United States
Environmental Protection
Agency

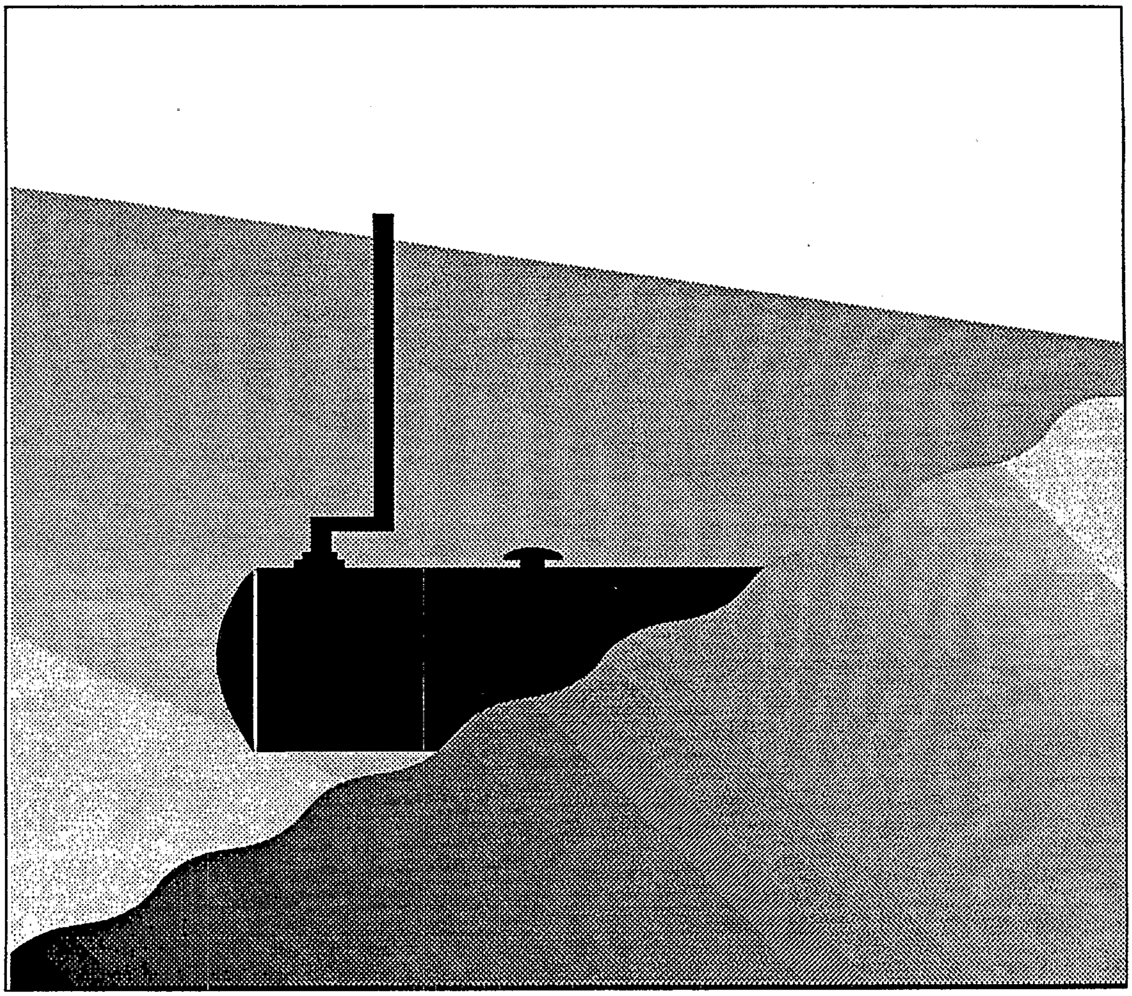
Solid Waste And
Emergency Response/
Research And Development
5403W

EPA/530/UST-90/006
March 1990

EPA

Standard Test Procedures for Evaluating Leak Detection Methods

Automatic Tank Gauging Systems



Printed on Recycled Paper

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

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 automatic tank gauging (ATG) systems must be capable of detecting a 0.20 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 ATG systems, for example, this will mean testing under both 0.0 gallon per hour and 0.20 gallon per hour leak rates. In the case of ground-water monitoring, this will mean testing with 0.0 and 0.125 inch of free product.

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

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

This document was written by Jairus D. Flora Jr., Ph.D., and Karin M. Bauer for the U.S. Environmental Protection Agency's Office of Underground Storage Tanks (EPA/OUST) under contract No. 68-01-7383. The Work Assignment Manager for EPA/OUST was Thomas Young and the EPA/OUST Project Officer was Vinay Kumar. Technical assistance and review were provided by the following people:

Russ Brauksieck - New York Department of Environmental Conservation
Tom Clark - Minnesota Pollution Control Agency
Allen Martinets - Texas Water Commission
Bill Seiger - Maryland Department of Environment

American Petroleum Institute
Leak Detection Technology Association
Petroleum Equipment Institute

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 automatic tank gauging (ATG) systems, the system must be capable of detecting a leak of 0.20 gallon per hour with a probability of (at least) 95%, while operating at a false alarm rate of 5% or less.

The regulations for ATG systems require (1) that automatic product level monitor test be able to detect a 0.20 gallon per hour leak from any portion of the tank that routinely contains product and (2) that its automatic inventory function meet the requirements for inventory control. That is, the equipment must be capable of:

- measuring the height of the liquid to the nearest one-eighth of an inch.
- measuring any water in the bottom of the tank at least once a month to the nearest one-eighth of an inch.
- conducting daily reconciliation of the inventory.
- declaring a leak on the basis of the inventory reconciliation if the discrepancy exceeds 1% of the flow-through plus 130 gallons on a monthly basis.

A large number of test devices and systems are reaching the market, but little evidence is available to support their performance claims. Advertising literature for these systems can be confusing. Owners and operators need to be able to determine whether a vendor's ATGS 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 ATG systems need to know how to evaluate their systems.

1.2 OBJECTIVES

The objectives of this protocol are twofold. First, it provides a procedure to test ATG systems in a consistent and objective manner. Secondly, it allows the regulatory community and regulators to verify compliance with regulations. This protocol provides a standard method that can be used to estimate the performance of an ATGS. 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 than) a 5% false alarm rate while having a probability of detection of (at least) 95% to detect a leak of 0.20 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 only evaluates the leak test function and the water sensing function of the ATGS since they are considered the primary leak detection modes. The protocol does not address the inventory function of the ATGS. Also, 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 ATGS on a tight tank and estimating the leak rate both under the no-leak conditions and under induced leak conditions. The leak rate measured by the ATGS is then compared with the induced leak rate for each test run. To estimate the performance of the ATGS, 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 to tanks of no more than 25% greater capacity than the test tank.

The testing also includes conditions designed to check the system'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 system's ability to deal with tank deformation. During some of the cycles of filling 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 system's temperature compensation. Four different nominal leak rates (including the no-leak condition) are used. This demonstrates how closely the system 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.

An important function of an ATGS is its ability to detect water in the product and to track the water level in the tank as a means of detecting leaks when a high water table is present. Since the ATGS acts as a continuous monitor with the tank in a normal operating condition, the relation of the product height to the height of the ground-water level outside the tank varies, producing different relative pressures as the product level changes during use. One part of most ATG systems is to detect the possible incursion of water. In evaluating the water sensor, the minimum water level that the system can detect, and the smallest change in water level that the system can reliably measure, are determined. The performance of the ATGS is evaluated on its ability to detect a hole in the tank by measuring the incursion of water into the product.

1.4 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 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 forms: a standard reporting form for the evaluation results, a standard form for describing the operation of the ATGS, data reporting forms, and individual test logs.

SECTION 2

SCOPE AND APPLICATIONS

This document presents a standard protocol for evaluating ATG systems. It is designed to evaluate systems that are installed in the tank and monitor product volume changes on a continuous basis during the test period. The protocol is designed to evaluate the leak detection functions of an ATGS. These functions are the test mode, water detection, and water level monitoring. The evaluation will estimate the performance of the system's test mode and compare it with the EPA performance standards of a false alarm rate of (no more than) 5% and the probability of detecting a leak of 0.20 gallon per hour of (at least) 95%.

The protocol provides tests to determine the threshold of water detection for the ATGS. In addition, the protocol tests the ability of the water sensor to measure changes in the water level and compares the results to the EPA performance standard of 0.125 inch. These are evaluated over a range of a few inches in the bottom of the tank. The threshold and height resolution of the water detector are converted to gallons using the geometry of the tank.

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 an ATGS meets the requirements of 40 CFR Part 280, Subpart D. The standard 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 evaluation.

SECTION 3

SUMMARY

The evaluation protocol for ATG systems 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. A tank tightness test in the 6 months preceding testing that indicates a tight tank.

2. At least three ATGS records with a different ATGS than that being tested within a 3-month period with inventory and test modes indicating a tight tank.

3. A 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 system under investigation, constitutes acceptable evidence. This information should be reported 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 ATGS is installed in the test tank and used to measure a leak rate under the no-leak condition and with three induced leak rates of 0.10, 0.20, and 0.30 gallon per hour. A total number of at least 24 tests is to be performed. The tank must be 50% full for half the tests. It is refilled to about 90% to 95% full for the other 12 tests. When filling the tank, 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 ATG system'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, 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.

The ability of the system to measure water in the bottom of a tank is tested by placing the system in a standpipe containing product. Measured amounts of water are added and the ability of the system to sense the water at given depths is determined experimentally. These results are also reported on the standard form in Appendix B.

SECTION 4

SAFETY

This discussion does not purport to address all the safety considerations involved in evaluating leak detection equipment and methods for underground storage tanks. The equipment used should be tested and determined to be safe for the products it is designed for. Each leak detection system should have a safety protocol as part of its standard operating procedure. This protocol should specify requirements for safe installation and use of the device or method. This safety protocol will be supplied by the vendor to the personnel involved in the evaluation. In addition, each institution performing an evaluation of a leak detection device should have an institutional safety policy and procedure that will be supplied to personnel on site and will be followed to ensure the safety of those performing the evaluation.

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

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

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

All safety procedures appropriate for the product in the tanks should be followed. In addition, any safety procedures required for a particular set of test equipment should be followed.

