MRI REPORT

Evaluation Protocol for Continuous In-Tank Leak Detection Systems

MRI Project No. 3453-M(03)

April 7, 1995

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PREFACE

This report was prepared for Veeder-Root by Midwest Research Institute (MRI) under Project No. 3453-M. This report contains an evaluation protocol for testing continuously operating in-tank leak detection systems for underground storage tanks to see whether the system under test meets the EPA performance requirements. The current document is a revision of the original document, dated June 3, 1994. This revision incorporates changes developed as a result of an extensive series of comments solicited by the State of California Water Resources Board. This protocol was developed by considering the requirements specified in the forward to existing EPA protocols. It used approaches found in two existing protocols as well as specifications unique to the continuously operating feature of developing technologies. It represents a formalization and generalization of test procedures developed and used by MRI in previous projects (MRI Project Nos. 3133 and 3453-02) for Veeder-Root. Mr. Robert Hart served as the contract technical manager. Dr. Flora served as project leader.

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April 7, 1995

ACKNOWLEDGMENTS

This document was written primarily by Dr. J. D. Flora, Jr., of MRI, with assistance and review by Dr. W. D. Glauz and Ms. Karin Bauer of MRI. Technical review was provided by Philip Durgin, then Senior Research Scientist at Veeder-Root, who chaired the Underground Storage Tank Section of ASTM under E50, Dr. H. Kendall Wilcox, of Wilcox Associates, who chaired the Statistical Inventory Reconciliation Task Group, and Mr. Randy Nelson, of EPA Region 7, who chaired the EPA Work Group on evaluation of leak detection methods for underground storage tanks. The contribution of these technical reviewers is gratefully acknowledged.

We would also like to acknowledge the California Water Resources Board, particularly James Giannopoulos, David Holtry, and Shahla Farahnak, who organized a technical seminar on the review of this protocol. This revision incorporates the technical changes agreed upon at that seminar.

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SECTION 1

INTRODUCTION

EPA regulations[1] specify performance standards for leak detection methods for underground storage tanks. In particular, monthly monitoring systems must be able to detect a leak of 0.20 gallon per hour or 150 gallons per month with a probability of detection, PD, of [at least] 95% while operating at a probability of false alarm, PFA, of [no more than] 5%. These leak detection systems must demonstrate that they can meet these performance standards. The EPA has provided a series of seven standard evaluation procedures for leak detection methods.[2] