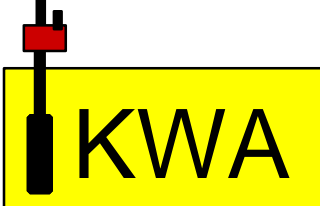# United States Environmental Protection Agency

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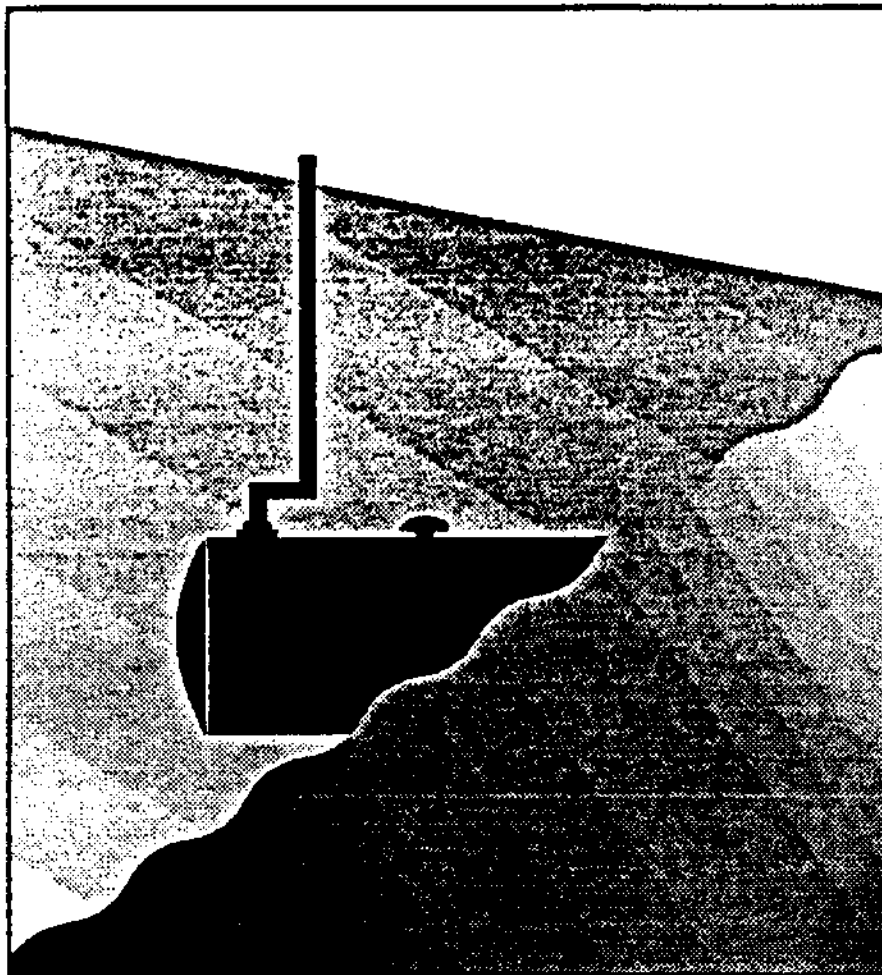
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Standard Test Procedures for Evaluating Leak Detection Methods:
Volumetric Tank Tightness Testing Methods

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

Final Report

U.S. Environmental Protection Agency
Office of Underground Storage Tanks

March 1990

FOREWORD

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

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

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

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

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

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

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

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

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

EPA Standard Test Procedures

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

1. "Standard Test Procedures for Evaluating Leak Detection Methods: Volumetric Tank Tightness Testing Methods"

2. "Standard Test Procedures for Evaluating Leak Detection Methods: Nonvolumetric Tank Tightness Testing Methods"

3. "Standard Test Procedures for Evaluating Leak Detection Methods: Automatic Tank Gauging Systems"

4. "Standard Test Procedures for Evaluating Leak Detection Methods: Statistical Inventory Reconciliation Methods"

5. "Standard Test Procedures for Evaluating Leak Detection Methods: Vapor-Phase Out-of-tank Product Detectors"

6. "Standard Test Procedures for Evaluating Leak Detection Methods: Liquid-Phase Out-of-tank Product Detectors"

7. "Standard Test Procedures for Evaluating Leak Detection Methods: Pipeline Leak Detection Systems"

Each test procedure provides an explanation of how to conduct the test, how to perform the required calculations, and how to report the results. The results from each standard test procedure provide the information needed by tank owners and operators to determine if the method meets the regulatory requirements.

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

National Consensus Code or Standard

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

Alternative Test Procedures Deemed Equivalent to EPA's

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

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

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

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

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

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

ACKNOWLEDGMENTS

CONTENTS

SECTION 1

INTRODUCTION

1.1 BACKGROUND

The regulations on underground storage tanks (40 CFR Part 280, Subpart D) specify performance standards for leak detection methods that are internal to the tank. For tank tightness testing, the tests must be capable of detecting a leak of 0.10 gallon per hour with a probability of (at least) 95%, while operating at a false alarm rate of 5% or less.

A large number of test devices and methods are reaching the market, but little evidence is available to support their performance claims. Advertising literature for the methods can be confusing. Owners and operators need to be able to determine whether a vendor's tank tightness test method meets the EPA performance standards. The implementing agencies (state and local regulators) need to be able to determine whether a tank facility is following the UST regulations, and vendors of tank tightness test methods need to know how to evaluate their systems.

Presently, there are two major categories of tank tightness testing methods on the market: (a) <u>volumetric</u> testing methods, which measure directly the leak rate in gallons per hour, and (b) <u>nonvolumetric</u> testing methods, which report only the qualitative assessment of leaking or not leaking. These two testing methods require different testing and statistical analysis procedures to evaluate their performance. The protocol in this document should be followed when the method is a volumetric one. The evaluation of the performance of nonvolumetric tank tightness testing methods is treated in a separate protocol. To simplify the terminology throughout this document, volumetric tank tightness testing methods are referred to as tank tightness testing methods.

1.2 OBJECTIVES

The objectives of this protocol are twofold. First, it provides a procedure to test tank tightness testing methods in a consistent and rigorous manner. Secondly, it allows the regulated community and regulators to verify compliance with regulations.

This protocol provides a standard method that can be used to estimate the performance of a tank tightness testing method. Tank owners and operators are required to demonstrate that the method of leak detection they use meets the EPA performance standards of operating at (no more

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than) a 5% false alarm rate while having a probability of detection of (at least) 95% to detect a leak of 0.10 gallon per hour. This demonstration must be made no later than December 22, 1990. The test procedure described in this protocol is one example of how this level of performance can be proven. The test procedure presented here is specific, based on reasonable choices for a number of factors. Information about other ways to prove performance is provided in the Foreword of this document.

It should be noted that this protocol does not address the issue of safety testing of equipment or operating procedure. The vendor is responsible for conducting the testing necessary to ensure that the equipment is safe for use with the type of product being tested.

1.3 APPROACH

In general, the protocol calls for using the method on a tight tank and estimating the leak rate both under no-leak conditions and under induced leak conditions. The leak rate measured by the method is then compared with the induced leak rate for each test run. To estimate the performance of the method, the differences are summarized and used with the normal probability model for the measurement errors. The results are applicable to tanks of the size used in the evaluation or tanks of no more than 50% greater capacity than the test tank.

The testing also includes conditions designed to check the method's ability to deal with some of the more important sources of interference. A number of cycles of filling and partially emptying the tank are incorporated to test the method's ability to deal with tank deformation. During some of the cycles of filling and partially emptying the tank, the product used to refill the tank is conditioned to have a temperature different from that of the product in the tank. This allows a check on the adequacy of the method's temperature compensation. Four different nominal leak rates (including the no-leak condition) are used. This demonstrates how closely the method can actually measure leak rates as well as demonstrates the size of the measurement error for a tight tank. The complete experimental design is given in Section 6 of this document.

1.4 EFFECTS OF HIGH GROUND-WATER LEVEL

The ground-water level is a potentially important variable in tank testing. Ground-water levels are above the bottom of the tank at approximately 25% of the tank sites nationwide, with higher proportions in coastal regions. Also, tidal effects may cause fluctuations in the ground-water level during testing in some coastal regions. If the ground-water level is above the bottom of the tank, the water pressure on the exterior of the tank will tend to counteract the product pressure from the inside of the tank. If the tank has a leak (hole) below the

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ground-water level, the leak rate in the presence of the high ground-water level will be less than it would be with a lower ground-water level. In fact, if the ground-water level is high enough, water may intrude into the tank through the hole.

The means by which the method deals with the ground-water level must be documented. A method that does not determine the ground-water level and does not take it into account is not adequate. If the ground-water level is determined to be above the bottom of the tank, an acceptable method must include a means of compensating for its presence. Three possible methods are overfilling, water level monitoring, and testing at two (or more) filling levels.

Overfilling involves determining the ground-water level and then filling the tank, perhaps using extensions to the risers, to produce a net positive pressure at the bottom of the tank comparable to the pressure that the normal product volume would produce in the absence of a high ground-water level in the tank. Water-level monitoring relies on detecting an increase in product level caused by an influx of high ground water into the tank. Finally, some methods have procedures for testing at two different product levels, on the theory that different estimated leak rates (because of two different differential pressures) will be observed. The procedure for testing methods with each of these approaches is described below.

A method that compensates for high ground-water levels by overfilling the tank to ensure that there is an outward pressure throughout the tank can be tested by the procedure described in this document. The method should determine the ground-water level at the test tank and use the appropriate product level.

A method that relies on detecting an increase in volume or product level from water incursion for tanks with a high ground-water level can also be tested with this procedure. The evaluator should determine that the test method does check for the ground-water level, and should determine that the test method indicates a leak if an increase in volume is seen. The evaluator should also determine how the test method ensures that there will be net flow either into or out of the tank in the presence of a high ground-water level. If parts of the tank are subject to inward pressure and parts to outward pressure during the test, there might be no net volume change during the test even though the tank had one or more holes. If the method ensures a flow by determining the ground-water level and calculating the pressure, then testing for product loss with a high product level and for water incursion with a low product level, the test matrix (in Section 6) needs to be augmented to test at both product levels.

A method that attempts to test in the presence of a high ground-water level by testing at two different product levels needs to be evaluated using its standard operating procedure. The evaluator must determine whether the method is sensitive enough to determine the change in flow resulting from the different heads. If the method does not

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determine the ground-water level and ensure that the pressure is in a constant direction throughout the tank, it is not clear that the compensation for high ground-water levels is adequate and the evaluator must test the method's approach under varying ground-water conditions (real or simulated).

The evaluation should include all modes of testing that the method uses. This may require the evaluating organization to develop and carry out an additional test series if the tank test method uses a mode of leak detection besides volumetric measurements. A method for evaluating the operation of a water sensor is described in the EPA "Standard Test Procedure for Evaluating Automatic Tank Gauging Systems" and is not repeated here because no volumetric methods are currently known that use water sensors.

In summary, the evaluating organization should make an engineering judgment about the method's approach to adjusting for the ground-water level. If in doubt, the evaluating organization may require tests in addition to those detailed in this protocol.

1.5 ORGANIZATION OF THIS DOCUMENT

The next section presents the scope and applications of this protocol. Section 3 presents an overview of the approach, and Section 4 presents a brief discussion of safety issues. The apparatus and materials needed to conduct the evaluation are discussed in Section 5. The step-by-step procedure is presented in Section 6. Section 7 describes the data analysis, and Section 8 provides some interpretation of the results. Section 9 describes how the results are to be reported.

Two appendices are included in this document. Definitions of some technical terms are provided in Appendix A. Appendix B presents a compendium of reporting forms: a standard reporting form for the evaluation results, a standard form for describing the operation of the tank tightness testing method, data reporting forms, and an individual test log. Appendix B thus forms the basis for a standard report.

SECTION 2

SCOPE AND APPLICATIONS

This document presents a standard protocol for evaluating volumetric tank tightness testing methods. The protocol is designed to evaluate methods that test a tank at a specific point in time by monitoring product volume changes in the tank during the test period. The protocol is designed to evaluate the method's ability to detect a leak of 0.10 gallon per hour with probability of 95% or higher while operating at a false alarm rate of 5% or less, as specified in the performance standards in the UST regulations.

Subject to the limitations listed on the Results of U.S. EPA Standard Evaluation form (see Appendix B), the results of this evaluation can be used to prove that a volumetric tank tightness testing method meets the requirements of 40 CFR Part 280, Subpart D. The Standard Evaluation Results form lists the test conditions. In particular, the results reported are applicable for the stabilization times (or longer) used in the tests and for temperature conditions no more severe than those used in the tests.

SECTION 3

SUMMARY

The evaluation protocol for volumetric test methods calls for conducting the testing on a tight tank. The organization performing the evaluation should have evidence that the tank used for testing is tight independent of the system currently being tested. The evidence that the tank is tight may consist of any of the following:

1. At least three automatic tank gauging system (ATGS) records within a 3-month period with inventory and test modes indicating a tight tank.

2. A tank tightness test by another test method in the 6 months preceding testing that indicates a tight tank.

3. Continuous vapor or liquid monitoring system installed that indicates a tight tank.

Any of the above, verified by a tight test result on the initial test (trial run) of the method under investigation, constitutes acceptable evidence. This information should be recorded on the data reporting form (see Appendix B).

The protocol calls for an initial test (trial run) under stable conditions to ensure that the equipment is working and that there are no problems with the tank, associated piping, and the test equipment. If the tank fails the trial run test, however, then testing should not proceed until the problem is identified and corrected. Only if the evaluating organization has strong evidence that the tank is tight, should testing proceed.

The tank tightness test device is installed in the test tank and is used to measure a leak rate under the no-leak condition and with three induced leak rates of 0.05, 0.10, and 0.20 gallon per hour. A total number of at least 24 tests is to be performed. The tank must be partially emptied (to half full or less) and then refilled to the test level for at least every other test. When filling the tank to the test level, product at least 5°F warmer than that in the tank is used for one third of the fillings and product at least 5°F cooler than that in the test tank is used for one third of the fillings. The other third of the fillings uses product at the same temperature. The volumetric test method's ability to track actual volume change is determined by the difference between the volume change rate measured by the test device and the actual, induced,

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volume change rate for each test run. These differences are then used to
calculate the performance of the method. Performance results are
reported on the Results of U.S. EPA Standard Evaluation form included in
Appendix B of this document.

SECTION 4

SAFETY

This discussion does not purport to address all the safety consider-
ations 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 method 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 detec-
tion 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 method's ability
to detect leaks. It does not address testing the equipment for safety
hazards. The manufacturer needs to arrange for other testing for con-
struction 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.

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SECTION 5

APPARATUS AND MATERIALS

5.1 TANKS

The evaluation protocol requires the use of an underground storage
tank known to be tight. A second tank or a tank truck is required to
store product for the cycles of emptying and refilling. As discussed
before, the tank should have been tested and shown to be tight by any of
the three methods described in Section 3. The tank should not have any
history of problems. In addition, the protocol calls for an initial
trial run with the test equipment under stable conditions. This test
should indicate that the tank is tight; if it does not, there may be a
problem with the tank and/or the test equipment that should be resolved
before proceeding with the evaluation.

The tank facility used for testing is required to have at least one
monitoring well. The primary reason for this is to determine the ground-
water level. The presence of a ground-water level above the bottom of
the tank would affect the leak rate in a real tank, that is, the flow of
product through an orifice. The flow would be a function of the differ-
ential pressure between the inside and outside of the tank. However, in
a tight tank with leaks induced to a controlled container separate from
the environment, the ground-water level will not affect the evaluation
testing. Consequently, it is not necessary to require that testing
against the evaluation protocol be done in a tank entirely above the
ground-water level. The monitoring well can also be used for leak detec-
tion at the site, either through liquid monitoring (if the ground-water
level is within 20 feet of the surface) or for vapor monitoring.

Because performance of internal tank test methods is generally worse
for large tanks, the size of the test tank is important. An 8,000-gallon
tank is recommended because this appears to be the most common tank in
use. However, testing may be done in tanks of any size. The results of
the evaluation would be applicable to all smaller tanks. The results are
also applicable to larger tanks with the restriction that the tanks be no
more than 50% larger in capacity than the test tank. That is, results
from a 6,000-gallon tank can also be applied to tanks of up to 9,000 gal-
lons in capacity. Results from 8,000-gallon tanks can be applied to
tanks up to 12,000 gallons, those from 10,000 gallons to up to
15,000 gallons, etc.

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Because the protocol calls for filling the tank a number of times, a second tank or a tank truck is needed to hold reserve product. A pump and associated hoses or pipes to transfer the product from the test tank to the reserve product tank or truck are also needed.

5.2 TEST EQUIPMENT

The equipment for each tank test method will be supplied by the vendor or manufacturer. Consequently, it will vary by method. In general, the test equipment will consist of some method for monitoring product volume or level and for compensating for temperature. It will also typically include instrumentation for collecting and recording the data and procedures for using the data to calculate a leak rate and interpret the result as a pass or fail for the tank.

It is recommended that the test equipment for the method being tested be operated by trained personnel who regularly use the equipment in commercial tests. This should ensure that the vendor's equipment is correctly operated and will eliminate problems that newly trained or untrained individuals might have with the equipment. On the other hand, if the equipment is normally operated by the station owner, then the evaluating organization should provide personnel to operate the equipment after the customary training.

5.3 LEAK SIMULATION EQUIPMENT

The protocol calls for inducing leaks in the tank. The method of inducing the leaks must be compatible with the leak detection method being evaluated. This is done by removing product from the tank at a constant rate, measuring the amount of product removed and the time of collection, and calculating the resulting induced leak rate. The experimental design in Section 6 gives the nominal leak rates that are to be used. These leak rates refer to leak rates that would occur under normal tank operating conditions. Test methods that use increased product head to increase flow rates to make leaks easier to detect should be tested with induced leaks at the higher flow rates that would occur under the test conditions. An approach to this is described below.

The actual change in the leak rate of a tank in response to a change in pressure is not known and may vary with tanks. For the purposes of the evaluation test, assume that the flow rate through an orifice is proportional to the square root of the pressure. To convert the nominal leak rates to leak rates under increased pressure head, determine the depth of product under the test conditions and form the ratio of the test depth to 7/8 of the tank diameter. Take the square root of this ratio and multiply it by the nominal leak rate. The result is the leak rate that would be expected under the test conditions corresponding to the nominal leak rate under operating conditions. For example, a method that tests one foot above grade on an 8-foot diameter tank buried 3 feet would have a factor of $\sqrt{12/7} = 1.31$. This factor will multiply each nominal

leak rate. Methods that do not overfill the tank are tested with the nominal leak rates.

A method that has been successfully used for inducing leaks in previous testing is based on a peristaltic pump. An explosion-proof motor is used to drive a peristaltic pump head. The sizes of the pump head and tubing are chosen to provide the desired flow rates. A variable speed pump head can be used so that different flow rates can be achieved with the same equipment. The flow is directed through a rotameter so that the flow can be monitored and kept constant. One end of the tubing is inserted into the product in the tank. The other end is placed in a container. Typically, volatile products are collected into a closed container in an ice bath. The time of collection is monitored, the amount of product weighed, and the volume at the temperature of the product in the tank is determined to obtain the induced leak rate. While it is not necessary to achieve the nominal leak rates exactly, the induced leak rates should be within ±30% of the nominal rates. The induced leak rates should be carefully determined and recorded. The leak rates measured by the test method will be compared to the induced leak rates. The method of inducing the leak must be compatible with the leak detection method under test. For example, one (nonvolumetric) tank tightness testing method uses the characteristic acoustical signal produced when air drawn into a liquid through a hole in the tank wall produces a bubble to detect a leak. Such a signal obviously cannot be simulated by pumping product out of a tank.

5.4 PRODUCT

The most common products in underground storage tanks are motor fuels, particularly gasoline and diesel fuel. Analysis of tank test data based on tanks containing a variety of products has shown no evidence of difference in test results by type of product, if the same size tank is considered. The only exception to this observation is that one tank test method did produce better results when testing tanks with pure chemicals (e.g., benzene, toluene, xylene) than when testing gasoline. This difference was attributed to better test conditions, longer stabilization times, and better cooperation from tank owners.

Any commercial petroleum product of grade number 2 or lighter may be used for testing, depending on the availability and restrictions of the test tanks. The choice of the product used is left to the evaluating organization, but it must be compatible with the test equipment.

The test plan requires some testing with addition of product at a different temperature from that of the fuel already in the tank. This requirement is to verify that the method can accommodate the range of temperature conditions that routinely occur. The procedure requires that some tests begin by the tank being filled from about half full to the test level with fuel that is 5°F warmer than the product in the tank, and some tests using fuel 5°F cooler than the product in the tank. This procedure requires that some method of heating and cooling the fuel be

provided, such as pumping the fuel through a heat exchanger, or by placing heating and cooling coils in the supply tank or tank truck before the fuel is transferred to the test tank.

5.5 MISCELLANEOUS EQUIPMENT

As noted, the test procedure requires the partial emptying and filling of the test tank. One or more fuel pumps of fairly large capacity will be required to accomplish the filling in a reasonably short time. Hoses or pipes will also be needed for fuel transfer. Many test methods require some reserve fuel for filling a standpipe or topping off a fill pipe. In addition, containers will be necessary to hold this product as well as that collected from the induced leaks. A variety of tools need to be on hand for making the necessary connections of equipment.

SECTION 6

TESTING PROCEDURE

The overall performance of the method is estimated by a comparison of the method's measured (or detected) leak rates and the actual induced leaks. Performance is measured over a variety of realistic conditions, including temperature changes and filling effects. The range of conditions does not represent the most extreme cases that might be encountered. Extreme conditions can cause any method to give misleading results. If the method performs well overall, then it may be expected to perform well in the field. The test procedures have been designed so that additional analysis can be done to determine whether the method's performance is affected by the stabilization time, different temperature effects, or the size of the leak.

The test procedure introduces three main factors that may influence the test: size of leak, temperature effects, and tank deformation. The primary consideration is the size of the leak. The method is evaluated on its ability to measure or detect leaks of specified sizes. If a method cannot closely measure a leak rate of 0.10 gallon per hour or if the method demonstrates excessive variability on a tight tank, then its performance is not adequate. The ability of the method to track the leak rate can be compared for the different leak rates.

The second consideration is the temperature of product added to fill a tank to the level needed for testing. Three conditions are used: added product at the same temperature as the in-tank product, added product that is warmer than that already in the tank, and added product that is cooler. The temperature difference is set at 5°F. The difference should be at least 5°F and should be measured and reported to the nearest degree F. The temperature difference is needed to ensure that the method can adequately test under realistic conditions. The performance under the three temperature conditions can be compared to determine whether these temperature conditions have an effect on the performance.

The third consideration is the tank deformation caused by pressure changes that are associated with product level changes. This consideration is addressed by requiring several empty-fill cycles. One test is conducted at the minimum stabilization time specified by the test method. A second test follows to test without any change in conditions (except possibly leak rate). Comparison of the order of the test pairs can determine whether the additional stabilization improves the performance. The actual times between completing the fills and starting the tests are recorded and reported.

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In addition to these factors, environmental data are recorded to document the testing conditions. These data may explain one or more anomalous test results.

6.1 ENVIRONMENTAL DATA RECORDS

In general, the evaluation protocol requires that the conditions during the evaluation be recorded. In addition to all the testing conditions, the following measures should be reported (see the Individual Test Log form in Appendix B):

- ambient temperature, monitored hourly throughout each test
- barometric pressure, monitored hourly throughout each test
- weather conditions such as wind speed; sunny, cloudy, or partially cloudy sky; rain; snow; etc.
- ground-water level if above bottom of tank
- any special conditions that might influence the results

Both normal and "unacceptable" test conditions for each method should be described in the operating manual for each method and should provide a reference against which the existing test conditions can be compared. The evaluation should not be done under conditions outside the vendor's recommended operating conditions.

Pertaining to the tank and the product, the following items should be recorded on the Individual Test Log (see Appendix B):

- type of product in tank
- tank volume
- tank dimensions and type
- amount of water in tank (before and after each test)
- temperature of product in tank before filling
- temperature of product added each time the tank is filled
- temperature of product in tank immediately after filling
- temperature of product in tank at start of test
- If tank is overfilled, height of product above tank.

6.2 INDUCED LEAK RATES AND TEMPERATURE DIFFERENTIALS

Following a trial run in the tight tank, 24 tests will be performed according to the experimental design exemplified in Table 1. In Table 1, LR_i denote the nominal leak rates and T_i denote the temperature differential conditions to be used in the testing. These 24 tests evaluate the method under a variety of conditions.

Table 1. LEAK RATE AND TEMPERATURE DIFFERENTIAL TEST SCHEDULE

	Test No.	Set No.	Nominal leak rate (gallon per hour)	Nominal temperature differential* (degree F)
Trial run	-	-	0	0
Empty/Fill cycle				
	1	1	LR_2	T_2
	2	1	LR_1	T_2
Empty/Fill cycle				
	3	2	LR_3	T_3
	4	2	LR_2	T_3
Empty/Fill cycle				
	5	3	LR_1	T_3
	6	3	LR_4	T_3
Empty/Fill cycle				
	7	4	LR_3	T_1
	8	4	LR_1	T_1
Empty/Fill cycle				
	9	5	LR_2	T_1
	10	5	LR_4	T_1
Empty/Fill cycle				
	11	6	LR_4	T_3
	12	6	LR_1	T_3
Empty/Fill cycle				
	13	7	LR_1	T_2
	14	7	LR_4	T_2
Empty/Fill cycle				
	15	8	LR_1	T_1
	16	8	LR_2	T_1
Empty/Fill cycle				
	17	9	LR_3	T_2
	18	9	LR_2	T_2
Empty/Fill cycle				
	19	10	LR_4	T_2
	20	10	LR_3	T_2
Empty/Fill cycle				
	21	11	LR_2	T_3
	22	11	LR_3	T_3
Empty/Fill cycle				
	23	12	LR_4	T_1
	24	12	LR_3	T_1

* Note: The temperature differential is calculated as the temperature of the product added minus the temperature of the product in the tank.

