.0 ATGS Controller Printout

Attach a copy of the ATGS controller printout with the vendor's reported leak rate to this form (Attach additional pages if needed).

Additional Comments (Attach additional pages if needed)

Appendix C

Using Multiple Test Results

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 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,

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

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.

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,

$$PFA = P_1^2 \qquad \text{(C-9)}$$

and

$$PD = P_2^2 \qquad \text{(C-10)}$$

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

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

and

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

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.

1. Conclude a leak if all 3 tests indicate a leak.
2. Conclude a leak if at least 2 of the 3 tests indicate a leak.
3. 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:

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

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

3. 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.