This test procedure only addresses the issue of the system's ability to detect leaks. It does not address testing the equipment for safety hazards. The manufacturer needs to arrange for other testing for construction standards to ensure that key safety hazards such as fire, shock, intrinsic safety, product compatibility, etc., are considered. The evaluating organization should check to see what safety testing has been done before the equipment is used for testing to ensure that the test operation will be as safe as possible.

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 differential 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 detection 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 25% 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 7,500 gallons in capacity. Results from 8,000-gal tanks can be applied to tanks up to 10,000 gallons, those from 10,000 gallons to up to 12,500 gallons, etc. If the method is intended to test larger tanks, e.g., 20,000 gallons, it must be evaluated in a tank within 25% of that size.

Because the protocol calls for filling or emptying 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 ATGS will be supplied by the vendor or manufacturer. Consequently, it will vary by system. In general, the ATGS equipment will consist of some system for monitoring product volume or level, for compensating for temperature, and for detecting and monitoring water in the product. 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.

Since ATG systems are installed permanently and left to the tank owner to be operated, it is recommended that the ATGS equipment being tested be operated by the evaluating organization personnel. The ATGS equipment is normally operated by the station owner, so 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 system under test. 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 described in Section 6 gives the nominal leak rates that are to be used.

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 is 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 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 ATGS will be compared to the induced leak rates.

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 90% to 95% full 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 WATER SENSOR EQUIPMENT

The equipment to test the water sensor consists of a vertical cylinder with an accurately known (to ±0.001 inch) inside diameter. This cylinder should be large enough to accommodate the water sensor part of the ATGS. Thus, it should be approximately 4 inches in diameter and 8 or more inches high. A means of mounting the ATGS so that its water sensor is in the same relation to the bottom of the cylinder as it would be to the bottom of a tank is needed. In addition, a means of repeatedly adding a small measured amount of water to the cylinder is needed. This can be accomplished by using a pipette.

5.6 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 be needed for fuel transfer. In addition, containers will be necessary to hold the product 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 evaluation protocol for ATG systems consists of two parts. The first evaluates the leak detection function of the ATGS. The second evaluates its water detection function and the system's resolution of water sensing.

The overall performance of the ATGS is estimated by a comparison of the system'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 system performs well overall, then it may be expected to perform well in the field. The test procedures have been designed so that additional analyses can be done to determine whether the system's performance is affected by the stabilization time, temperature of added product, the amount of product in the tank, or the size of the leak.

The test procedure introduces four main factors that may influence the test: size of leak, amount of product in the tank, temperature differentials, and tank deformation. An additional factor is the method's ability to deal with ground-water level effects. This factor is evaluated when determining the system's water sensing threshold and resolution.

The primary consideration is the size of the leak. The system is evaluated on its ability to measure or detect leaks of specified sizes. If a system cannot closely measure a leak rate of 0.20 gallon per hour or if the system demonstrates excessive variability on a tight tank, then its performance is not adequate. The ability of the system to track the leak rates 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 should be at least 5°F and should be measured and recorded to the nearest degree F. The temperature difference is needed to ensure that the system 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 system's 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 leak rate). Comparison of the order of the test pairs can determine if the additional stabilization improves performance. The actual times between completing the fills and starting the tests are recorded and reported.

The fourth consideration is the amount of product in the tank. Since ATG systems work at different levels of product in the tank, the required monthly test may be done at various levels. Two levels have been chosen to represent these product levels. One is half full, which requires the most sensitive level measurement. The other is 90% to 95% full, which requires the most sensitive temperature compensation.

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

The ground-water level is a potentially important variable in tank testing, and the system's means of dealing with it is to be documented. A system that does not determine the ground-water level and take it into account is not adequate. Ground-water levels are above the bottom of the tank at approximately 25% of underground storage tank sites nationwide, with higher proportions in coastal regions. The water sensing function of the ATGS is used to detect leaks in the presence of a ground-water level above the bottom of the tank. If the ground-water level is high enough so that there is an inward pressure through most levels of product in the tank, then water will come into the tank if there is a hole below the ground-water level. Since an ATGS must operate at normal operating levels of product in the tank, it uses water incursion to detect leaks if there is a high ground-water level. This protocol evaluates two aspects of the system's water sensing function: the minimum detectable water level and the minimum detectable change in water level. Together, these can be used with the dimensions of the tank to determine the ability of the system's water sensing device to detect inflows of water at various rates.

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 system should be described in the operating manual for the ATGS 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

6.2 ATGS LEAK DETECTION MODE

The following presents the test conditions and schedule to determine the performance of the ATGS.

6.2.1 Induced Leak Rates, Temperature Differentials, and Product Volume

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

Table 1. PRODUCT VOLUME, LEAK RATE, AND TEMPERATURE DIFFERENTIAL TEST SCHEDULE

	Test No.	Pair No.	Set No.	Nominal leak rate (gallon per hour)	Nominal temperature differential* (degree F)
Trial run	-	-	-	0.00	0
Empty to 50% full (if applicable)					
Fill to 90-95% full					
	1	1	1	LR_1	T_2
	2	1	1	LR_2	T_2
Empty to 50% full					
	3	2	1	LR_4	T_2
	4	2	1	LR_3	T_2
Fill to 90-95% full					
	5	3	2	LR_1	T_1
	6	3	2	LR_4	T_1
Empty to 50% full					
	7	4	2	LR_2	T_1
	8	4	2	LR_3	T_1
Fill to 90-95% full					
	9	5	3	LR_4	T_3
	10	5	3	LR_1	T_3
Empty to 50% full					
	11	6	3	LR_3	T_3
	12	6	3	LR_2	T_3
Fill to 90-95% full					
	13	7	4	LR_3	T_2
	14	7	4	LR_4	T_2
Empty to 50% full					
	15	8	4	LR_2	T_2
	16	8	4	LR_1	T_2
Fill to 90-95% full					
	17	9	5	LR_2	T_1
	18	9	5	LR_3	T_1
Empty to 50% full					
	19	10	5	LR_4	T_1
	20	10	5	LR_1	T_1
Fill to 90-95% full					
	21	11	6	LR_3	T_3
	22	11	6	LR_2	T_3
Empty to 50% full					
	23	12	6	LR_4	T_3
	24	12	6	LR_1	T_3

*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
0.10	6.3
0.20	12.6
0.30	18.9

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).

Product Volumes

The tests will be run in sets of two pairs, holding the temperature differential constant within a set of four tests but changing the leak rate within each pair. The product volume will alternate from pair to pair. The first pair of tests within a set will be run with the tank filled to 90% to 95% capacity. Then the tank will be emptied to 50% full and the second pair of tests in the set will be run.

Randomization

A total of 24 tests will be performed by inducing 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) at the two product volumes (50% full and 90% to 95% full) as outlined in Table 1.

The randomization of the tests is achieved by randomly assigning the nominal leak rates of 0, 0.10, 0.20 and 0.30 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. In addition, the evaluating organization should randomly assign the groups of four tests to the set numbers 1 to 6, without disturbing the order of the four tests within a set.

The vendor will install the ATGS and train the evaluating organization to operate it. After the trial run the ATGS will be operated as it would be in a commercial establishment. The evaluating organization will operate the ATGS and record its data. Note that since an ATGS operates automatically, it is not necessary to keep the induced leak rates blind to the operator. The operator merely starts the leak detection function of the ATGS at the appropriate time and records the results. The randomization is used to balance any unusual conditions and to ensure that the vendor does not have prior knowledge of the sequence of leak rates and conditions to be used.

In summary, each test set consists of two pairs of tests. Each pair of tests is performed using two induced leak rates, one induced temperature differential (temperature of product to be added - temperature of product in tank), and one in-tank product level. Each pair of tests indicates the sequence in which the product volumes (in gallon per hour) will be removed from the tank at a given product temperature differential.

Notational Conventions

The nominal leak rates, that is 0, 0.10, 0.20, and 0.30 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 ATGS 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.

6.2.2 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 ATGS equipment and provide instructions to the operators 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 leaky valves or plumbing problems 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, temperature differentials, and in-tank product levels as shown in Table 1 above. The time lapse between the two tests in each pair should be kept as short as practical. The date and time of starting each test are to be recorded and reported in the test log. Twelve pairs of tests will be carried out. After each pair of tests, the test procedure starts anew with either emptying the tank to half full or filling it up to 90% to 95% capacity, stabilizing, etc. The details of the testing schedule are presented next.

Step 1: Randomly assign the nominal leak rates of 0, 0.10, 0.20, and 0.30 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. Randomly assign the groups of four tests to the 6 sets. This will be done by the evaluating organization supervising the testing.

Step 2: Follow the vendor's instructions and install the ATGS in the tank. Also 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 ATGS. Perform any calibration or operation checks needed with the installation of the ATGS.

Step 3: **Trial run.** Following the test system's standard operating procedure, fill (if needed) the tank to the recommended level for operation in the leak detection mode, and allow for the stabilization period called for by the system or longer. Any 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 ATGS equipment. Perform any necessary repairs or modifications identified by the trial run.

Step 4: Empty the tank to 50% full if the product volume was above that level during the trial run.

Step 5: Fill the tank to 90% to 95% capacity. Fill with product at the temperature required by the randomized test schedule. 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.

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: Continue with the system's standard operating procedure and conduct a test on the tank, using the system's recommended test duration. Record the date and time of starting the test. This test will be performed under the first nominal leak rate of the <u>first</u> set in Table 1. This nominal leak rate to be induced is <u>LR_1.</u>

When the first test is complete, determine and record the actual induced leak rate, S_1, and the system'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.

Step 7: Change the nominal leak rate to the <u>second</u> in the first set, that is LR_2 (see Table 1). **Repeat Step 6.** 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 (dates and times, measured and induced leak rates, temperatures, calculations, etc.).

Step 8: Empty the tank to 50% capacity (to within ±6 inches of the tank midpoint). The temperature of the in-tank product will remain unchanged.

Step 9: Change the nominal leak rate to the third in the first set, that is LR_4. **Repeat Step 6.** Record all results.

Step 10: Change the nominal leak rate to the fourth in the first set, that is LR_3. **Repeat Step 7.** Record all results.

Step 11: **Repeat Step 5.** The temperature differential will be changed to T_1.

Step 12: **Repeat Steps 6 through 10,** using each of the four nominal leak rates of the second set, in the order given in Table 1.

Steps 5 through 10, which correspond to a fill and empty cycle and one set of two pairs of tests, will be repeated until all 24 tests are performed.

6.3 TESTING PROBLEMS AND SOLUTIONS

Inevitably, some test runs will be inconclusive due to broken equipment, spilled 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 rule applies.

Rule 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 2: If equipment fails during the first run (first test of a set of four tests) 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 3: If equipment fails during a later test (after the first run in a set of four has been completed successfully), and if the time needed for fixing the problem(s) is less than 8 hours, then repeat the test. Otherwise, repeat the whole sequence of empty/fill cycle, stabilization, and test at the given conditions.

6.4 ATGS EVALUATION PROTOCOL FOR WATER DETECTION

Typically the ATGS probe has a water sensor near the bottom of the tank. A standpipe device to test the function of the water sensor consists of a cylinder with an accurately known (to ±0.001 inch) inside diameter attached to the bottom of a 4- to 6-inch diameter pipe. The probe is mounted so that the sensor is in the same relation to the bottom of the cylinder as to the bottom of a tank. Enough product is put into the cylinder and pipe so that the product level sensor is high enough so as not to interfere with the water sensor. A measured amount of water is then added to the cylinder until the water sensor detects it, at which time the water level is calculated and recorded. Additional measured amounts of water are added to produce calculated level changes. The amount of water added, the calculated level change, and the level change measured by the ATGS are recorded. This is done over the range of the water sensor or 6 inches, whichever is less. When testing is complete, the product and water are removed, separated, and the process is repeated. The testing procedure is given in detail next.

Step 1: Install the probe temporarily in a test standpipe. The bottom section of about 1 foot should have an accurately known (to ±0.001 inch) inside diameter. The diameter must be large enough to accommodate the probe and must be known accurately so that the volume of water added can be used to calculate the water level.

Step 2: Fill the bottom section of the standpipe with the product (typically this will require a gallon or less). Enough product needs to be added so that the product level is high enough not to interfere with the water sensor.

Step 3: Add water in increments to the cylinder with a pipette until the sensor detects the presence of the water. Record the volume of water added and the sensor reading at each increment. The sensor reading will be zero until the first sensor response. At that point, total the water increments and calculate the corresponding level, X_1, of water detected. Record all data on page 1 of the Reporting Form for Water Sensor Evaluation Data in Appendix B.

Step 4: Add enough water to the cylinder with a pipette to produce a height increment, h, measured to the lesser of 1/16 inch or half of the claimed resolution. At each increment, record the volume of water added and the water height (denoted by $W_{i,j}$ in Table 3 of Section 7.2) measured by the sensor. Use pages 2 to 4 as necessary of the Reporting Form for Water Sensor Evaluation Data in Appendix B. Repeat the incremental addition of water at least 20 times to cover the height of about 6 inches (or, the range limit of the sensor, if less).

Step 5: Empty the product and water from the standpipe, refill with product (the same product can be used after separating the water) and **repeat Steps 2 and 3** 20 times to obtain 20 replications. **Repeat Step 4** at least 3 times or as needed to obtain a minimum of 100 increments.

Record all data using the reporting form for ATGS water sensor data in Appendix B. The 20 minimum detectable water levels are denoted by X_j, $j=1,\ldots,20$. The sensor reading at the i^{th} increment of the j^{th} test is denoted by $W_{i,j}$ as described in Section 7.2 and Table 3.

6.5 ALTERNATIVE EVALUATION PROCEDURE

As noted in the Foreword, EPA will accept alternative evaluation protocols to the specific one just described. An overview of an alternative protocol is presented next. Although it is not completely specified, enough detail is presented so that an evaluating organization should be able to set it up and carry it out.

The previous sections (6.1 to 6.4) provide a test plan that can be accomplished in about three calendar weeks. The approach described there requires a tank that can be fully devoted to testing, which may be a difficult requirement. The following alternative approach uses in-service tanks. Only a limited amount of work is required that would prohibit using the tank for dispensing product.

The alternative approach consists of installing the ATGS in a number of tanks. Since the ATGS operates automatically, it can be programmed to perform a test whenever the tank is out of service for a long enough period, typically each night. With several available tanks, a large set of tests could be performed in a relatively short time. By selecting tanks in different climates or observing tanks over the change of seasons, tests can be performed under a wide variety of conditions. Thus, with little expenditure of effort, a large data base of test results on tight tanks can be obtained readily.

The alternative approach will provide test data under a variety of actual conditions. In selecting the sites and times for the data collection, the evaluating organization should attempt to obtain a wide variety of temperature conditions and to conduct the tests at a wide variety of product levels in the tank as well as a variety of times after the tank receives a product delivery. This alternative approach will produce data under conditions as actually observed in the field. The primary difference between the standard and alternative procedures is how the test conditions are attained. Both approaches attempt to conduct the evaluation testing under conditions representative of the real world. The standard approach does this by controlling the test conditions, while the alternative tests under a variety of situations and records the test conditions.

Next, the data base of ATGS test results on tight tanks needs to be supplemented with a limited number of tests using an induced leak. This is to demonstrate that the system can track an induced leak adequately, that is, that it will respond to and identify a loss of product from the tank of the magnitude specified in the EPA performance standard. The combined data sets can then be analyzed to estimate the performance of the ATGS. If the resulting performance estimate meets the performance standard for an ATGS, that would constitute demonstration that the system meets the EPA standard.

This alternative approach will result in a large number of tests on tight tanks, and relatively few tests under induced leak rate conditions. A suggested sample size is 100 tight tank tests and 10 induced leak rate tests. Larger numbers of either type of test can be used. It should be easy to obtain the tight tank tests, however, some work will be needed to prepare the data base, recording the ancillary data. It will also be necessary to exclude some tests, for example those that were started, but had a delivery or dispensing operation during the test period thus invalidating the test.

The following steps provide an outline of this method of evaluation.

Step 1: Identify a number of tanks for installation of the ATG systems. These tanks should be known to be tight, by meeting one of the criteria described in Section 3. The tanks can be of varying sizes, but the sizes used will limit the applicability of the results. The tanks should be at several sites, with a suggested minimum of 5 different sites and 10 different tanks.

Step 2: Install identical ATG systems in the tanks. Arrange to collect and record ancillary data to document the test conditions. The data needed are:

- the average in-tank product temperature prior to a delivery.
- the time and date of each delivery.
- the average in-tank product temperature immediately after a delivery.
- the amount of product added at each delivery.
- the date, time, and results of each test.
- the product level when the test is run.
- the tank size, type of tank, product contained, etc., (see the Individual Test Log for a form to record these data).

Step 3: Conduct tests in each tank for at least a two-week period. Tests should be run approximately nightly or as frequently as practical with the tank's use. Report the starting and ending dates of the test period. Record the test result along with the data listed in Step 2. The data above define the conditions of each test in terms of the time since the last fill (stabilization time), the product level, and the difference between the temperature of the product added and that of the product in the tank. Report all test results, even if some tests must be discarded because of product delivery or dispensing during the scheduled test period. Identify and report the reason for discarding any test data on the test log.

Step 4: Conduct tests with an induced leak at the rate between 0.10 and 0.20 gallon per hour. These induced leak tests will generally require a person on site to monitor the induced leak rates and measure the rates actually achieved. A minimum of 10 such tests is suggested, with some conducted shortly after a fill with a nearly full tank, and others conducted when the tank is about half full. The induced leak tests should be conducted on the largest available tanks to demonstrate the performance on the largest tank that the ATGS is intended for.

Step 5: At some time during the evaluation period, evaluate the performance of the water sensor function. This can be done at a separate site and does not require a tank. Follow the procedure described in Section 6.4.

Step 6: Using the resulting data, analyze the differences between the leak rate measured by the ATGS and the induced leak rate achieved (zero for the many tests on tight tanks) for teach test to estimate the performance.

The data base can be used to investigate the relationship of the error size (the leak rate differences) to each of the variables measured for the tests. These include tank size, length of stabilization time, temperature differential, product level, and presence of induced leaks. Multiple regression techniques can be used for these analyses, most of which would fall under the category of optional analyses. However, the data should be analyzed with the two groups of tight tank tests and induced leak rate tests separately to demonstrate that the system can determine the leak rates. Otherwise, it would be possible to have such a large number of tight tests that small errors on those would obscure large errors on the small number of induced leak rates tests. An outline of the data analysis approach is given in Section 7.4.

SECTION 7

CALCULATIONS

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

The evaluation of the ATGS in its leak detection mode is presented first. These calculations compare the system'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 ATGS 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, product level, and temperature can be tested to provide additional information to the vendor.

A separate section (Section 7.2) presents the calculations to estimate the minimum water level (detection threshold) and the minimum water level change that the sensor can detect.

7.1 ATGS LEAK DETECTION MODE

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 product volumes) of measured leak rates and induced leak rates will be available. These data form the basis for the performance evaluation of the system. The measured leak rates are denoted by $L_1, \ldots, L_{24}$ and the associated induced leak rates by $S_1, \ldots, S_{24}$. These leak rates are numbered in chronological order. Table 2 summarizes the notation used throughout this protocol, using the example test plan of Table 1.

7.1.1 Basic Statistics

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

Table 2. NOTATION SUMMARY

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

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.

Bias, B

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

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 system and can be either positive or negative.

Variance and Standard Deviation

The variance is obtained as follows:

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

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 potentially larger differences in the results from the first test of each set of tests, among the three temperature differentials, or between in-tank product levels. This could suggest that the system calls for an inadequate stabilization time after filling, that the system does not properly compensate for temperature differences between in-tank product and product to be added, or that the system is influenced by the product level. (See Sections 7.3.3, 7.3.4, and 7.3.5 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 than 24 tests are done, replace 24 with the number of tests, n, throughout. A larger number 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 performed). 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.

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.

7.1.2 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 0.20 gallon per hour.

The vendor will supply the criterion (threshold) for interpreting the results of the ATGS test function. Typically, the leak rate measured by the ATGS is compared to that threshold and the results interpreted as indicating a leak if the measured leak rate exceeds the threshold. Denote the system'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.

False Alarm Rate With Negligible Bias

In the case of a nonsignificant bias (Section 7.1.1), compute the t-statistic

$$t_1 = C/SD$$

where SD is the standard deviation calculated above and C is the system'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%), $t_a = 1.714$.