Leak Rates

The following four nominal leak rates will be induced during the procedure:

English units (gallon per hour)	Metric units (milliliters per minute)
0.00	0.00
0.05	3.2
0.10	6.3
0.20	12.6

Temperature Differentials

In addition, three nominal temperature differentials between the temperature of the product to be added and the temperature of the product in the tank during each fill cycle will be used. These three temperature differentials are -5°, 0°, and +5°F (-2.8°, 0°, and +2.8°C).

Randomization

A total of 24 tests consisting of duplicates of the 12 combinations of the four leak rates (LR_1, LR_2, LR_3, and LR_4) and the three temperature differentials (T_1, T_2, and T_3) will be performed. The 24 tests have been arranged in pairs (sets), each pair consisting of two tests performed at the same temperature differential. However, the leak rates within a pair have been randomly assigned to the first or second position in the testing order. An example test schedule is outlined in Table 1 above.

The randomization of the tests is achieved by randomly assigning the nominal leak rates of 0, 0.05, 0.10, and 0.20 gallon per hour to LR_1, LR_2, LR_3, and LR_4 and by randomly assigning the nominal temperature differentials of 0°, -5°, and +5°F to T_1, T_2, and T_3, following the sequence of 24 tests as shown in Table 1. The organization performing the evaluation is responsible for randomly assigning the four leak rates to LR_1, LR_2, LR_3, and LR_4 and the three temperature conditions to T_1, T_2, and T_3. The results of the randomized sequence should be kept blind to the vendor. That is, the vendor should not know which induced leak rate is used or which temperature condition is present in advance. The vendor should measure the leak rate and compensate for temperature based on his instrumentation and standard operating procedure without knowledge of the induced conditions. Randomization should be done separately for each method evaluated. The order of performing set numbers should also be randomized or varied as needed for practicality and kept blind to the vendor.

Each test set consists of two tests performed using two induced leak rates and one induced temperature differential (temperature of product to be added - temperature of product in tank). Each set indicates the

sequence in which the product volumes (in gallons per hour) will be removed from the tank at a given product temperature differential.

Note: The tests are given in pairs for economy. An acceptable alternative is to fill and empty the tank with product at the indicated temperature difference before each of the 24 tests. A minimum of 12 empty/fill cycles must be done, with a minimum of 24 tests.

Notational Conventions

The nominal leak rates to be induced, that is 0, 0.05, 0.10, and 0.20 gallon per hour, after randomizing the order, are denoted by LR_1, LR_2, LR_3, and LR_4. It is clear that these figures cannot be achieved exactly in the field. Rather, these numbers are targets that should be achieved within ±30%.

The leak rates actually induced for each of the 24 tests will be measured during each test. They will be denoted by S_1, S_2,..., S_{24}. These are the leak rates against which the leak rates obtained by the vendors performing their tests will be compared.

The leak rates measured by the vendor's equipment during each of the 24 tests will be denoted by L_1, L_2,...,L_{24} and correspond to the induced leak rates S_1, S_2,...,S_{24}.

The subscripts 1,....,24 correspond to the order in which the tests were performed (see Table 1). That is, for example, S_5 and L_5 correspond to the test results from the fifth test in the test sequence.

Optional Experimental Design

The experimental design given in Table 1 is one example of a possible design. It has been set up so that each leak rate occurs twice with each temperature differential condition. In addition, each leak rate occurs once as the first of a pair and once as the second. Maintaining this balance is desirable for the supplemental data calculations. However, it is not necessary for different leak rates to be used in each pair. In fact, from a randomization point of view it is desirable if some pairs include the same leak rates. It would also aid in keeping the experimental conditions, especially the induced leak rates, blind to the tester.

As an illustration of other randomization designs, consider the arrangement in Table 2 below. In Table 2, the combinations of leak rate with one temperature condition, say T_1, are shown. Each option column indicates a different possible arrangement of the leak rates that maintains the property that each leak rate appears once as the first of a pair and once as the second, while also appearing exactly twice with the temperature condition. The first option includes four pairs, each with different leak rates; the second option includes one pair in which both

tests use the same leak rate; the third option includes two pairs in which both tests use the same leak rate; and the fourth option includes all pairs with the same leak rate for each member of the pair. For randomization, one of the four possible options in Table 2 can be selected at random for each temperature condition. The four leak rates can be assigned at random to LR_1, LR_2, LR_3, and LR_4 in each temperature condition. Finally, the four pairs of tests for each temperature condition can be interspersed in random order with the pairs from the other two temperature conditions.

Table 2. OPTIONAL EXPERIMENTAL DESIGN FOR RANDOMIZATION

Pair No.	Nominal temperature differential	Nominal leak rate Option 1	Nominal leak rate Option 2	Nominal leak rate Option 3	Nominal leak rate Option 4
1	T_1	LR_2	LR_1	LR_1	LR_1
1	T_1	LR_1	LR_1	LR_1	LR_1
2	T_1	LR_4	LR_4	LR_4	LR_2
2	T_1	LR_3	LR_3	LR_4	LR_2
3	T_1	LR_2	LR_3	LR_2	LR_3
3	T_1	LR_4	LR_2	LR_3	LR_3
4	T_1	LR_1	LR_2	LR_3	LR_4
4	T_1	LR_3	LR_4	LR_2	LR_4

6.3 TESTING SCHEDULE

The first test to be done is a trial run. This test should be done with a tight tank in a stable condition and this should be known to the vendor. The results of the trial run will be reported along with the other data, but are not explicitly used in the calculations estimating the performance of the method.

There are two purposes to this trial run. One is to allow the vendor to check out the tank testing equipment before starting the evaluation. As part of this check, any faulty equipment should be identified and repaired. A second part is to ensure that there are no problems with the tank and the test equipment. Such practical field problems as loose risers, leaky valves, leaks in plumbers plugs, etc., should be identified and corrected with this trial run. The results also provide current verification that the tank is tight and so provide a baseline for the induced leak rates to be run in the later part of the evaluation.

The testing will be performed using a randomized arrangement of nominal leak rates and temperature differentials as listed in Table 1 above. The time lapse between the two tests in each set should be kept as short as practical. It should not exceed 30 minutes, and preferably should be held to 15 minutes or less. The date and time of starting each test are to be reported on the test log. Twelve sets of two tests each will be carried out. After each set of two tests, the test procedure starts anew with emptying the tank to half full, refilling, stabilizing, etc. The details of the testing schedule are presented next.

Step 1: Randomly assign the nominal leak rates of 0, 0.05, 0.10, and 0.20 gallon per hour to LR_1, LR_2, LR_3, and LR_4. Also, randomly assign the temperature differentials of 0°, -5°, and +5°F to T_1, T_2, and T_3. This will be done by the organization performing the evaluation and needs to be kept blind to the crew performing the testing.

Step 2: Follow the vendor's instructions and install the leak simulation equipment in the tank if this has not already been done, making sure that the leak simulation equipment will not interfere with the test equipment.

Step 3: Trial run. Following the test method's standard operating procedure, fill the tank to the recommended level, and allow for the stabilization period called for by the method or longer. The product added should be at the same temperature as that of the in-tank product. Conduct a test on the tight tank to check out the system (tank, plumbing, etc.) and/or the method. Perform any necessary repairs or modifications identified by the trial run.

Step 4: Empty the tank to half full. Fill with product at the recommended temperature. The temperature differential will be T_2 (Table 1, Test No. 1). Record the date and time at the completion of the fill. Allow for the recommended stabilization period, but not longer.

Step 5: Continue with the method's standard operating procedure and conduct a test on the tank, using the method's recommended test duration. Record the date and time of starting the test. This test will be performed under the first nominal leak rate, LR_2, of the _first_ set in Table 1.

When the first test is complete, determine and record the actual induced leak rate, S_1, and the method's measured leak rate, L_1. If possible, also record the data used to calculate the leak rate and the method of calculation. Save all data sheets, computer printouts, and calculations. Record the dates and times at which the test began and ended. Also record the length of the stabilization period. The Individual Test Log form in Appendix B is provided for the purpose of reporting these data and the environmental conditions for each test.

Record the temperature of the product in the test tank and that of the product added to fill the test tank. After the product has been added to fill the test tank, record the average temperature in the test tank. Measuring the temperature of the product in the tank is not a trivial task. One suggested way to measure the temperature of the product in the tank is to use a probe with five temperature sensors spaced to cover the diameter of the tank. The probe is inserted in the tank (or installed permanently), and the temperature readings of those sensors in the liquid are used to obtain an average temperature of the product. The temperature sensors can be spaced to represent equal volumes or the temperatures can be weighted with the volume each represents to obtain an average temperature for the tank.

Step 6: Change the nominal leak rate to the <u>second</u> in the first set, that is LR_1 (see Table 1). Repeat Step 5. Note that there will be an additional period (the time taken by the first test and the set-up time for the second test) during which the tank may have stabilized. When the second test of the first set is complete, again record all results (times and dates, measured and induced leak rates, temperatures, calculations, etc.).

Step 7: Repeat Step 4. The temperature differential will be changed to T_3.

Step 8: Change the nominal leak rate to the first in the second set, that is LR_3. Repeat Step 5. Record all results.

Step 9: Change the nominal leak rate to the second in the second set, that is LR_2. Repeat Step 6. Record all results.

Step 10: Repeat Step 4. The temperature differential will be changed to the following one in Table 1. In this case, it remains unchanged at T_3

Step 11: Repeat Steps 5 through 9, using each of the two nominal leak rates of the third set, in the order given in Table 1.

Steps 4 through 9, which correspond to two empty/fill cycles and two sets of two tests, will be repeated until all 24 tests are performed.

6.4 TESTING PROBLEMS AND SOLUTIONS

Inevitably, some test runs will be inconclusive due to broken equipment, spilling of product used to measure the induced leak rate, or other events that have interrupted the testing procedure. It is assumed that, in practice, the field personnel would be able to judge whether a test result is valid. Should a run be judged invalid during testing, then the following rules should apply.

Rule No. 1   The total number of tests must be at least 24. That is, if a test is invalid, it needs to be rerun. Report the test results as invalid together with the reason and repeat the test.

Rule No. 2   If equipment fails during the <u>first</u> run (first test of a set of two) and if the time needed for fixing the problem(s) is short (less than 20% of the stabilization time or less than 1 hour, whichever is greater), then repeat that run. Otherwise, repeat the empty/fill cycle, the stabilization period, etc. Record all time periods.

Note: The average stabilization time will be reported on the Results of U.S. EPA Standard Evaluation form in Appendix B. If the delay would increase this time noticeably, then the test sequence should be redone.

Rule No. 3   If equipment fails during the <u>second</u> run (after the first run in a set has been completed successfully), and if the time needed for fixing the problem(s) is less than 4 hours, then repeat the second run. Otherwise, repeat the whole sequence of empty/fill cycle, stabilization, and test at the given conditions.

SECTION 7

CALCULATIONS

From the results obtained after all testing is completed, a series of calculations will be performed to evaluate the method's performance.

The evaluation of the method as a whole is presented first. These calculations compare the method's measured leak rate with the induced leak rate under a variety of experimental conditions. The probability of false alarm and the probability of detection are estimated using the difference between these two numbers. If the overall performance of the tank tightness testing method is satisfactory, analysis and reporting of results could end at this point. However, the experimental design has been constructed so that the effects of stabilization time and temperature can be tested to provide additional information to the vendor. This is described in Section 7.5.

After all tests are performed according to the schedule outlined in Section 6, a total of at least n = 24 pairs (4 leak rates x 3 temperature differentials x 2 testing orders within a set) of measured leak rates and induced leak rates will be available. These data form the basis for the performance evaluation of the test method. The measured leak rates are denoted by $L_1, \ldots, L_{24}$ and the associated induced leak rates by $S_1, \ldots, S_{24}$. The leak rates are numbered in chronological order. Table 3 summarizes the notation used throughout this protocol.

7.1 BASIC STATISTICS

The n = 24 pairs of data are used to calculate the mean squared error, MSE, the bias, B, and the variance of the method as follows.

Mean Squared Error, MSE

$$MSE = \sum_{i=1}^{24} (L_i - S_i)^2 / 24$$

where L_i is the measured leak rate obtained from the ith test at the corresponding induced leak rate, S_i, with i=1, ..., 24.