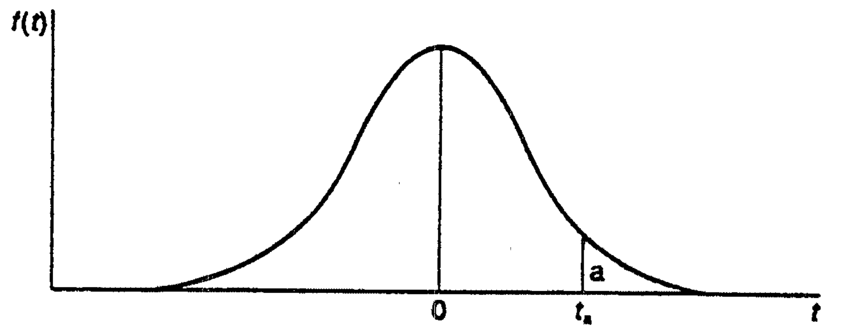


Figure 1. Student's t-Distribution Function.

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, 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.

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 right of the calculated value t_2. (Recall that C is positive, but the bias could be either positive or negative.)

7.1.3 Probability of Detecting a Leak Rate of 0.20 gallon per hour, P(D)

The probability of detecting a leak rate of 0.20 gallon per hour, P(D), is the probability that the measured leak rate exceeds C when the true mean leak rate is 0.20 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.

P(D) With Negligible Bias

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

$$t_3 = (C-0.20)/SD$$

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

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

$$t_4 = (C-B-0.20)/SD$$

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).

7.1.4 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 6 temperature differences actually achieved during testing (these 6 tests are the first in each of the 6 sets). 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 6 tests that started immediately after the specified waiting time (first test in each set). (Note: If more than 6 tests are done immediately after the filling, use all such tests. However, do not use the time to the start of the remaining 3 tests in a set 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 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.

7.2 ATGS WATER DETECTION MODE

Two parameters will be estimated for the water detection sensor: the minimum detectable water level or threshold that the sensor can determine, and the smallest change in water level that the device can record. These results will also be reported on the Results of U.S. EPA Standard Evaluation form in Appendix B.

7.2.1 Minimum Detectable Water Level

The data obtained consist of 20 replications of a determination of the minimum detectable water level (see test schedule, Section 6.4). These data, denoted by $X_j, j=1,...20$, are used to estimate the minimum water level, or threshold, that can be detected reliably.

Step 1: Calculate the mean, $\overline{X}$, of the 20 observations:

$$\overline{X} = \sum_{j=1}^{20} X_j/20$$

Step 2: Calculate the standard deviation, SD, of the 20 observations:

$$SD = \left[\frac{\sum_{j=1}^{20} (X_j - \overline{X})^2}{20-1} \right]^{1/2}$$

Step 3: From a table of tolerance coefficients, K, for one-sided normal tolerance intervals with a 95% probability level and a 95% coverage, obtain K for a sample size of 20. This coefficient is K = 2.396. (Reference: Lieberman, Gerald F. 1958. "Tables for One-Sided Statistical Tolerance Limits." *Industrial Quality Control*. Vol. XIV, No. 10.)

Step 4: Calculate the upper tolerance limit, TL, for 95% coverage with a tolerance coefficient of 95%:

$$TL = \bar{X} + K\ SD,$$

or

$$TL = \bar{X} + 2.396\ SD$$

TL estimates the minimum level of water that the sensor can detect. That is, with 95% confidence, the ATGS should detect water at least 95% of the time when the water depth in the tank reaches TL.

7.2.2 Minimum Water Level Change

The following statistical procedure provides a means of estimating the minimum water level change that the water sensor can detect, based on the schedule outlined in Section 6.4.

Denote by $W_{i,j}$ the sensor reading (in inches) at the jth replicate and the ith increment ($i=1,\ldots,n_j$, with n_j being 20 or more in each replicate). Note that the number of steps in each replicate need not be the same, so the sample sizes are denoted by n_j.

Denote by h (measured to the lesser of 1/16 inch or half the claimed resolution) the level change induced at each increment. Let m (greater than or equal to 3) be the number of replicates.

Step 1: Calculate the differences between consecutive sensor readings. The first increment will be $W_{1,1}-X_1$ for the first replicate (j=1); more generally, $W_{1,j}-X_j$, for the jth replicate. The second increment will be $W_{2,1}-W_{1,1}$ for the first replicate; more generally, $W_{2,j}-W_{1,j}$ for the jth replicate, etc.

Step 2: Calculate the difference, at each incremental step, between h, the level change induced during testing, and the difference obtained in Step 1. Denote these differences by $d_{i,j}$, where i and j represent increment and replicate numbers, respectively. Table 3 below summarizes the notations.

Table 3. NOTATION SUMMARY FOR WATER SENSOR READINGS AT THE jth REPLICATE

Increment No.	Calculated level change (inch) A	Sensor reading (inch) B	Measured sensor increment (inch) C	Increment difference calculated-meas. (inch) C-A
1	+ h	$W_{1,j}$	$W_{1,j}-X_j$*	$d_{1,j}$
2	+ h	$W_{2,j}$	$W_{2,j}-W_{1,j}$	$d_{2,j}$
3	+ h	$W_{3,j}$	$W_{3,j}-W_{2,j}$	$d_{3,j}$
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
n_j	+ h	$W_{n_j,j}$	$W_{n_j,j}-W_{n_j-1,j}$	$d_{n_j,j}$

* X_j is the water level (inches) detected for the first time by the sensor during the jth replication of the test.

Note that the first sensor reading, X_j, may vary from replicate to replicate, so that the number of differences $d_{i,j}$ will also vary. Let n_j be the number of increments necessary during replicate j.

Step 3: Calculate the average, D_j, of the differences $d_{i,j}$, $i=1,\ldots,n_j$, separately for each replicate j, $j=1,\ldots,20$.

$$D_j = \sum_{i=1}^{n_j} d_{i,j}/n_j$$

Step 4: Calculate the variance of the differences $d_{i,j}$, $i=1,\ldots,n_j$ separately for each replicate j, $j=1,\ldots,m$.

$$Var_j = \sum_{i=1}^{n_j} (d_{i,j} - D_j)^2/(n_j-1)$$

Step 5: Calculate the pooled variance, Var_p, of the m variances $Var_1,\ldots,Var_m$.

$$Var_p = \frac{(n_1-1)\ Var_1 + \cdots + (n_m-1)\ Var_m}{\sum_{j=1}^{m} (n_j-1)}$$

Step 6: Calculate the pooled standard deviation, SD_p.

$$SD_p = \sqrt{Var_p}$$

Step 7: From a table of tolerance factors, K, for two-sided tolerance intervals with 95% probability and 95% coverage, obtain K for $(\sum n_j-m)$ degrees of freedom. For the suggested sample size, the value corresponding to a total of 100 degrees of freedom (K = 2.233) can be used unless the number of differences obtained is less than 100. (Reference: *CRC Handbook of Tables for Probability and Statistics*. 1966. William H. Beyer (ed.). pp. 31-35. The Chemical Rubber Company.)

Step 8: Calculate the minimum water level change, MLC, that the sensor can detect.

$$MLC = K\ SD_p$$

or

$$MLC = 2.233\ SD_p$$

The result, MLC, is an estimate of the minimum water level change that the water sensor can detect.

7.2.3 Time to Detect a 0.20-Gallon per Hour Water Incursion (Optional)

The minimum detectable water level and the minimum detectable change can be used to determine a minimum time needed to detect a water incursion into the tank at a specified rate. This time is specific to each tank size and geometry. The calculations are illustrated for an 8,000-gallon steel tank with a 96-inch diameter and 256 inches long.

Suppose there are x inches of water in the tank. The tank is made of quarter-inch steel, so the inside diameter is 95.5 inches, giving a radius, r, of 47.75 inches. The water surface will be 2d wide, where d, in inches, is calculated as

$$d = \sqrt{r^2 - (r - x)^2}$$

where x is the water depth. The area of the water surface at depth of x inches of water is then given by 255.5 x 2d $inch^2$. Multiplying this by the minimum level change and dividing the result by 231 $inch^3$ per gallon gives approximately the volume change in gallons that the sensor can detect reliably. This differs with the level of water in the tank. (For a somewhat more accurate approximation, calculate d at level x and at level x + MLC and average the two readings for the d to be used to calculate the change in volume of water that can be detected.)

To determine how long the ATGS will take to detect a water incursion at the rate of 0.20 gallon per hour, divide the minimum volume change that the water sensor can detect by 0.20 gallon per hour. As a numerical example, suppose the depth of the water were 1 inch and the minimum detectable change were 1/8 inch. In an 8,000-gallon tank with inside diameter 95.5 inches and length 255.5 inches, the water surface width, d, is calculated as

$$d = \sqrt{(47.75)^2 - (46.75)^2} = 9.72 \text{ inches}$$

The volume, in $inch^3$, corresponding to a 1/8-inch increase is

$$V = 2(9.72) \times 255.5 \times (1/8)$$

or

$$V = 620.94 \text{ inch}^3$$

In gallons, the volume is

$$V = 220.94/231 = 2.688 \text{ gallons}$$

The time that the sensor will take to detect water incursions at the rate of 0.20 gallon per hour will be

$$\text{time} = 2.688 \text{ gallons}/0.20 \text{ gallon per hour} = 13.44 \text{ hours}$$

Thus, the sensor would detect water coming in at the rate of 0.20 gallon per hour after 13.4 hours, or about half a day. The incursion of the water into the tank should be obvious on a day-to-day basis under these conditions.

7.3 SUPPLEMENTAL CALCULATIONS AND DATA ANALYSES (OPTIONAL)

Other information can be obtained from the test data. This information is not required for establishing that the ATGS meets the federal EPA performance requirements, but may be useful to the vendor of the ATGS. 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, a minimum detectable leak rate, and relating the performance to factors such as temperature differential, waiting time, and product level. Such information may be particularly useful to the vendor for future improvements of his ATGS.

The experimental design tests the system under a variety of conditions chosen to be reasonably representative of actual test conditions. The tests occur in pairs after each fill cycle. A comparison of the results from the first 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 allow one to determine whether the temperature conditions affected the performance. A comparison among test results performed with a tank either full or half empty will provide an assessment of the effect of product level on the system's performance. Finally, the performance under the four induced leak conditions can be compared to determine whether the system 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, temperature, and product volume 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 knowledge and computer programs available.

7.3.1 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 system 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 significantly different from zero (Section 7.1.1), then replace B with 0. From the t-table 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 of a nonsignificant bias, this would be $C_{5\%} = 1.714$ SD.

7.3.2 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 a 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 previously calculated.

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

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

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 calculated threshold, $C_{5\%}$, determined to give a false alarm of 5%, minus twice the bias if the bias is statistically significant.

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

If the bias is statistically significant:

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

7.3.3 Test for Adequacy of Stabilization Period

The performance estimates obtained in Sections 7.1.2 and 7.1.3 will indicate whether the system meets the EPA performance standards. The calculations in this section allow one to determine whether the system's performance is affected by the additional stabilization time the tank has experienced by the second test after each fill cycle. These statistical tests are designed primarily to help determine why an ATGS did not meet the performance standards.

The procedure outlined in Section 6 allows time for the tank to stabilize after fuel is pumped into the tank prior to the first test of each set. Thus, additional stabilization takes place between the first and second tests of the first pair in each set. The length of the stabilization period following refueling as well as the time between tests are specified by each ATGS. 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 in each set is too short, then one would expect larger discrepancies between measured and induced leak rates for these first tests as compared to those for the second tests.

Step 1: Calculate the absolute value of the 12 differences, d_i, between the measured (L) and induced (S) leak rates for the first 2 tests in each set (last column in Table 2).

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

$$D_1 = (d_1 + d_5 + d_9 + d_{13} + d_{17} + d_{21})/6$$

$$D_2 = (d_2 + d_6 + d_{10} + d_{14} + d_{18} + d_{22})/6$$

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

$$S_1^2 = \{(d_1 - D_1)^2 + (d_5 - D_1)^2 + \cdots + (d_{21} - D_1)^2\} /5$$

$$S_2^2 = \{(d_2 - D_2)^2 + (d_6 - D_2)^2 + \cdots + (d_{22} - D_2)^2\} /5$$

Step 4: Calculate the pooled standard deviation.

$$S_p = \sqrt{\frac{5S_1^2 + 5S_2^2}{10}} = \sqrt{\frac{S_1^2 + S_2^2}{2}}$$

Step 5: Calculate the t-statistic:

$$t = \frac{(D_1 - D_2)}{S_p \sqrt{\frac{2}{6}}} = \frac{\sqrt{3}\,(D_1 - D_2)}{S_p}$$

Step 6: From the t-table, obtain the critical value corresponding to a t with (6+6-2) = 10 degrees of freedom and a two-sided 5% significance level (a = 0.025 in the table). This value is 2.228.

Step 7: Compare the absolute value of t, abs(t), to 2.228. If abs(t) is less than 2.228, 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 an additional stabilization effect between the beginning of the testing and the end. Otherwise, conclude that the difference is statistically significant, that is, the system's performance is different with a longer stabilization period.

If the results are statistically significant, then the performance of the system 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 system would show improved performance if it increased its required stabilization period. If the system's overall performance did not meet the EPA performance standard, performance estimates with the additional stabilization can be calculated using only the 6 test results with the additional stabilization. If the results indicate that the system 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 system would still need to conduct the full 24 tests at the longer stabilization time before claiming to meet the EPA performance standard.

7.3.4 Test for Adequate Temperature Compensation

This section allows one to test whether the system'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 system's performance in compensating for temperature differentials. If the temperature compensation of the system 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.

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

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

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

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

Table 4. ORGANIZATION OF DATA TO TEST FOR TEMPERATURE EFFECTS

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

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.

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

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: Miller, Ruppert G., Jr. 1981. *Simultaneous Statistical Inference*. Second Edition. Springer-Verlay, 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.

$$\text{Compare } |M_1 - M_2| \text{ with SE x 2.60}$$

$$\text{Compare } |M_1 - M_3| \text{ with SE x 2.60}$$

$$\text{Compare } |M_2 - M_3| \text{ with SE x 2.60}$$

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

If the results are statistically significant, the system'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 system 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 system needs to improve its temperature compensation and/or stabilization time in order to meet EPA performance standards. Again, an evaluation testing the modified ATGS would need to be conducted to document the performance before the ATGS could claim to meet the performance standards.

7.3.5 Test for Effect of In-Tank Product Volume

The procedure outlined in Section 6 required that the tank be either half full or filled to between 90% and 95% capacity. As shown in Table 1, 12 tests will have been run with the tank half full, and 12 tests with the tank full to 90% to 95% capacity. The 24 tests have been ordered by product volume and test number in Table 5 for the example order of tests from Table 1.

The test results from the two volume levels are compared to check for the effect of product volume on the system's performance. If the effect is negligible, the two groups of results should be comparable. If the system's performance is affected by the product level, then the ATGS may not meet EPA performance standards at all product levels. If it does meet the performance standards at both levels, it can be used in the test mode at any product level. However, if there is a significant difference in performance at the two levels, it might be advisable to recommend that the ATGS be used in its test mode only for certain product levels. If the performance is not adequate for one of the product levels, the performance of the ATGS is probably marginal. The operation of the test function could be restricted to the product level where the performance was adequate.

Table 5. ORGANIZATION OF DATA TO TEST FOR PRODUCT VOLUME EFFECT

Test No.	Pair No.	Set No.	In-tank product volume	Absolute leak rate difference $\|L - S\|$ (gallon per hour)	Group
1	1	1	90-95% full	d_1	Group 1
2	1	1	90-95% full	d_2	
5	3	2	90-95% full	d_5	
6	3	2	90-95% full	d_6	
9	5	3	90-95% full	d_9	
10	5	3	90-95% full	d_{10}	
13	7	4	90-95% full	d_{13}	
14	7	4	90-95% full	d_{14}	
17	9	5	90-95% full	d_{17}	
18	9	5	90-95% full	d_{18}	
21	11	6	90-95% full	d_{21}	
22	11	6	90-95% full	d_{22}	
3	2	1	50% full	d_3	Group 2
4	2	1	50% full	d_4	
7	4	2	50% full	d_7	
8	4	2	50% full	d_8	
11	6	3	50% full	d_{11}	
12	6	3	50% full	d_{12}	
15	8	4	50% full	d_{15}	
16	8	4	50% full	d_{16}	
19	10	5	50% full	d_{19}	
20	10	5	50% full	d_{20}	
23	12	6	50% full	d_{23}	
24	12	6	50% full	d_{24}	

One of the consequences of using an ATGS to test at various levels of product in the tank is that the test can only find leaks below the product level used in the test. The performance standard calls for detecting a leak from any portion of the tank that normally contains product. Ideally, the test should be run with the tank as full as it is filled in practice so that leaks can be detected from any part of the tank. If the test results were restricted to testing when the tank was half full, for example, the test could not find leaks in the upper half of the tank.

The following statistical procedure (two-sample t-test) provides a means for testing the effect of product volume on the test results.

Step 1. Calculate the average of the absolute differences in the two groups.

$$M_1 = \sum_{g_1} d_i/12 \quad \text{where } g_1 \text{ denotes the 12 subscripts in Group 1}$$

$$M_2 = \sum_{g_2} d_i/12 \quad \text{where } g_2 \text{ denotes the 12 subscripts in Group 2}$$

Step 2. Calculate the variance of the absolute differences in the two groups.

$$Var_1 = \sum_{g_1} (d_i - M_1)^2/11$$

or

$$Var_2 = \sum_{g_2} (d_i - M_2)^2/11$$

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

$$Var_p = \frac{11Var_1 + 11Var_2}{24 - 2}$$

or

$$Var_p = (Var_1 + Var_2)/2$$

Step 4. Compute the standard error, SE, of the difference between M_1 and M_2.

$$SE = \left[Var_p\left(\frac{1}{12} + \frac{1}{12}\right)\right]^{1/2}$$

$$SE = \sqrt{Var_p/6}$$

Step 5. Calculate the t-statistic:

$$t = \frac{\left(M_1 - M_2\right)}{SE}$$

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. 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 with a tank half full is not significantly different (at the 5% significance level) from the average difference between measured and induced leak rates obtained with a tank filled to 90% to 95% capacity. In other words, the amount of product, in this given range, has no significant impact on the leak rate results. Otherwise, conclude that the difference is statistically significant, that is, the system's performance depends on the amount of product in the tank.

7.4 OUTLINE OF CALCULATIONS FOR ALTERNATIVE APPROACH

This section describes the data analysis required for the alternative protocol described in Section 6.5.

The water sensor data will be identical to that obtained with the standard protocol outlined in Section 6.4. Consequently, the same data analysis will be used. Refer to Section 7.2 for the details.

7.4.1 Calculation of P(FA) and P(D)

Using the leak rate reported by the ATGS and the actual leak rate (zero for tight tank tests, measured for the induced leak rate tests), calculate the differences between the measured and actual leak rates. Calculate the mean and standard deviation of these differences as in Section 7.1.1. Perform the test for significant bias and estimate the P(FA) and the P(D) as described in that section.

Calculate the variances of the differences separately for the data from the tests on the tight tanks and those from the tests on tanks with induced leak rates. This can be done as in Section 7.3.3, except that the two groups are now defined by the leak status of the tanks and the sample sizes will not be equal. Let the subscript "1" denote the tight tank data set and "2" denote the data from the tests with induced leaks.

Let n_1 be the number of test results from tight tanks and n_2 be the number of test results from induced leak rate tests. Denote by d_{ji} the difference between measured and induced leak rates for each test, where j=1 or 2, and i=1,...,n_1 or n_2. Then calculate

$$S_1^2 = \sum_{i=1}^{n_1} (d_{1i} - \bar{d}_1)^2/(n_1 - 1)$$

and

$$S_2^2 = \sum_{i=1}^{n_2} (d_{2i} - \bar{d}_2)^2/(n_2 - 1)$$

where the summations are taken over the appropriate groups of data, and where $\bar{d}_j$ denotes the mean of the data in group j, and is given by

$$\bar{d}_j = \sum_{i=1}^{n_j} d_{ji}/n_j$$

Form the ratio

$$F = S_2^2/S_1^2$$

and compare this statistic to the F statistic with (n_2-1) and (n_1-1) degrees of freedom for the numerator and denominator, respectively, at the 5% significance level. (The F statistic can be obtained from the F-Table found in any statistical reference book.) If the calculated F statistic is larger than the tabulated F value, conclude that the data from the induced leak rate tests are significantly more variable than those from the tight tanks. If this is the case, it might impair the ability of the ATGS to detect leaks. Recompute the P(D) (see Section 7.1.3) using the standard deviation calculated from just the induced leak rate tests, S_2, to verify that P(D) is still at least 95%.