Table 3. NOTATION SUMMARY

Test No.	Set No.	Nominal temperature differential (degree F)	Nominal leak rate (gallon per hour)	Induced leak rate (gallon per hour)	Measured leak rate (gallon per hour)	Absolute leak rate difference $\lvert L - S \rvert$ (gallon per hour)
1	1	T_2	LR_2	S_1	L_1	d_1
2	1	T_2	LR_1	S_2	L_2	d_2
3	2	T_3	LR_3	S_3	L_3	d_3
4	2	T_3	LR_2	S_4	L_4	d_4
5	3	T_3	LR_1	S_5	L_5	d_5
6	3	T_3	LR_4	S_6	L_6	d_6
7	4	T_1	LR_3	S_7	L_7	d_7
8	4	T_1	LR_1	S_8	L_8	d_8
9	5	T_1	LR_2	S_9	L_9	d_9
10	5	T_1	LR_4	S_{10}	L_{10}	d_{10}
11	6	T_3	LR_4	S_{11}	L_{11}	d_{11}
12	6	T_3	LR_1	S_{12}	L_{12}	d_{12}
13	7	T_2	LR_1	S_{13}	L_{13}	d_{13}
14	7	T_2	LR_4	S_{14}	L_{14}	d_{14}
15	8	T_1	LR_1	S_{15}	L_{15}	d_{15}
16	8	T_1	LR_2	S_{16}	L_{16}	d_{16}
17	9	T_2	LR_3	S_{17}	L_{17}	d_{17}
18	9	T_2	LR_2	S_{18}	L_{18}	d_{18}
19	10	T_2	LR_4	S_{19}	L_{19}	d_{19}
20	10	T_2	LR_3	S_{20}	L_{20}	d_{20}
21	11	T_3	LR_2	S_{21}	L_{21}	d_{21}
22	11	T_3	LR_3	S_{22}	L_{22}	d_{22}
23	12	T_1	LR_4	S_{23}	L_{23}	d_{23}
24	12	T_1	LR_3	S_{24}	L_{24}	d_{24}

Bias

$$B = \sum_{i=1}^{24} (L_i - S_i)/24$$

The bias, B, is the average difference between measured and induced leak rates over the number of tests. It is a measure of the accuracy of the test method and can be either positive or negative.

Variance and Standard Deviation

The variance is obtained as follows:

$$\text{Variance} = \sum_{i=1}^{24} [(L_i - S_i) - B]^2/23$$

Denote by SD the square root of the variance. This is the standard deviation.

NOTE: It is recommended that the differences between the measured and induced leak rates be plotted against the time or the order in which they were performed. This would allow one to detect any patterns that might exist indicating possibly larger differences in the first test of each set or among the three temperature differentials. This could suggest that the method calls for an inadequate stabilization time after filling or that the method does not properly compensate for temperature differences between in-tank product and product to be added. (See Sections 7.5.3 and 7.5.4 for appropriate statistical tests.)

Test for Zero Bias

To test whether the method is accurate--that is, the bias is zero-- the following test on the bias calculated above is performed.

Compute the t-statistic

$$t_B = \sqrt{24} \ B/SD$$

From the t-table in Appendix A, obtain the critical value corresponding to a t with $(24-1) = 23$ degrees of freedom and a two-sided 5% significance level. This value is 2.07. Note: If more tests are done, replace 24 with the number of tests, n, throughout. A larger number of tests will change the t-value.

Compare the absolute value of t_B, abs(t_B), to 2.07 (or to the appropriate t-value if more than 24 tests were done). If abs(t_B) is less than 2.07, conclude that the bias is not statistically different from zero, that is, the bias is negligible. Otherwise, conclude that the bias is statistically significant.

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The effect of a statistically significant bias on the calculations of the probability of false alarm and the probability of detection is clearly visible when comparing Figures A-1 and A-2 in Appendix A.

7.2 FALSE ALARM RATE, P(FA)

The normal probability model is assumed for the errors in the measured leak rates. Using this model, together with the statistics estimated above, allows for the calculation of the predicted false alarm rate and the probability of detection of a leak of 0.10 gallon per hour.

The vendor will supply the criterion for interpreting the results of his test method. Typically, the leak rate measured by the method is compared to a threshold and the results interpreted as indicating a leak if the measured leak rate exceeds the threshold. Denote the method's criterion or threshold by C. The false alarm rate or probability of false alarm, P(FA), is the probability that the measured leak rate exceeds the threshold C when the tank is tight. Note that by convention, all leak rates representing volume losses from the tank are treated as positive.

P(FA) is calculated by one of two methods, depending on whether the bias is statistically significantly different from zero.

7.2.1 False Alarm Rate With Negligible Bias

In the case of a nonsignificant bias (Section 7.1), compute the t-statistic

$$t_1 = C/SD$$

where SD is the standard deviation calculated above and C is the method's threshold. Using the notational convention for leak rates, C is positive. P(FA) is then obtained from the t-table, using 23 degrees of freedom. P(FA) is the area under the curve to the _right_ of the calculated value t_1.

In general, t-tables are constructed to give a percentile, t_a, corresponding to a given number of degrees of freedom, df, and a preassigned area, a or alpha, under the curve, to the right of t_a (see Figure 1 below and Table A-1 in Appendix A). For example, with 23 degrees of freedom and a = 0.05 (equivalent to a P(FA) of 5%), t_a = 1.714.
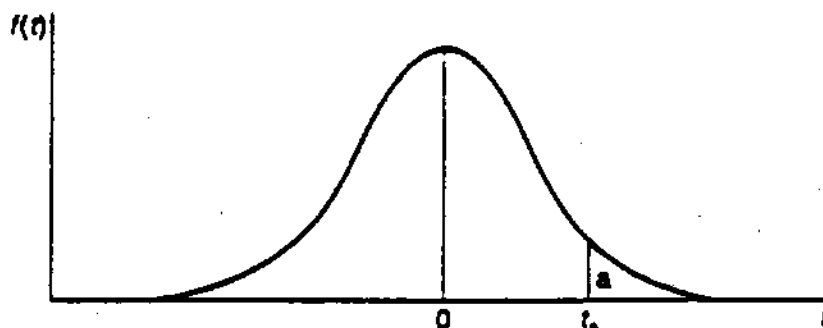
Figure 1. Student's t-Distribution Function.

In our case, however, we need to determine the area under the curve to the right of the calculated percentile, t_1, with a given number of degrees of freedom. This can be done by interpolating between the two areas corresponding to the two percentiles in Table A-1 on either side of the calculated statistic, t_1. The approach is illustrated next.

Suppose that the calculated $t_1 = 1.85$ and has 23 degrees of freedom. From Table A-1, Appendix A, obtain the following percentiles at df = 23:

t_a	a (alpha)
1.714	0.05
1.85	X to be determined
2.069	0.025

Calculate X by linearly interpolating between 1.714 and 2.069 corresponding to 0.05 and 0.025, respectively.

$$X = 0.05 - \frac{(0.05 - 0.025)}{(1.714 - 2.069)} \times (1.714 - 1.85) = 0.040$$

Thus the probability of false alarm corresponding to a t_1 of 1.85 would be 4%.

A more accurate approach would be to use a statistical software package (e.g., SAS or SYSTAT) to calculate the probability. Another method would be to use a nomograph of Student's t such as the one given by Lloyd S. Nelson in *Technical Aids*, 1986, American Society for Quality Control.

7.2.2 False Alarm Rate With Significant Bias

The computations are similar to those in the case of a nonsignificant bias with the exception that the bias is included in the calculations, as shown next. Compute the t-statistic

$$t_2 = (C-B)/SD$$

P(FA) is then obtained by interpolating from the t-table, using 23 degrees of freedom. P(FA) is the area under the curve to the <u>right</u> of the calculated value t_2. (Recall that C is positive, but the bias could be either positive or negative.)

7.3 PROBABILITY OF DETECTING A LEAK RATE OF 0.10 GALLON PER HOUR, P(D)

The probability of detecting a leak rate of 0.10 gallon per hour, P(D), is the probability that the measured leak rate exceeds C when the true mean leak rate is 0.10 gallon per hour. As for P(FA), one of two methods is used in the computation of P(D), depending on whether the bias is statistically significantly different from zero.

7.3.1 P(D) With Negligible Bias

In the case of a nonsignificant bias--that is, the bias is zero--compute the t-statistic

$$t_3 = (C-0.10)/SD$$

Next, using the t-table at 23 degrees of freedom, determine the area under the curve to the <u>right</u> of t_3. The resulting number will be P(D).

7.3.2 P(D) With Significant Bias

The procedure is similar to the one just described, except that B is introduced in the calculations as shown below. Compute the t-statistic

$$t_4 = (C-B-0.10)/SD$$

Next, using the t-table at 23 degrees of freedom, determine the area under the curve to the <u>right</u> of t_4. The resulting number will be P(D).

7.4 OTHER REPORTED CALCULATIONS

This section describes other calculations needed to complete the Results of U.S. EPA Standard Evaluation form (Appendix B). Most of these calculations are straightforward and are described here to provide complete instructions for the use of the results form.

Size of Tank

The evaluation results are applicable to tanks up to 50% larger capacity than the test tank and to all smaller tanks. Multiply the volume of the test tank by 1.50. Round this number to the nearest 100 gallons and report the result on page 1 of the results form.

Maximum Allowable Temperature Difference

Calculate the standard deviation of the 12 temperature differences actually achieved during testing. Multiply this number by the factor ± 1.5 and report the result as the temperature range on the limitations section of the results form.

The nominal temperature difference of 5°F used in the design was obtained from data collected on the national survey (Flora, J. D., Jr., and J. E. Pelkey, "Typical Tank Testing Conditions," EPA Contract No. 68-01-7383, Work Assignment 22, Task 13, Final Report, December 1988). This difference was approximately the standard deviation of the temperature differences observed in the tank tests conducted during the national survey. The factor 1.5 is a combination of two effects. One effect results from scaling up the standard deviation of the design temperature differences to 5°F. The second effect results from using the rule that about 80% of the temperature differences on tank tests are expected to be within ± 1.282 times the standard deviation.

Average Waiting Time After Filling

Calculate the average of the time intervals between the end of the filling cycle and start of the test for the 12 tests that started immediately after the specified waiting time. (Note: if more than 12 tests are done immediately after the filling, use all such tests. However, do not use the time to the start of the second test in a pair as this would give a misleading waiting time.) Report this average time as the waiting time after adding product on the results form. Note: The median may be used as the average instead of the mean if there are atypical waiting times.

Average Waiting After "Topping Off"

If the method fills the tank up into the fill pipe, calculate the average time interval between the time when the final topping off was completed and the start of the test. Calculate this average using data from all tests when this step was performed. Report the result on the results form as the waiting time after "topping off" to the final testing level. If this step is not performed (e.g., for a test with the tank at 95% of capacity), enter NA (not applicable) in the appropriate space on the results form. Note: The median may be used instead of the mean if there are some atypical waiting times.

Average Data Collection Time Per Test

Use the duration of the data collection phase of the tests to calculate the average data collection time for the total number (at least 24) of tests. Report this time as the average data collection time per test.

Product Level

If all tests are done at the same product level, report that level on the results form. If testing was done at different levels, report the applicable product level as the acceptable range (e.g. from 60% to 90% full) used in the testing.

Minimum Total Testing Time

Finally, calculate an average total test time from the test data. This is the time it would take from the time the test crew arrives at the site until a test is completed, the equipment dismantled and the tank returned to service. Typically, it will be the time required for stabilization after the tank is filled, plus the time from initial setup of equipment through the first test data collection, plus the time required to dismantle the equipment. Report this total time lapse on the results form as the minimum time that the tank can be expected to be out of service for a test of this type.

7.5 SUPPLEMENTAL CALCULATIONS AND DATA ANALYSES (OPTIONAL)

Other information can be obtained from the test data. This information is not required for establishing that the method meets the federal EPA performance requirements, but may be useful to the vendor of the test method. The calculations described in this section are therefore optional. They may be performed and reported to the vendor, but are not required and are not reported on the results form. These supplemental calculations include determining a minimum threshold, minimum detectable leak rate, and relating the performance to factors such as temperature differential, waiting time, and relation to leak size. Such information may be particularly useful to the vendor for future improvements of his system.

7.5.1 Minimum Threshold

The 24 test results can also be used to determine a threshold to give a specified false alarm rate of say 5%. This threshold may not be the same as the threshold, C, pertaining to the method as reported by the vendor. Denote by $C_{5\%}$ the threshold corresponding to a P(FA) of 5%. The following demonstrates the approach for computing $C_{5\%}$.

Solve the equation

$$P(FA) = P[t > (C_{5\%} - B)/SD] = 0.05$$

for $C_{5\%}$. If the bias is not statistically significant (Section 7.1), then replace B with 0. From the t-table (Appendix A) with 23 degrees of freedom obtain the 5th-percentile. This value is 1.714. Solving the equation above for $C_{5\%}$ yields

$$(C_{5\%} - B)/SD = 1.714$$

In the case a nonsignificant bias, this would be $C_{5\%} = 1.714 \; SD$.

7.5.2 Minimum Detectable Leak Rate

With the data available from the evaluation, the minimum detectable leak rate, $R_{5\%}$, corresponding to a probability of detection, P(D), of 95% and the calculated threshold, $C_{5\%}$, can be calculated by solving the following equation for $R_{5\%}$:

$$P(D(R_{5\%})) = P[t > (C_{5\%} - R_{5\%} - B)/SD] = 0.95$$

where $C_{5\%}$ is the threshold corresponding to a P(FA) of 5%, as calculated in 7.5.1.