7.4.2 Limitations on the Results

The limitations on the results must be calculated from the actual test conditions. Since the conditions were not controlled, here, but were observed, the following approach is taken to determine the applicable conditions.

Size of Tank

List the tank sizes of the tests in the complete data set (all valid tests). Order the sizes from smallest to largest. Determine the 80th percentile of these ordered sizes. (That is, the smallest size just exceeded by 20% of the tank sizes.) Multiply that size by 1.25 and report the result as the maximum size to which the performance results can be extended. Note that this implies that at least 20% of the tanks must be of at least a specified size if the ATGS is intended to work on that size of tank.

Maximum Allowable Temperature Difference

Calculate the temperature difference between the product in the tank and that of newly added product for each delivery in the data set. Note that the temperature of the delivered product can be calculated from the temperature of the product in the tank immediately before delivery, the temperature of the product in the tank immediately after delivery, and the volumes of product by the following formula:

$$T_D = \frac{T_A V_A - T_B V_B}{V_D}$$

The subscript A denotes product in tank after delivery, B denotes product in tank before delivery, D denotes product delivered, T denotes product temperature, and V denotes volume.

Calculate the standard deviation of the temperature differentials and multiply this by 1.5. Report this as the maximum temperature differential for which the ATGS evaluation is valid.

When the calculations are complete, enter the results on the standard results reporting form in Appendix B. Also check the box on that form to indicate that the evaluation was done using the alternative approach.

Average Waiting Time After Filling

Use the time interval between the most recent fill or product delivery and each following test as a stabilization time. Order these times from least to greatest and determine the 20th percentile. Report this as the minimum stabilization time.

Average Data Collection Time Per Test

The tests often have a constant or nearly constant duration prescribed by the ATGS. If so, simply report this as the test data collection time. If the ATGS software determines a test time from the data, report the average test time actually taken by the test and note that the ATGS software determines the applicable test time.

SECTION 8

INTERPRETATION

Each function of the ATGS is evaluated separately based on data analysis of experimental test results. This section covers the leak detection function, water level detection function, and measurement of minimum water level change. The entire evaluation process results in performance estimates for the leak detection function of the ATGS. 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 weather conditions can occur and might adversely affect the performance of the ATGS. The performance of the leak detection function should be at least as good for tanks smaller than the test tank. However, the performance evaluation results should only be scaled up to tanks of 25% greater capacity than the test tank. The performance of the water sensor in terms of minimum detectable level and minimum detectable change are independent of the tank size. However, the volume that corresponds to these heights of water does depend on tank size. It should be emphasized that the performance estimates are based on average results obtained in the tests. 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 a test, such as a standard error for their calculated leak rate at that site, along with the leak rate and test results.

8.1 LEAK TEST FUNCTION EVALUATION

The relevant performance measures for proving that an ATGS meets EPA standards are the P(FA) and P(D) for a leak rate of 0.20 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 0.20 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 ATGS did not meet the EPA performance requirements, the vendor may want to investigate the conditions that affected the performance as described in Section 7.3, Supplemental Calculations and Data Analyses. If the stabilization time, temperature condition, or the product level can be shown to affect the performance of the ATGS, this may suggest ways to improve the ATGS. 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 ATGS does meet the performance standards.

The relationship of performance to test conditions is primarily of interest when the ATGS 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.

8.2 WATER LEVEL DETECTION FUNCTION

The minimum water level detected by the ATGS is estimated from the average threshold of detection, and the variability of the water level threshold is estimated by the standard deviation of the test data. The minimum water level that will be detected at least 95% of the time is the level to be reported. Statistically, this is a one-sided tolerance limit.

The tolerance limit calculated in Section 7.2.1 estimates the minimum water level that the ATGS can detect above the bottom of the probe. If the installation of the ATGS leaves the probe at a specified distance above the bottom of the tank (for example, 1 inch), then this minimum distance needs to be added to the reported minimum detectable water level.

8.3 MINIMUM WATER LEVEL CHANGE MEASUREMENT

Since ATG systems operate with the product at all levels of normal tank operation, the water sensor can be used to test for leaks in the event of a high ground-water level. If the ground-water level is above the bottom of the tank, there will be an inward pressure when the product level is sufficiently low, and if there is a hole in the tank, water will flow into the tank under these conditions. Based on the ability of the water sensor to detect a change in the level of water in the product, one can determine how much water must enter the tank in order for an increase in the water level to be detected. From this information, in turn, one can determine the size of a leak of water into the tank that the ATGS can detect at a given time.

The standard deviation of the differences between the change in water level measured by the sensor and the change induced during the tests is used to determine the ability of the water level sensor to detect changes in the water level. A two-sided 95% tolerance interval is then calculated for this detection ability (Section 7.2.2).

The minimum change in water level that can be detected is used to compute a minimum change in water volume in the tank. This conversion is specific to the tank size. Using the minimum change in water volume that the sensor can detect, the time needed for the ATGS to detect an incursion of water at the rate of 0.20 gallon per hour is calculated (Section 7.2.3). This calculation indicates the time needed for the water detector to identify an inflow of water at the minimum leak rate and to alert the operator that the water level has increased. If the particular ATGS has a water alarm, and if the conditions for activating the water alarm are specified, the length of time for that alarm to be activated can be calculated.

SECTION 9

REPORTING OF RESULTS

Appendix B is designed to be the framework for a standard report. There are five 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 system 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 ATGS. 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.

The fifth part of Appendix B provides a form to record the test results when evaluating the system's water sensor. The data to be recorded follow the testing protocol (in Section 6.4) to determine the minimum level of water and the minimum water level change that the system can detect.

If the optional calculations described in Section 7.3 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 7.1.4 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.

One practical limitation of the results is the size of the tank. Tests based on volumetric changes 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 25% 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 12,500 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 the ATGS must perform a test shortly after the tank has been filled. 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 ATGS. 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 system's performance. In practice, an ATGS will often test late at night when the tank is not used. This will usually result in a stabilization time as long or longer than that used in the evaluation. If an ATGS is used in a very active tank and does not do daily tests, then the required monthly test should be scheduled to have at least the minimum stabilization time used in the evaluation.

The duration of the data collecting phase of the test is another limitation of the ATGS. If a test shortens the data collection time and so collects less data, this may adversely affect the system's 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 minimum depth of water that the sensor can detect is reported. In addition, the minimum change in water level that the sensor can detect is reported. This minimum detectable change is compared to the EPA performance standard of 0.125 inch. From this minimum detectable change in water level, a minimum volume change can be calculated based on the tank size and depth of the water. A minimum time for detection is calculated and reported as the time needed for water flowing into the tank at the rate of 0.20 gallon per hour to increase the water volume enough for the sensor to detect.

The same reporting forms can be used for the alternative evaluation described in Section 6.5. The data analysis for the alternative approach is described in Section 7.4. This analysis will result in reporting observed average conditions during the evaluation. The limitations are based on the observed conditions instead of experimentally controlled conditions, but the results are reported on the same form. The Individual Test Log form should be applicable to the induced leak rate tests under the alternative evaluation procedure. However, the evaluating organization may find it more efficient to design a different data collection form for recording the data from the many tight tank tests.

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 terms, 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.

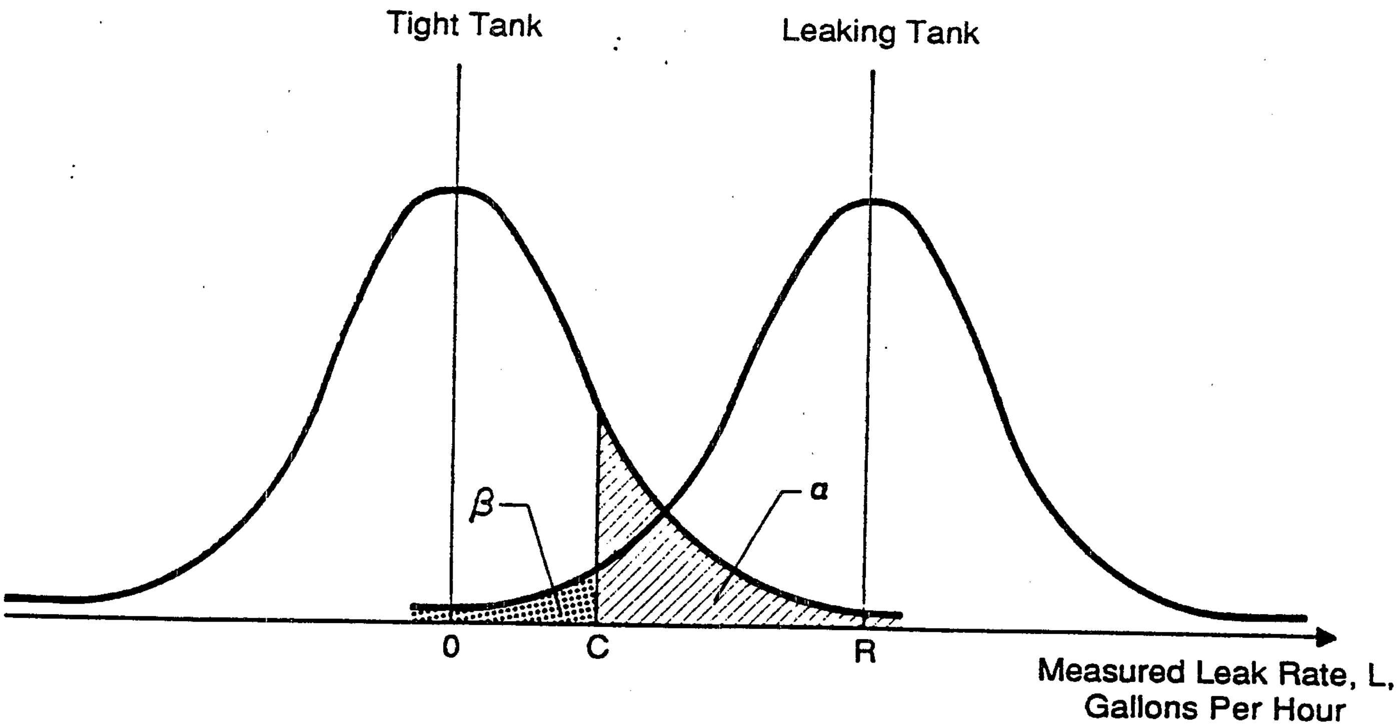
Root Mean Squared Error, RMSE: The positive square root of the mean squared error.