At the P(FA) of 5%, solving the equation above is equivalent to solving

$$(C_{5\%} - R_{5\%} - B)/SD = -1.714$$

$$\text{or}$$

$$R_{5\%} = 1.714 \; SD + C_{5\%} - B$$

which, after substituting 1.714 SD for $(C_{5\%} - B)$, is equivalent to

$$R_{5\%} = 2C_{5\%} - 2B$$

Substitute 0 for B in all calculations when the bias is not statistically significant. Otherwise, use the value of B estimated from the data.

Thus, the minimum detectable leak rate with a probability of detection of 95% is twice the threshold, $C_{5\%}$, determined to give a false alarm of 5%, minus twice the bias if the bias is statistically significant.

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In summary, based on the 24 pairs of measured and induced leak rates, the minimum threshold, $C_{5\%}$, and the minimum detectable leak rate, $R_{5\%}$, are calculated as shown below.

If the bias is not statistically significant:

For a P(FA) of 5% $C_{5\%} = 1.714 \text{ SD}$
For a P(D(R)) of 95% $R_{5\%} = 2C_{5\%}$

If the bias is statistically significant:

For a P(FA) of 5% $C_{5\%} = 1.714 \text{ SD} + \text{Bias}$
For a P(D(R)) of 95% $R_{5\%} = 2C_{5\%} - 2 \text{ Bias}$

Remark: Other significance levels can also be used by substituting the appropriate values from the statistical table.

7.5.3 Test for Adequacy of Stabilization Period

· The performance estimates obtained in Sections 7.2 and 7.3 will indicate whether the method meets the EPA performance standards. The calculations in this section allow one to determine whether the method's performance is affected by the additional stabilization time the tank has experienced by the start of the second test after each empty and fill cycle. These tests are designed primarily to help determine why a method did not meet the performance standard.

The experimental design tests the method under a variety of conditions chosen to be reasonably representative of actual test conditions. The tests occur in pairs within an empty-fill cycle. A comparison of the results from the first test of the pair with the second of that pair allows one to determine if the additional stabilization time improved the performance. Similarly, comparisons among the tests at each temperature condition allows one to determine whether the temperature conditions affected the performance. Finally, the performance under the four induced leak conditions can be compared to determine whether the method performance varies with leak rate.

The factors can be investigated simultaneously through a statistical technique called analysis of variance. The detailed computational formulas for a generalized analysis of variance are beyond the scope of this protocol. For users unfamiliar with analysis of variance, equations to test for the effect of stabilization period and temperature individually are presented in detail, although the evaluating organization should feel free to use the analysis of variance approach to the calculations if they have the computer programs and knowledge available.

The procedure outlined in Section 6 allows the amount of time specified by the manufacturer for the tank to stabilize after fuel is pumped into the tank prior to the first test in each set. Additional stabilization takes place between the first and second tests of each

set. The actual length of the stabilization period following refueling as well as the time between tests are recorded for each tank test. The following statistical test is a means to detect whether the additional stabilization period for the second test improves performance. If the stabilization period prior to the first test is too short, then one would expect larger discrepancies between measured and induced leak rates for the first tests in a set as compared to those for the second tests.

Step 1: Calculate the absolute value of the 24 differences, d_i, $i=1, \ldots, 24$, between the measured (L) and induced (S) leak rates for all tests (last column in Table 3).

Step 2: Calculate the average of the absolute differences for the first and second test in each set separately.

$$D_1 = (d_1 + d_3 + \cdots + d_{21} + d_{23})/12 \qquad \text{(all odd subscripts)}$$

$$D_2 = (d_2 + d_4 + \cdots + d_{22} + d_{24})/12 \qquad \text{(all even subscripts)}$$

Step 3: Calculate the variances of the absolute differences from the first and second tests in each set separately.

$$S_1^2 = \left[(d_1 - D_1)^2 + (d_3 - D_1)^2 + \cdots + (d_{23} - D_1)^2 \right]/11$$

$$S_2^2 = \left[(d_2 - D_2)^2 + (d_4 - D_2)^2 + \cdots + (d_{24} - D_2)^2 \right]/11$$

Step 4: Calculate the pooled standard deviation.

$$S_p = \sqrt{\frac{11S_1^2 + 11S_2^2}{24 - 2}} = \sqrt{\frac{S_1^2 + S_2^2}{2}}$$

Step 5: Calculate the t-statistic:

$$t = \frac{(D_1 - D_2)}{S_p \sqrt{\frac{2}{12}}} = \frac{\sqrt{6}\,(D_1 - D_2)}{S_p}$$

Step 6: From the t-table in Appendix A, obtain the critical value corresponding to a t with (12+12-2) = 22 degrees of freedom and a two-sided 5% significance level (a = 0.025 in the table). This value is 2.074.

Step 7: Compare the absolute value of t, abs(t), to 2.074. If abs(t) is less than 2.074, conclude that the average difference between measured and induced leak rates obtained from the first

tests after stabilization is not significantly different (at the 5% significance level) from the average difference between measured and induced leak rates obtained from the second tests after stabilization. In other words, there has not been a significant additional stabilization effect between the beginning and the end of a test. Otherwise, conclude that the difference is statistically significant, that is, the method's performance is different with a longer stabilization period.

If the results are statistically significant, then the performance of the method is different for the tests with the additional stabilization period. If the performance is better, that is, if the absolute differences for the testing with additional stabilization are smaller than those for the tests with the minimum stabilization period, then the method would show improved performance if it increased its required stabilization period. If the method's overall performance did not meet the EPA performance standard, performance estimates with the additional stabilization can be calculated using only the 12 test results with the additional stabilization. If the estimates obtained by applying the calculations in Sections 7.2 and 7.3 to the 12 tests with the longer stabilization indicate that the method does not meet the EPA performance standard but could meet the EPA performance standard with the additional stabilization, that finding should be reported. Note that the evaluation procedure would still need to conduct a full 24-test series at the longer stabilization time before claiming to meet the performance standard.

7.5.4 Test for Adequate Temperature Compensation

This section allows one to test whether the method's performance is different for various temperature conditions. A total of eight tests will have been performed with each of the three temperature differentials, T_1, T_2, and T_3 (the nominal values of $0°$, $-5°$, and $+5°F$ will have been randomly assigned to T_1, T_2, and T_3). The 24 tests have been ordered by temperature differential and test number in Table 4 for the example order of sets from Table 1. In general, group the tests by temperature condition.

The test results from the three temperature conditions are compared to check the method's performance in compensating for temperature differentials. If the temperature compensation of the method is adequate, the three groups should give comparable results. If temperature compensation is not adequate, results from the conditions with a temperature differential will be less reliable than results with no temperature difference.

The following statistical procedure (Bonferroni t-tests) provides a means for testing for temperature effect on the test results. With three temperature differentials considered in the test schedule, three comparisons will need to be made: T_1 vs. T_2, T_1 vs. T_3, and T_2 vs. T_3.

Table 4. ORGANIZATION OF DATA TO TEST FOR TEMPERATURE EFFECT

Test No.	Set No.	Nominal temperature differential (degree F)	Absolute leak rate difference $\|L - S\|$ (gallon per hour)	
7	4	T_1	d_7	
8	4	T_1	d_8	
9	5	T_1	d_9	
10	5	T_1	d_{10}	Group 1
15	8	T_1	d_{15}	
16	8	T_1	d_{16}	
23	12	T_1	d_{23}	
24	12	T_1	d_{24}	
1	1	T_2	d_1	
2	1	T_2	d_2	
13	7	T_2	d_{13}	
14	7	T_2	d_{14}	Group 2
17	9	T_2	d_{17}	
18	9	T_2	d_{18}	
19	10	T_2	d_{19}	
20	10	T_2	d_{20}	
3	2	T_3	d_3	
4	2	T_3	d_4	
5	3	T_3	d_5	
6	3	T_3	d_6	Group 3
11	6	T_3	d_{11}	
12	6	T_3	d_{12}	
21	11	T_3	d_{21}	
22	11	T_3	d_{22}	

Step 1. Calculate the average of the absolute differences in each group.

$$M_1 = \sum_{g_1} d_i/8 \quad \text{where } g_1 \text{ denotes the 8 subscripts in Group 1}$$

$$M_2 = \sum_{g_2} d_i/8 \quad \text{where } g_2 \text{ denotes the 8 subscripts in Group 2}$$

$$M_3 = \sum_{g_3} d_i/8 \quad \text{where } g_3 \text{ denotes the 8 subscripts in Group 3}$$

Step 2. Calculate the variance of the absolute differences in each group.

$$Var_1 = \sum_{g_1} (d_i - M_1)^2/7$$

$$Var_2 = \sum_{g_2} (d_i - M_2)^2/7$$

$$Var_3 = \sum_{g_3} (d_i - M_3)^2/7$$

Step 3. Calculate the pooled variance of Var_1, Var_2, and Var_3.

$$Var_p = \frac{7Var_1 + 7Var_2 + 7Var_3}{24 - 3}$$

or

$$Var_p = (Var_1 + Var_2 + Var_3)/3$$

Step 4. Compute the standard error, SE, of the difference between each pair of the means, M_1, M_2, and M_3.

$$SE = \left[Var_p \left(\frac{1}{8} + \frac{1}{8} \right) \right]^{1/2}$$

or

$$SE = \frac{1}{2} \sqrt{Var_p}$$

Step 5. Obtain the 95th percentile of the Bonferroni t-statistic with (24-3) = 21 degrees of freedom and three comparisons. This statistic is t = 2.60. (Reference: Ruppert G. Miller, Jr., 1981. *Simultaneous Statistical Inference*, Second Edition. Springer-Verlag, New York, New York.)

Step 6. Compute the critical difference, D, against which each pairwise difference between group means will be compared.

$$D = SE \times t = SE \times 2.60$$

Step 7. Compare the absolute difference of the three pairwise differences with D.

Compare $|M_1 - M_2|$ with $SE \times 2.60$

Compare $|M_1 - M_3|$ with $SE \times 2.60$

Compare $|M_2 - M_3|$ with $SE \times 2.60$

If any difference in group means, in absolute value, exceeds the critical value of $SE \times 2.60$, then conclude that the method's performance is influenced by the temperature conditions.

If the results are significant, the method's performance is affected by the temperature conditions. If the overall performance evaluation met the EPA standards, the effect of a 5°F temperature difference on the method does not degrade performance severely. However, this does not eliminate the possibility that larger differences could give misleading results. If the overall performance did not meet the EPA performance standards, and the temperature effect was significant, then the method needs to improve its temperature compensation and/or stabilization time in order to meet EPA performance standards. Again, an evaluation testing the modified method would need to be conducted to document the performance before the method could claim to meet the performance standards.

SECTION 8

INTERPRETATION

The results reported are valid for the experimental conditions during the evaluation, which have been chosen to represent the most common situations encountered in the field. These should be typical of most tank testing conditions, but extreme conditions can occur and might adversely affect the performance of the method. The performance should be at least as good for tanks smaller than the test tank. However, the performance evaluation results should only be scaled up to a tank of 50% greater capacity than the test tank. It should be emphasized that the performance estimates are based on average results. An individual test may not do as well. Some individual tests may do better. Vendors are encouraged to provide a measure of the precision of each test, such as a standard error for their calculated leak rate at that site, along with the leak rate and test results.

The relevant performance measures for proving that a tightness test method meets EPA standards are the P(FA) and P(D) for a leak rate of 0.10 gallon per hour. The estimated P(FA) can be compared with the EPA standard of P(FA) not to exceed 5%. In general, a lower P(FA) is preferable, since it implies that the chance of mistakenly indicating a leak on a tight tank is less. However, reducing the false alarm rate may also reduce the chance of detecting a leak. The probability of detection generally increases with the size of the leak. The EPA standard specifies that P(D) be at least 95% for a leak of 0.10 gallon per hour. A higher estimated P(D) means that there is less chance of missing a small leak.

If the estimated performance of the method did not meet the EPA performance requirements, the vendor may want to investigate the conditions that affected the performance as described in Section 7.5, Supplemental Calculations and Data Analyses. If the stabilization time or temperature can be shown to affect the performance of the method, this may suggest ways to improve the method. It may be possible to improve the performance simply by changing the procedure (e.g., waiting longer for the tank to stabilize) or it may be necessary to redesign the hardware. In either case, a new evaluation with the modified system is necessary to document that the method does meet the performance standards.

The relationship of performance to test conditions is primarily of interest when the method did not meet the EPA performance standards. Developing these relationships is part of the optional or supplementary data analysis that may be useful to the vendor, but is not of primary interest to many tank owners or operators.

SECTION 9

REPORTING OF RESULTS

Appendix B is designed to be the framework for a standard report. There are four parts to Appendix B, each of which is preceded by instructions for completion. The first part is the Results of U.S. EPA Standard 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. Consequently, it is quite succinct. 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 Tank Tightness Testing Method. A description form is included in Appendix B 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 B. This table summarizes the test results and contains the information on starting dates and times, test duration, leak rate results, etc.

The fourth part of 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.