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.



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

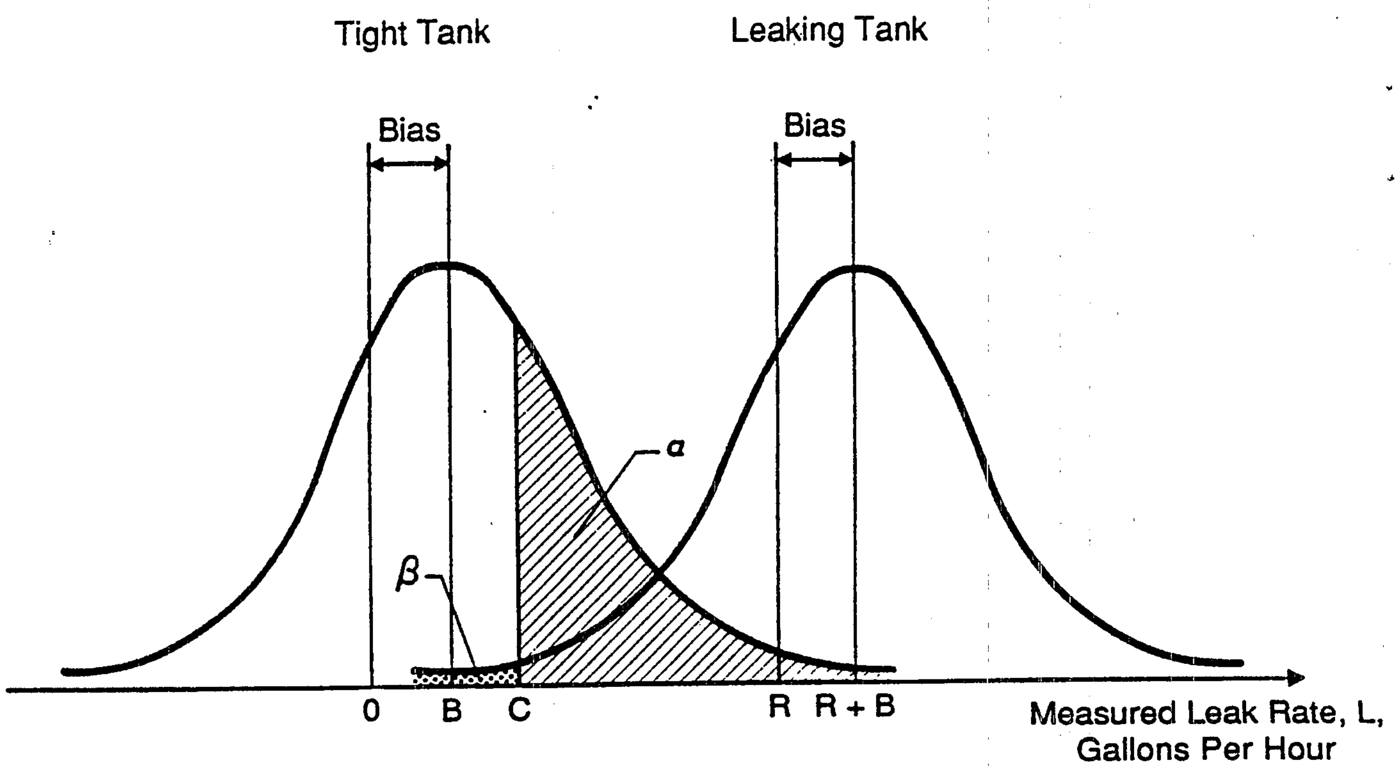
α = Probability of False Alarm, P(FA)

β = Probability of not detecting a leak rate R

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

R = Leak Rate

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

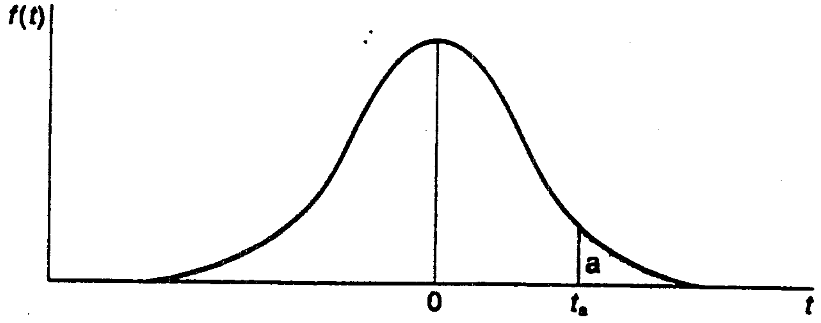
1 - β = Probability of detecting a leak rate R, P(D(R))

R = Leak Rate

B = Bias

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

Table A-1. PERCENTAGE POINTS OF STUDENT'S t-DISTRIBUTION



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 five 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--Automatic Tank Gauging System** (two pages)

2. **Description--Automatic Tank Gauging System** (six pages)

3. **Reporting Form for Leak Rate Data--Automatic Tank Gauging System** (two pages)

4. **Individual Test Log--Automatic Tank Gauging System** (five pages)

5. **Reporting Form for Water Sensor Evaluation Data--Automatic Tank Gauging System** (four 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 Automatic Tank Gauging System.** The **evaluating organization** assisted by the **vendor** will complete this form by 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 ATGS 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 during testing. It is recommended that the evaluating organization 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.

5. **Reporting Form for Water Sensor Evaluation Data.** These forms provide a template for the water sensor evaluation data. They are to be used and completed by the **evaluating organization's field crew.** It is recommended that the evaluating organization reproduce a sufficient number (at least 20 copies) of the blank form provided in this appendix and produce a bound notebook to be used in the field.

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 7.3 of the protocol), these results can be attached to the standard report. There is no reporting requirement for these calculations, however.

If the alternative EPA test procedure described in Section 6.5 was followed, then the reporting is essentially the same as that for the standard evaluation procedure. The major difference is that the Results of U.S. EPA Standard Evaluation form will be completed using the results of the calculations described in Section 7.4. A box is provided to indicate which evaluation procedure was used. Individual test logs will only be available for those tests performed under the induced leak rate conditions. All data collected on the tanks under the no-leak condition need to be reported by attaching copies of the forms on which the results were recorded. In addition, the tank test results (no-leak and induced leak rate conditions) will be summarized on the Reporting Form for Leak Rate Data. There will be no changes in the reporting of the water sensor performance since only one testing procedure is presented.

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 7.3), 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
Automatic Tank Gauging System (ATGS)

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 ATGS. This form will contain the most important information relative to the ATGS evaluation. All items are to be filled out and the appropriate boxes checked. If a question is not applicable to the ATGS, write 'NA' in the appropriate space.

This form consists of five main parts. These are:

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

ATGS Description

Indicate the commercial name of the ATGS, the version, and the name, address, and telephone number of the vendor. Some vendors use different versions of their ATGS 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 ATGS, then indicate the home office name and address of the responsible party.

Evaluation Results

The ATG system'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 7.1.2. Report P(FA) in percent. P(FA) may be rounded to the nearest whole percent.

P(D) is the probability of detecting a leak rate of 0.20 gallon per hour and is calculated in Section 7.1.3. Report P(D) in percent. P(D) may be rounded to the nearest whole percent.

The minimum detectable water level and the minimum detectable level change that the sensor can detect will have been obtained from the calculations in Sections 7.2.1 and 7.2.2.

If the P(FA) calculated in Section 7.1.2 is 5% or less and if the P(D) calculated in Section 7.1.3 is 95% or more, then check the first 'does' box. Otherwise, check the first 'does not' box. If the minimum water level change calculated in Section 7.2.2 is less than or equal to 1/8 inch, then check the second 'does' box. If the minimum water level change exceeds 1/8 inch, then check the second '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. Note, if more than one tank, product, or level was used in the testing, indicate this 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, and the total data collection time should be completed using the results from calculations in Section 7.1.4.

If the alternative evaluation procedures described in Section 6.5 has been followed, then report the results obtained from the calculations in Section 7.4.

Certification of Results

Here, the responsible person at the evaluating organization indicates which test procedure was followed and provides his/her name and signature, and the name, address, and telephone number of the organization.

Results of U.S. EPA Standard Evaluation

Automatic Tank Gauging System (ATGS)

This form tells whether the automatic tank gauging system (ATGS) 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: Automatic Tank Gauging Systems." 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.

ATGS Description

Name ______________________________

Version number ______________________________

Vendor ______________________________

____
(street address)

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

Evaluation Results

This ATGS, 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 0.20 gallon per hour leak is _____%.

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

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

Therefore, this ATGS ☐ does ☐ does not meet the **federal** performance standards established by the U.S. Environmental Protection Agency (0.20 gallon per hour at P(D) of 95% and P(FA) of 5%), and this ATGS ☐ does ☐ does not meet the **federal** performance standard of measuring water in the bottom of the tank to the nearest 1/8 inch.

Test Conditions During Evaluation

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

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 tests were conducted with the tank product levels _________ and _________ % full.

The product used in the evaluation was _________________.

Name of ATGS ______________________________
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 installing and operating the ATGS are followed.
- The tank contains a product identified on the method description form.
- The tank is no larger than __________ gallons.
- The tank is at least __________ percent full.
- The waiting time after adding any substantial amount of product to the tank is __________ hours.
- The temperature of the added product does not differ more than __________ degrees Fahrenheit from that already in the tank.
- The total data collection time for the test is at least __________ hours.
- Other limitations specified by the vendor or determined during testing:
  ____
  ____

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

Certification of Results

I certify that the ATGS was installed and operated according to the vendor's instructions and that the results presented on this form are those obtained during the evaluation. I also certify that the evaluation was performed according to one of the following:

☐ standard EPA test procedure for ATGS
☐ alternative EPA test procedure for ATGS

______________________________ (printed name)

______________________________ (organization performing evaluation)

______________________________ (signature)

______________________________ (city, state, zip)

______________________________ (date)

______________________________ (phone number)

Description of Automatic Tank Gauging System

Instructions for completing the form

This 6-page form is to be filled out by the evaluating organization with assistance from the vendor, as part of the evaluation of the ATGS. This form provides supporting information on the principles behind the system 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. ATGS 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 ATGS in the first part.