If the optional calculations described in Section 7.5 are performed, they should be reported to the vendor. It is suggested that these results be reported in a separate section of the report, distinct from the standard report. This would allow a user to identify the parts of the standard report quickly while still having the supplemental information available if needed.

The limitations on the results of the evaluation are to be reported on the Results of U.S. EPA Standard Evaluation form. The intent is to document that the results are valid under conditions represented by the test conditions. Section 7.4 describes the summary of the test conditions that should be reported as limitations on the results form. These items are also discussed below. The test conditions have been chosen to represent the majority of testing situations, but do not include the most extreme conditions under which testing could be done. The test conditions were also selected to be practical and not impose an undue burden for evaluation on the test companies.

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One practical limitation of the results is the size of the tank. Volumetric tests generally perform less well as the size of the tank increases. Consequently, the results of the evaluation may be applied to tanks smaller than the test tank. The results may also be extended to tanks of 50% larger capacity than the test tank. Thus, if testing is done in a 10,000-gallon tank, the results may be extended to tanks up to 15,000 gallons in size. If a company wants to document that it can test large tanks, the evaluation needs to be done in a large tank.

A second limitation on the results is the temperature differential between the product added to the tank and that of the product already in the tank. Often, product must be added to bring the product level to the test level required by the method. The reported results apply provided the temperature differential is no more than that used in the evaluation. Testing during the EPA national survey (Flora, J. D., Jr., and J. E. Pelkey, "Typical Tank Testing Conditions," EPA Contract No. 68-01-7383, Work Assignment 22, Task 13, Final Report, December 1988) found that temperature differentials were no more than 5°F for at least 60% of the tests. However, it is clear that larger differences could exist. The evaluation testing may be done using larger temperature differentials, reporting those actually used. The results cannot be guaranteed for temperature differentials larger than those used in the evaluation.

A third limitation on the results is the stabilization time needed by the method. The Individual Test Logs call for recording the actual stabilization time used during the testing. The mean of these stabilization times is reported. The results are valid for stabilization times at least as long as those used in the evaluation. This is viewed as an important limitation, since shorter stabilization times can adversely affect the performance. Also, there may be a market pressure to shorten the times in the field. In practice, many methods may require the tank to be filled the day before the test starts, allowing an overnight stabilization time, resulting in somewhat longer times in the field than used in the evaluation. Similarly, the time after "topping off" the tank for a test that overfills the tank can be important. If applicable, this is also reported as a limitation.

The duration of the data collecting phase of the test is another limitation of the method. If a test shortens the data collection time and so collects less data, this may adversely affect its performance. As a consequence, the results do not apply if the data collection time is shortened. This is primarily of concern in documenting that a tank is tight. If results clearly indicate a leak, this may sometimes be ascertained in less time than needed to document a tight tank, particularly if the leak rate is large. Thus, while the false alarm rate may be larger if the test time is shortened, this is not usually a problem in that if test results indicate a leak, efforts are usually made to identify and correct the source of the leak.

The presence of a high ground-water level can interfere with many tank tests. The organization performing the evaluation must consider the

method's approach to testing for and dealing with a high ground-water level. On the basis of the method's approach to adjusting for high ground-water levels, the determination of whether the method can successfully test in high ground-water level situations is made and reported by checking the appropriate box at the end of the "Limitations on the Results" section of the Results of U.S. EPA Standard Evaluation form. If the method cannot be used in a high ground-water level situation, then the method must determine the ground-water level and state that it is not to be used when the ground-water level is above a specified level on the tank.

The product level in the tank during the test is reported to let the user know at what levels this method can be used to give a valid test. Finally, the average time for the total testing process is reported as a guide for users as what to realistically expect when their tank is tested with the method.

APPENDIX A

DEFINITIONS AND NOTATIONAL CONVENTIONS

In this protocol leaks are viewed as product lost from the tank. As a convention, leak rates are positive numbers, representing the amount of product loss per unit time. Thus a larger leak represents a greater product loss. Parts of the leak detection industry report volume changes per unit time with the sign indicating whether product is lost from the tank (negative sign) or is coming into the tank (positive sign). We emphasize that here, leaks refer to the direction out of the tank and the rate to the magnitude of the flow.

The performance of a leak detection method is expressed in terms of the false alarm rate, P(FA), and the probability of detecting a leak of specified size, P(D(R)), where R is the leak rate. In order to understand these concepts, some explanation is helpful. Generally, the volumetric leak detection method, either a precision tank test or the leak test function of an automatic tank gauging system (ATGS), estimates a leak rate. This calculated rate is compared to a criterion or threshold, C, determined by the manufacturer. If the calculated rate is in excess of the criterion, the tank is declared to be leaking, otherwise, the tank is called tight.

Figure A-1 represents the process of determining whether a tank is leaking or not. The curve on the left represents the inherent variability of the measured leak rate on a tight tank (with zero leak rate). If the measured leak rate exceeds C, the tank is declared to leak, a false alarm. The chance that this happens is represented by the shaded area under the curve to the right of C, denoted α (alpha).

The variability of the measured leak rates for a tank that is actually leaking at the rate R is represented by the curve on the right in Figure A-1. Again, a leak is declared if the measured rate exceeds the threshold, C. The probability that the leaking tank is correctly identified as leaking is the area under the right hand curve to the right of C. The probability of mistakenly declaring the leaking tank tight is denoted by β (beta), the area of the left of C under the leaking tank curve.

Changing the criterion, C, changes both α and β for a fixed leak rate, R. If the leak rate R is increased, the curve on the right will shift further to the right, decreasing β and increasing the probability of detection for a fixed criterion, C. If the precision of a method is increased, the curve becomes taller and narrower, decreasing both α and β, resulting in improved performance.

A bias is a consistent error in one direction. This is illustrated by Figure A-2. In it, both curves have been shifted to the right by an amount of bias, B. In this illustration, the bias indicates a greater leak rate than is actually present (the bias is positive in this case). This has the effect of increasing the probability of a false alarm, while reducing the probability of failing to detect a leak. That is, the probability of detecting a leak of size R is increased, but so is the

chance of a false alarm. A bias toward underestimating the leak rate would have the opposite effect. That is, it would decrease both the false alarm rate and the probability of detecting a leak.

Definitions of some of the terms used throughout the protocol are presented next.

Nominal Leak Rate:	The set or target leak rate to be achieved as closely as possible during testing. It is a positive number in gallon per hour.
Induced Leak Rate:	The actual leak rate, in gallon per hour, used during testing, against which the results from a given test device will be compared.
Measured Leak Rate:	A positive number, in gallon per hour, measured by the test device and indicating the amount of product leaking out of the tank. A negative leak rate would indicate that water is leaking into the tank.
Critical Level, C:	The leak rate above which a method declares a leak. It is also called the threshold of the method.
False Alarm:	Declaring that a tank is leaking when in fact it is tight.
Probability of False Alarm, P(FA):	The probability of declaring a tank leaking when it is tight. In statistical terms, this is also called the Type I error, and is denoted by alpha (α). It is usually expressed in percent, say, 5%.
Probability of Detection, P(D(R)):	The probability of detecting a leak rate of a given size, R, gallon per hour. In statistical term, it is the power of the test method and is calculated as one minus beta (β), where beta is the probability of not detecting (missing) a leak rate R. Commonly, the power of a test is expressed in percent, say, 95%.
Method Bias, B:	The average difference between measured and induced (actual) leak rates, in gallon per hour. It is an indication of whether the test device consistently overestimates (positive bias) or underestimates (negative bias) the actual leak rate.

Mean Squared Error, MSE	An estimate of the overall performance of a test method.
Root Mean Squared Error, RMSE:	The positive square root of the mean squared error.
Precision:	A measure of the test method's ability in producing similar results (i.e., in close agreement) under identical test conditions. Statistically, the precision of repeated measurements is expressed as the standard deviation of these measurements.
Variance:	A measure of the variability of measurements. It is the square of the standard deviation.
Accuracy:	The degree to which the measured leak rate agrees with the induced leak rate on the average. If a method is accurate, it has a very small or zero bias.
Resolution:	The resolution of a measurement system is the least change in the quantity being measured which the system is capable of detecting.

Figure A-1. Distribution of measurement error on a tight
and leaking tank.

C = Criterion or Threshold for declaring a leak
(a leak is declared if the measured rate exceeds C)

α = Probability of False Alarm, P(FA)

β = Probability of not detecting a leak rate R

$1 - \beta$ = Probability of detecting a leak rate R, P(D(R))

R = Leak Rate

Figure A-2. Distribution of measurement error on a tight and leaking tank in the case of a positive bias.

C = Criterion or Threshold for declaring a leak
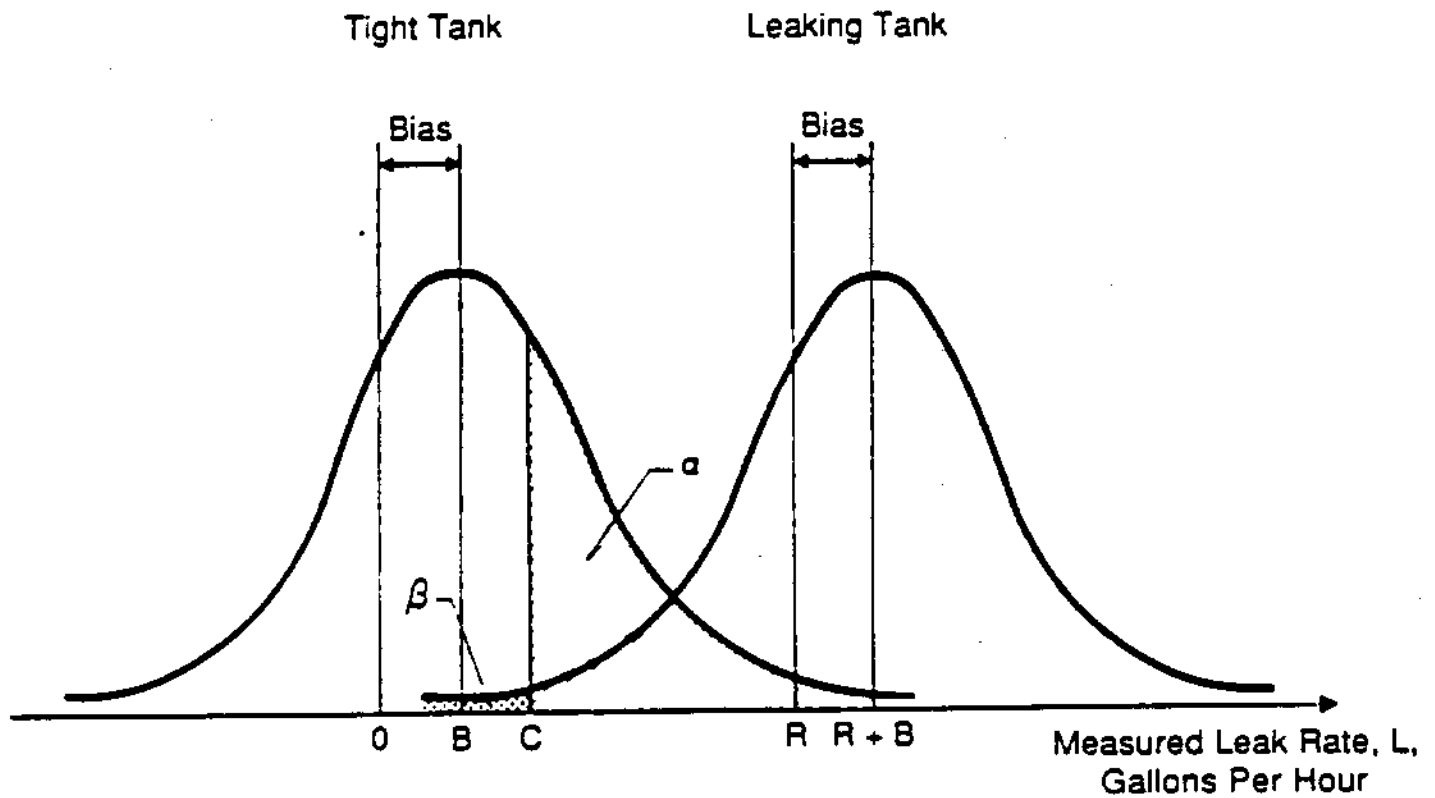(a leak is declared if the measured rate exceeds C)

α = Probability of False Alarm, P(FA)

β = Probability of not detecting a leak rate R

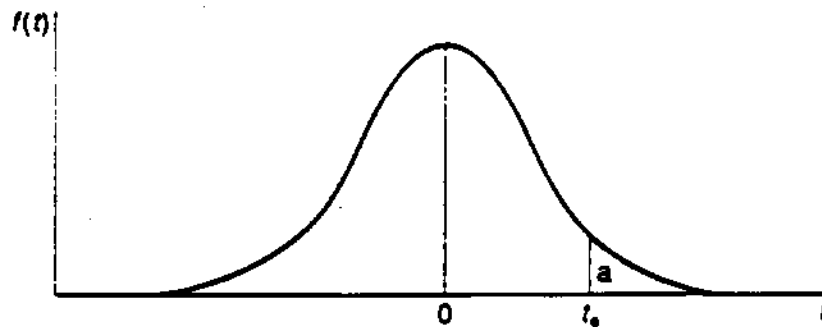1 - β = Probability of detecting a leak rate R, P(D(R))

R = Leak Rate

B = Bias

df	a = 10	a = 05	a = 025	a = 010	a = 005
1	3 078	6 314	12 706	31 821	63 657
2	1 886	2 920	4 303	6 965	9 925
3	1 638	2 353	3 182	4 541	5 841
4	1 333	2 132	2 776	3 747	4 604
5	1 476	2 015	2 571	3 365	4 032
6	1 440	1 943	2 447	3 143	3 707
7	1 415	1 895	2 365	2 998	3 499
8	1 397	1 860	2 306	2 896	3 355
9	1 383	1 833	2 262	2 821	3.250
10	1 372	1 812	2 228	2.764	3 169
11	1 363	1 796	2.201	2 718	3 106
12	1 356	1 782	2 179	2 681	3 055
13	1 350	1 771	2 160	2 650	3.012
14	1 345	1 761	2 145	2 624	2 977
15	1 341	1 753	2 131	2 602	2 947
16	1 337	1 746	2 120	2 583	2.921
17	1 333	1 740	2 110	2 567	2 898
18	1 330	1 734	2 101	2 552	2 878
19	1 328	1 729	2 093	2 539	2 861
20	1 325	1 725	2 086	2 528	2 845
21	1 323	1 721	2.080	2 518	2.831
22	1 321	1 717	2.074	2 508	2 819
23	1 319	1.714	2 069	2 500	2 807
24	1 318	1 711	2 064	2 492	2 797
25	1 316	1 708	2 060	2 485	2.787
26	1 315	1 706	2 056	2 479	2 779
27	1 314	1 703	2 052	2 473	2 771
28	1 313	1 701	2.048	2 467	2 763
29	1 311	1 699	2.045	2 462	2.756
30	1.310	1.697	2 042	2.457	2 750
40	1.303	1 684	2 021	2 423	2 704
60	1 296	1 671	2.000	2 390	2.660
120	1 289	1 658	1 980	2 358	2.617
inf	1.282	1 645	1 960	2.326	2.576

APPENDIX B

REPORTING FORMS

Appendix B provides four sets of blank forms. Once filled out, these forms will provide the framework for a standard report. They consist of the following:

1. Results of U.S. EPA Standard Evaluation--Volumetric Tank Tightness Testing Method (two pages)

2. Description--Volumetric Tank Tightness Testing Method (seven pages)

3. Reporting Form for Leak Rate Data--Volumetric Tank Tightness Testing Method (two pages)

4. Individual Test Log--Volumetric Tank Tightness Testing Method (five pages)

Each set of forms is preceded by instructions on how the forms are to be filled out and by whom. The following is an overview on various responsibilities.

Who is responsible for filling out which form?

1. Results of U.S. EPA Standard Evaluation. The evaluating organization is responsible for completing this form at the end of the evaluation.

2. Description of Volumetric Tank Tightness Testing Method. The evaluating organization assisted by the vendor (or his field crew) will complete this form at the end of the evaluation.

3. Reporting Form for Leak Rate Data. This form is to be completed by the evaluating organization. In general, the statistician analyzing the data will complete this form. A blank form can be developed on a personal computer, the data base for a given evaluation generated, and the two merged on the computer. The form can also be filled out manually. The input for that form will consist of the field test results recorded by the evaluating organization's field crew on the Individual Test Logs (below) and the vendor's test results.

4. Individual Test Logs. These forms are to be used and completed by the evaluating organization's field crew. These forms need to be kept blind to the vendor's field crew. It is recommended to reproduce a sufficient number (at least 24 copies) of the blank form provided in this appendix and produce a bound notebook for the complete test period.

At the completion of the evaluation, the evaluating organization will collate all the forms into a single Standard Report in the order listed above. In those cases where the evaluating organization performed additional, optional calculations (see Section 7.5 of the protocol), these results can be attached to the standard report. There is no reporting requirement for these calculations, however.

Distribution of the Evaluation Test Results

The organization performing the evaluation will prepare a report to the vendor describing the results of the evaluation. This report consists primarily of the forms in Appendix B. The first form reports the results of the evaluation. This two-page form is designed to be distributed widely. A copy of this two-page form will be supplied to each tank owner/operator who uses this method of leak detection. The owner/operator must retain a copy of this form as part of his record keeping requirements. The owner/operator must also retain copies of each tank test performed at his facility to document that the tank(s) passed the tightness test. This two-page form will also be distributed to regulators who must approve leak detection methods for use in their jurisdiction.

The complete report, consisting of all the forms in Appendix B, will be submitted by the evaluating organization to the vendor of the leak detection method. The vendor may distribute the complete report to regulators who wish to see the data collected during the evaluation. It may also be distributed to customers of the leak detection method who want to see the additional information before deciding to select a particular leak detection method.

The optional part of the calculations (Section 7.5), if done, would be reported by the evaluating organization to the vendor of the leak detection method. This is intended primarily for the vendor's use in understanding the details of the performance and perhaps suggesting how to improve the method. It is left to the vendor whether to distribute this form, and if so, to whom.

The evaluating organization of the leak detection method provides the report to the vendor. Distribution of the results to tank owner/operators and to regulators is the responsibility of the vendor.

**Results of U.S. EPA Standard Evaluation
Volumetric Tank Tightness Testing Method**

Instructions for completing the form

This 2-page form is to be filled out by the evaluating organization upon completion of the evaluation of the method. This form will contain the most important information relative to the method evaluation. All items are to be filled out and the appropriate boxes checked. If a question is not applicable to the method, write 'NA' in the appropriate space.

This form consists of five main parts. These are:

1. Method Description
2. Evaluation Results
3. Test Conditions
4. Limitations on the Results
5. Certification of Results

Method Description

Indicate the commercial name of the method, the version, and the name, address, and telephone number of the vendor. Some vendors use different versions of their method when using it with different products or tank sizes. If so, indicate the version used in the evaluation. If the vendor is not the party responsible for the development and use of the method, then indicate the home office name and address of the responsible party.

Evaluation Results

The method's threshold, C, is supplied by the vendor. This is the criterion for declaring a tank to be leaking. Typically, a method declares a tank to be leaking if the measured leak rate exceeds C.

P(FA) is the probability of false alarm calculated in Section 7.2. Report P(FA) in percent rounded to the nearest whole percent.

P(D) is the probability of detecting a leak rate of 0.10 gallon per hour and is calculated in Section 7.3. Report P(D) in percent rounded to the nearest whole percent.

If the P(FA) calculated in Section 7.2 is 5% or less and if the P(D) calculated in Section 7.3 is 95% or more, then check the 'does' box. Otherwise, check the 'does not' box.

Test Conditions During Evaluation

Insert the information in the blanks provided. The nominal volume of the tank in gallons is requested as is the tank material, steel or fiberglass. Also, give the tank diameter and length in inches. Report the product used during the testing. Give the range of temperature

differences actually measured as well as the standard deviation of the observed temperature differences. Also indicate the level in the tank at which the testing was done. Note, if more than one tank, product, or level was used in the testing, indicate this by a footnote and refer to the data summary form where these should be documented.

Limitations on the Results

The size (gallons) of the largest tank to which these results can be applied is calculated as 1.50 times the size (gallons) of the test tank.

The temperature differential, the waiting time after adding the product until testing, the waiting time after "topping off" (if applicable), the total data collection time, and the product level in tank, should be completed using the results from calculations in Section 7.4.

If the method compensates for ground-water levels above the bottom of a tank, then check the 'can' box. Otherwise, check the 'cannot' box. (See Section 1.4.)

Certification of Results

Here, the responsible person at the evaluating organization provides his/her name and signature, and the name, address, and telephone number of the organization.

Description of Volumetric Tank Tightness Testing Method

Instructions for completing the form

This 7-page form is to be filled out by the evaluating organization with assistance from the vendor, upon completion of the evaluation of the method. This form provides supporting information on the principles behind the method or on how the equipment works.

To minimize the time to complete this form, the most frequently expected answers to the questions have been provided. For those answers that are dependent on site conditions, please give answers that apply in "typical" conditions. Please write in any additional information about the testing method that you believe is important.

There are seven parts to this form. These are:

1. Method Name and Version
2. Product
   > Product type
   > Product level
3. Level Measurement
4. Temperature Measurement
5. Data Acquisition
6. Procedure Information
   > Waiting times
   > Test duration
   > Total time
   > Identifying and correcting for interfering factors
   > Interpreting test results
7. Exceptions

Indicate the commercial name and the version of the method in the first part.

NOTE: The version is provided for methods that use different versions of the equipment for different products or tank sizes.

For the six remaining parts, check all appropriate boxes for each question. Check more than one box per question if it applies. If a box 'Other' is checked, please complete the space provided to specify or briefly describe the matter. If necessary, use all the white space next to a question for a description.

Description
Volumetric Tank Tightness Testing Method

This section describes briefly the important aspects of the volumetric tank tightness testing method. It is not intended to provide a thorough description of the principles behind the method 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
- ☐ fuel oil #6
- ☐ solvent
- ☐ waste oil
- ☐ other (list) _____

> Product level

What minimum product level is required to conduct a test?

- ☐ above grade
- ☐ within the fill pipe
- ☐ greater than 90% full
- ☐ greater than 50% full
- ☐ other (specify) _____

Is a method used to add or withdraw product to maintain a constant level of product?

- ☐ yes
- ☐ no

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

Level Measurement

What technique is used to measure changes in product volume?

☐ 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.) _____

☐ other (describe briefly) _____

Temperature Measurement

If product temperature is measured during a test, how many temperature sensors are used?

☐ single sensor, without circulation

☐ single sensor, with circulation

☐ 2-4 sensors

☐ 5 or more sensors

☐ temperature-averaging probe

If product temperature is measured during a test, what type of temperature sensor is used?

☐ 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 minimum waiting period between adding a large volume of product to bring the level to test requirements and the beginning of the test (e.g., from 50% to 95% capacity)?

☐ no waiting period

☐ less than 3 hours

☐ 3-6 hours

☐ 7-12 hours

☐ more than 12 hours

☐ variable, depending on tank size, amount added, operator discretion, etc.

What is the minimum waiting period between "topping off" the tank (adding a small amount of product to fine tune the desired level for testing, e.g., from 2 inches to 5 inches above grade) and beginning the test?

☐ no waiting period

☐ less than 1 hour

☐ 1-2 hours

☐ more than 2 hours

☐ variable, depending on the amount of product added

> Test duration

What is the minimum time for collecting data?

- ☐ less than 1 hour
- ☐ 1 hour
- ☐ 2 hours
- ☐ 3 hours
- ☐ 4 hours
- ☐ 5-10 hours
- ☐ more than 10 hours
- ☐ variable

> Total time

What is the total time needed to test with this method?

(setup time plus waiting time plus testing time plus time to return tank to service)

_____ hours _____ minutes

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

> 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?

- ☐ observation well near tank
- ☐ information from USGS, etc.
- ☐ information from personnel on-site
- ☐ presence of water in the tank
- ☐ other (describe briefly) _____
- ☐ level of ground water above bottom of the tank not determined

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

☐ head pressure increased by raising the level of the product

☐ different head pressures tested and leak rates compared

☐ method tests for changes in water level in tank

☐ other (describe briefly) _____

☐ no action

How does the method identify the presence of vapor pockets?

☐ erratic temperature, level, or temperature-compensated volume readings

☐ sudden large changes in readings

☐ statistical analysis of variability of readings

☐ other (describe briefly) _____

☐ not identified

☐ not applicable; underfilled test method used

How does the method correct for the presence of vapor pockets?

☐ bleed off vapor and start test over

☐ identify periods of pocket movement and discount data from analysis

☐ other (describe briefly) _____

☐ not corrected

☐ not applicable; underfilled test method used

How does the test method determine when tank deformation has stopped following delivery of product?

☐ wait a specified period of time before beginning test

☐ watch the data trends and begin test when decrease in product level has stopped

☐ other (describe briefly) _____

☐ no procedure

Are the temperature and level sensors calibrated before each test?

☐ yes

☐ no

If not, how often are the sensors calibrated?

☐ weekly

☐ monthly

☐ yearly or less frequently

☐ never

> 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?

☐ product 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 of last _____ hours of test period

☐ from data determined valid by statistical analysis

☐ other (describe briefly) _____

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

☐ 0.05 gallon per hour

☐ 0.10 gallon per hour

☐ 0.20 gallon per hour

☐ other (list) _____

Under what conditions are test results considered inconclusive?

- ☐ ground-water level above bottom of tank
- ☐ presence of vapor pockets
- ☐ 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 bottom of tank
- ☐ presence of vapor pockets
- ☐ large difference between ground temperature and delivered product temperature
- ☐ high 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 testing personnel on-site?