NOTE: The version is provided for ATG systems 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
Automatic Tank Gauging System

This section describes briefly the important aspects of the automatic tank gauging system (ATGS). It is not intended to provide a thorough description of the principles behind the system or how the equipment works.

ATGS Name and Version

____

Product

> Product type

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

- ☐ gasoline
- ☐ diesel
- ☐ aviation fuel
- ☐ fuel oil #4
- ☐ fuel oil #6
- ☐ solvents
- ☐ waste oil
- ☐ other (list) ______________________________

> Product level

What product level is required to conduct a test?

- ☐ greater than 90% full
- ☐ greater than 50% full
- ☐ other (specify) ______________________________

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

- ☐ yes
- ☐ no

Does the ATGS 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 (i.e., a delivery) and the beginning of a test (e.g., filling from 50% to 90-95% 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.

> 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 (explain) ______________________________

> Total time

What is the total time needed to test with this ATGS after a delivery?
(waiting time plus testing time)

______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 (explain) ______________________________

> Identifying and correcting for interfering factors

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

- ☐ system tests for water incursion
- ☐ different product levels tested and leak rates compared
- ☐ other (describe briefly) ______________________________
- ☐ no action

How does the ATGS 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 frequently 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?

- ☐ actual sample taken for each test and Ce determined from specific gravity
- ☐ value supplied by vendor of product
- ☐ average value for type of product
- ☐ other (describe briefly) ________________________________

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

- ☐ average of subsets of all data collected
- ☐ difference between first and last data collected
- ☐ from data from last ________ hours of test period
- ☐ from data determined to be valid by statistical analysis
- ☐ other (describe 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?

- ☐ 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?

- ☐ water in the excavation zone
- ☐ large difference between ground temperature and delivered product temperature
- ☐ extremely high or low ambient temperature
- ☐ invalid for some products (specify) ____________________
- ☐ other (describe briefly) ____________________

What are acceptable deviations from the standard testing protocol?

- ☐ none
- ☐ lengthen the duration of test
- ☐ other (describe briefly) ____________________

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

- ☐ product level when test is conducted
- ☐ when to conduct test
- ☐ waiting period between filling tank and beginning test
- ☐ length of test
- ☐ determination that tank deformation has subsided
- ☐ determination of "outlier" data that may be discarded
- ☐ other (describe briefly) ____________________
- ☐ none

Reporting Form for Leak Rate Data
Automatic Tank Gauging System (ATGS)

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 ATGS in its leak detection mode. 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 ATGS and the period of evaluation above the table. The version is provided for ATG systems 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 ATGS test results.

The table consists of 11 columns. One line is provided for each test performed during evaluation of the ATGS. 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 6.1 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	ATGS records
11	Measured minus induced leak rate	By subtraction

The product temperature differential (column 7) is the difference between the temperature of the product added and that of the product in the tank each time the tank is filled from 50% full to between 90% to 95% full. This temperature differential is the actual differential achieved in the field and not the nominal temperature differential. The difference can be calculated by one of two methods. If the field crew measured the temperature of the product added and that of the product in the tank just prior to filling, then take the difference between these two temperatures. If the field crew measured the temperature of the product in the tank before and after filling and recorded the amount of product added, then calculate the temperature differential based on volumes and temperatures according to the formula in Section 7.4 The data necessary for these calculations should all be provided on the Individual Test Log.

Reporting Form for Leak Rate Data

Automatic Tank Gauging System (ATGS)

ATGS 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										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										

Reporting Form for Leak Rate Data

Automatic Tank Gauging System (ATGS)

ATGS 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)
25										
26										
27										
28										
29										
30										
31										
32										
33										
34										
35										
36										
37										
38										
39										
40										
41										
42										
43										
44										
45										
46										
47										
48										

Individual Test Log
Automatic Tank Gauging System (ATGS)

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 including the trial run (at least 25.) The information on these forms is to be kept blind to the vendor during the period of evaluation of the ATGS.

The form consists of eight parts. These are:

1. Header information
2. General background information
3. Conditions before testing
4. Conditions at beginning of test
5. Conditions at completion of testing
6. Leak rate data
7. Additional comments, if needed
8. 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 <u>not</u> 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 ATGS. Include a version identification if the ATGS uses different versions for different products or tank sizes. The vendor's recommended stabilization period (if applicable) 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.

Note that the term "conditioning" refers to all activities undertaken by the evaluating field crew to prepare for a test. As such, the term refers to emptying or filling the tank, heating or cooling product, and changing the leak rate. In some cases, all of the above is performed, in others, only one parameter might be changed.

Special Case Reporting

Use the Individual Test Log form to record all data pertaining to the **trial run.** Next, when emptying the tank to half full and then filling to 90% to 95% capacity before performing the **first test,** note on the form that this has been done. Simply indicate on page 1 the dates and time periods and volumes when product was removed and then added. This is the only case where emptying and filling are performed in sequence without a test being performed in between. Record all other information (e.g., temperature of product added) as applicable.

Conditions at Beginning of Test

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 ATGS starts the actual testing, record the date and time that the ATGS 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 (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 recorded by the ATGS for that test.

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.

Name of Field Operator ______________________________

Signature of Field Operator ____________________ **Test No.** __________

Date of Test __________

Individual Test Log

Automatic Tank Gauging System (ATGS)

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

ATGS 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

If applicable, 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 conditioning test tank

- Product ______ inches ______ gallons
- Water ______ inches ______ gallons

Temperature of product in test tank before conditioning ______ °F ☐ or °C ☐

Stick reading after conditioning test tank

- Product ______ inches ______ gallons

Amount of product (check **one only**):

- ☐ no change in product level
- ☐ removed from tank (by subtraction) ______ gallons
- ☐ added to tank (by subtraction) ______ gallons

Name of Field Operator ____________________

Signature of Field Operator ____________________ **Test No.** __________

Date of Test __________

Conditions Before Testing (continued)

If product was added

Temperature of product added to fill test tank to test level

_______ °F ☐ or °C ☐

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

Date and time at completion of conditioning _________ date _________ military time

---

Conditions at Beginning of Test

Date and time at start of ATGS test data collection

_________ date _________ military time

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

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 ☐

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			

Name of Field Operator ____________________

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			

Reporting Form for Water Sensor Evaluation Data
Automatic Tank Gauging System

This 4-page form is to be filled out by the field crew of the evaluating organization when evaluating the performance of the ATGS water sensor. A separate form is to be filled out for each individual test replicate (at least 20). The form provides a template to record the data and consists of three parts. These are:

1. Header information
2. Template for recording the data obtained to determine the minimum water level that the sensor can detect in each replicate (page 1)
3. Template for recording the data obtained when determining the minimum water level change that the sensor can detect in each replicate (pages 2-4).

Header Information

The header information is to be repeated on all four pages, if used. If a page is not used, cross it out and initial it.

Indicate the commercial name of the ATGS. Include a version identification if the ATGS uses different versions for different products or tank sizes. Complete the date of test and product type information. Indicate the test (replicate) number on each sheet for each test.

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.

Minimum Detectable Water Level Data

Follow the test protocol described in Section 6.4 and record all data on page 1 of the form. When the sensor first detects the water, stop testing for this replicate. The minimum detected water level is calculated from the total amount of water added until the first sensor response and the geometry of the probe and the cylinder. This calculation can be done after all testing is completed and is generally performed by the statistician or other person responsible for data analysis.

Minimum Detectable Water Level Change

After the first sensor response, continue with the test protocol as described in Section 6.4. Record all amounts of water added and the sensor readings at each increment using pages 2 to 4 as necessary. The data to be entered in the third, fifth, and sixth columns on pages 2, 3, and 4 of the form will be calculated once all testing is completed. Again, the person responsible for the data analysis will generally compute these data and enter the calculated minimum water level detected in that replicate run.

Reporting Form for Water Sensor Evaluation Data
Automatic Tank Gauging System

ATGS Name and Version: ______________________________

Date of Test: ________________ Name of Field Operator: ________________

Product Type: ________________ Signature of Field Operator: ________________

Test No. ___

Increment No.	Volume of Water Added (mL)	Sensor Reading (inch)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
Total Volume (mL)		

Calculated Minimum Detectable Water Level (inches)

NOTE: This form provides a template for data reporting. Since the number of increments is not known from the start, the length of the report form will vary from test to test.

Reporting Form for Water Sensor Evaluation Data
Automatic Tank Gauging System

ATGS Name and Version: ______________________________

Date of Test: ________________ Name of Field Operator: ________________

Product Type: ________________ Signature of Field Operator: ________________

Test No. ___

Increment No. A	Volume of Water Added (mL) B	Calculated Water Height Increment, h (in) C	Sensor Reading (in) D	Measured Sensor Increment (in) E	Increment Difference Calc.–Meas. (in) C – E
Minimum water level detected, X:			**inches (from page 1)**		
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					

NOTE: This form provides a template for data reporting.
Use as many pages as necessary.

Reporting Form for Water Sensor Evaluation Data
Automatic Tank Gauging System

ATGS Name and Version: ______________________________

Date of Test: ____________________ Name of Field Operator: ____________________

Product Type: ____________________ Signature of Field Operator: ____________________

Test No. ___

Increment No. A	Volume of Water Added (mL) B	Calculated Water Height Increment, h (in) C	Sensor Reading (in) D	Measured Sensor Increment (in) E	Increment Difference Calc.–Meas. (in) C – E
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					
41					
42					
43					
44					
45					
46					
47					
48					
49					
50					

NOTE: This form provides a template for data reporting.
Use as many pages as necessary.

Name of ATGS ______________________________
Version ______________________________

Limitations on the Results (continued)

- The difference between added and in-tank product temperatures is no greater than + or - ______ degrees Fahrenheit.
- The waiting time between the end of filling and the start of the test data collection is at least __________ hours.
- The total data collection time for the test is at least __________ hours.

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

Certification of Results

I certify that the ATGS was installed and operated according to the vendor's instructions and that the results presented on this form are those obtained during the evaluation. I also certify that the evaluation was performed according to one of the following:

☐ standard EPA test procedure for ATGS
☐ alternative EPA test procedure for ATGS
☐ equivalent test procedure for ATGS (describe below or reference document)

____
____
____
____
____
____
____

____
(printed name)

____
(signature)

______________________________ ______________________________
(organization performing evaluation) (city, state)

______________________________ ______________________________
(date) (phone number)