- ☐ waiting period between filling tank and beginning test
- ☐ length of test
- ☐ determination of presence of vapor pockets
- ☐ determination that tank deformation has subsided
- ☐ determination of "outlier" data that may be discarded
- ☐ other (describe briefly) _____
- ☐ none

Reporting Form for Leak Rate Data
Volumetric Tank Tightness Testing Method

Instructions for completing the form

This 1- or 2-page form is to be filled out by the evaluating organization upon completion of the evaluation of the method. A single sheet provides for 24 test results, the minimum number of tests required in the protocol. Use as many pages as necessary to summarize all of the tests attempted.

Indicate the commercial name and the version of the method and the period of evaluation above the table. The version is provided for methods that use different versions of the equipment for different products or tank sizes.

In general, the statistician analyzing the data will complete this form. A blank form can be developed on a personal computer, the data base for a given evaluation generated, and the two merged on the computer. The form can also be filled out manually. The input for that form will consist of the field test results recorded by the evaluating organization's field crew on the Individual Test Logs and the vendor's test results.

The table consists of 11 columns. One line is provided for each test performed during evaluation of the method. If a test was invalid or was aborted, the test should be listed with the appropriate notation (e.g., invalid) on the line.

The Test Number in the first column refers to the test number from the randomization design determined according to the instructions in Section 6 of the protocol. Since some changes to the design might occur during the course of the field testing, the test numbers might not always be in sequential order.

Note that the results from the trial run need to be reported here as well.

The following list matches the column input required with its source, for each column in the table.

Column No.	Input	Source
1	Test number or trial run	Randomization design
2	Date at completion of last fill	Individual Test Log
3	Time at completion of last fill	Individual Test Log
4	Date test began	Individual Test Log
5	Time test began	Individual Test Log
6	Time test ended	Individual Test Log
7	Product temperature differential	Individual Test Log
8	Nominal leak rate	Randomization design
9	Induced leak rate	Individual Test Log
10	Measured leak rate	Vendor's records
11	Measured minus induced leak rate	By subtraction

Results of U.S. EPA Standard Evaluation
Volumetric Tank Tightness Testing Method

This form tells whether the tank tightness testing method described below complies with the performance requirements of the federal underground storage tank regulation. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Volumetric Tank 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 to prove compliance with the federal regulations. Tank owners should check with State and local agencies to make sure this form satisfies their requirements.

Method Description

Name _____

Version _____

Vendor _____

_____
(street address)

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

Evaluation Results

This method, which declares a tank to be leaking when the measured leak rate exceeds the threshold of _____ gallon per hour, has a probability of false alarms [P(FA)] of _____%.

The corresponding probability of detection [P(D)] of a 0.10 gallon per hour leak is _____%.

Therefore, this method ☐ does ☐ does not meet the **federal** performance standards established by the U.S. Environmental Protection Agency (0.10 gallon per hour at P(D) of 95% and P(FA) of 5%).

Test Conditions During Evaluation

The evaluation testing was conducted in a _____ gallon ☐ steel ☐ fiberglass tank that was _____ inches in diameter and _____ inches long.

The tests were conducted with the tank _____ percent full.

The temperature difference between product added to fill the tank and product already in the tank ranged from _____ °F to _____ °F, with a standard deviation of _____ °F.

The product used in the evaluation was _____.

Volumetric TTT Method_____
Version_____

Limitations on the Results

The performance estimates above are only valid when:

- The method has not been substantially changed.

- The vendor's instructions for using the method are followed.

- The tank is no larger than _____ gallons.

- The tank contains a product identified on the method description form.

- The tank is at least _____ percent full.

- The waiting time after adding any substantial amount of product to the tank is at least _____ hours.

- The temperature of the added product does not differ more than _____ degrees Fahrenheit from that already in the tank.

- The waiting time between the end of "topping off," if any, and the start of the test data collection is at least _____ hours.

- The total data collection time for the test is at least _____ hours.

- Large vapor pockets are identified and removed (for methods that overfill the tank).

- This method ☐ can ☐ cannot be used if the ground-water level is above the bottom of the tank.

- Other limitations specified by the vendor or determined during testing:

  _____

  _____

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

Certification of Results

I certify that the volumetric tank tightness testing method was operated according to the vendor's instructions. I also certify that the evaluation was performed according to the standard EPA test procedure for volumetric tank tightness testing methods and that the results presented above are those obtained during the evaluation.

_____   _____
(printed name)   (organization performing evaluation)

_____   _____
(signature)   (city, state, zip)

_____   _____
(date)   (phone number)

Individual Test Log
Volumetric Tank Tightness Testing Method

Instructions for completing the form

This 5-page test log form is to be filled out by the field crew of the evaluating organization. A separate form is to be filled out for each individual test (at least 24.) The information on these forms is to be kept blind to the vendor's crew during the period of evaluation of their method.

The form consists of nine parts. These are:

1. Header information
2. General background information
3. Conditions before testing
4. Topping off records (if applicable)
5. Conditions at beginning of test
6. Conditions at completion of testing
7. Leak rate data
8. Additional comments, if needed
9. Induced leak rate data sheets

All items are to be filled out and the appropriate boxes checked. If a question is not applicable, then indicate so as "NA". The following provides guidance on the use of this form.

Header Information

The header information is to be repeated on all five pages, if used. If a page is not used, cross it out and initial it. The field operator from the evaluating organization needs to print and sign his/her name and note the date of the test on top of each sheet.

The test number is the number obtained from the randomization design. It is not the sequential running test number. If a test needs to be rerun, indicate the test number of the test being rerun and indicate that on the test log (e.g., Test No. 5 repeat).

General Background Information

Indicate the commercial name of the method. Include a version identification if the method uses different versions for different products or tank sizes. The vendor's recommended stabilization period has to be obtained from the vendor prior to testing. This is important since it will impact on the scheduling of the evaluation. All other items in this section refer to the test tank and product. Indicate the ground-water level at the time of the test.

Theoretically, this information would remain unchanged for the whole evaluation period. However, weather conditions could change and affect the ground-water level. Also, the evaluating organization could change the test tank.

Conditions Before Testing

Fill in all the blanks. If the information is obtained by calculation (for example the amount of water in the tank is obtained from the stick reading and then converted to volume), this can be done after the test is completed. Indicate the unit of all temperature measurements by checking the appropriate box.

Topping Off Records (if applicable)

If "topping off" is not part of the procedure, indicate so as "NA". Fill in all the blanks.

Conditions at Beginning of Test

Indicate the date and time when the vendor began setting up his test equipment. This is not the start of the test data collection itself.

The evaluating organization's field crew starts inducing the leak rate and records the time on pages 4 and 5. All leak simulation data are to be recorded using the form on pages 4 and 5.

Once the evaluating organization's field crew is ready with the induced leak rate simulation, and the vendor's crew starts the actual testing, record the date and time that the vendor's test data collection starts. Also, indicate the product temperature at that time. Fill out the weather condition section of the form. Indicate the nominal leak rate which is obtained from the randomization design.

Conditions at Completion of Testing

Indicate date and time when the test is completed.

Again, stick the tank and record the readings and the amount of water in the tank. Record all weather conditions as requested.

Leak Rate Data

This section is to be filled out by the evaluating organization's statistician or analyst performing the calculations. This section can therefore be filled out as the evaluation proceeds or at the end of the evaluation.

The nominal leak rate is obtained from page 2 (Test Conditions at Beginning of Test). It should be checked against the nominal leak rate in the randomization design by matching test numbers.

The induced leak rate is obtained by calculation from the data reported by the evaluating field crew on page 4 (and 5, if needed) of this form. The measured leak rate is that reported by the vendor's crew for that test.

Name of Field Operator _____

Signature of Field Operator _____   **Test No.** _____

Date of Test _____

Individual Test Log
Volumetric Tank Tightness Testing Method

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.

General Background Information

Method Name and Version _____

Product Type   _____

Type of Tank   _____

Tank Dimensions (nominal)

    Diameter   _____ inches

    Length   _____ inches

    Volume   _____ gallons

Ground-water level _____ inches above bottom of tank

Recommended stabilization period before test (per vendor SOP)

    _____ hours _____ minutes

Conditions Before Testing

Date and time at start of conditioning test tank _____ date _____ military time

Stick reading before partial emptying of tank

    Product _____ inches _____ gallons

    Water _____ inches _____ gallons

Temperature of product in tank before partial emptying _____ °F ☐ or °C ☐

Stick reading after partial emptying of tank

    Product _____ inches _____ gallons

Amount of product removed from tank (by subtraction) _____ gallons

Name of Field Operator _____

Signature of Field Operator _____ Test No. _____

Date of Test _____

Conditions Before Testing (continued)

Stick reading after filling to test level

    Product _____ inches _____ gallons

    Water   _____ inches _____ gallons

Amount of product added to fill tank (by subtraction) _____ gallons

Temperature of product added to fill tank   _____ °F ☐ or °C ☐

Temperature of product in tank immediately after filling _____ °F ☐ or °C ☐

Date and time at completion of fill _____ date _____ military time

---

Topping Off Records (if applicable)

Date and time at completion of topping off _____ date _____ military time

Approximate amount of product added   _____ gallons

If tank overfilled, height of product above tank _____ inches

---

Conditions at Beginning of Test

Date and time vendor began setting up test equipment

    _____ date _____ military time

> **Complete induced leak rate data sheet (use attached pages 4 and 5)**

Date and time at start of vendor's test data collection

    _____ date _____ military time

Temperature of product in tank at start of test _____ °F ☐ or °C ☐

Weather Conditions at Beginning of Test

    Temperature _____ °F ☐ or °C ☐

    Barometric pressure _____ mm Hg ☐ or _____ in. Hg ☐

    Wind   None ☐   Light ☐   Moderate ☐   Strong ☐

    Precipitation   None ☐   Light ☐   Moderate ☐   Heavy ☐

    Sunny ☐   Partly Cloudy ☐   Cloudy ☐

Nominal leak rate _____ gallon per hour

Name of Field Operator _____

Signature of Field Operator _____ **Test No.** _____

Date of Test _____

Conditions at Completion of Testing

Date and time at completion of test data collection

_____ date _____ military time

Stick reading at completion of test data collection

Product _____ inches _____ gallons

Water _____ inches _____ gallons

Weather Conditions at End of Test

Temperature _____ °F ☐ or °C ☐

Barometric pressure _____ mm Hg ☐ or _____ in. Hg ☐

Wind	None ☐	Light ☐	Moderate ☐	Strong ☐
Precipitation	None ☐	Light ☐	Moderate ☐	Heavy ☐

Sunny ☐   Partly Cloudy ☐   Cloudy ☐

Date and time test equipment is disassembled (if done for this test)

and tank is ready for service _____ date _____ military time

Leak Rate Data (not to be filled out by field crew)

Nominal leak rate _____ gal/h

Induced leak rate _____ gal/h

Leak rate measured by vendor's method _____ gal/h

Difference (measured rate minus induced rate) _____ gal/h

Additional Comments (Use back of page if needed)

Name of Field Operator _____

Signature of Field Operator _____

Date of test _____   Test No._____

Induced Leak Rate Data Sheet

	Time at product collection (military)	Amount of product collected (mL)	Comments (if applicable)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			

Signature of Field Operator _____

Date of test _____   Test No._____

Induced Leak Rate Data Sheet (continued)

	Time at product collection (military)	Amount of product collected (mL)	Comments (if applicable)
25			
26			
27			
28			
29			
30			
31			
32			
33			
34			
35			
36			
37			
38			
39			
40			
41			
42			
43			
44			
45			
46			
47			
48			

The difference is simply calculated by subtracting the induced from the measured leak rate.

Additional Comments (if needed)

Use this page for any comments (e.g., adverse weather conditions, equipment failure, reason for invalid test, etc.) pertaining to that test.

Induced Leak Rate Data (pages 4 and 5)

This form is to be filled out by the evaluating organization's field crew. From the randomization design, the crew will know the nominal leak rate to be targeted. The induced leak rate will be known accurately at the end of the test. However, the protocol requires that the induced leak rate be within 30% of the nominal leak rate.

Reporting Form for Leak Rate Data
Volumetric Tank Tightness Testing Method

Method Name and Version: _____

Evaluation Period: _____ from _____ to _____ (Dates)

Test No.	Date at Completion of Last Fill (m/d/y)	Time at Completion of Last Fill (military)	Date Test Began (m/d/y)	Time Test Began (military)	Time Test Ended (military)	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)
Trial Run						0	0	0		
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
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21										
22										
23										
24										

Reporting Form for Leak Rate Data

Volumetric Tank Tightness Testing Method

Method Name and Version: _____

Evaluation Period: _____ from _____ to _____ (Dates)

Test No.	Date at Completion of Last Fill (m/d/y)	Time at Completion of Last Fill (military)	Date Test Began (m/d/y)	Time Test Began (military)	Time Test Ended (military)	Product Temperature Differential (deg F)	Nominal Leak Rate (gal/h)	Induced Leak Rate (gal/h)	Measured Leak Rate (gal/h)	Meas.-I Leak Ra (gal/h)
25										
26										
27										
28										
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Jlumetric TTT Method–Data Reporting Form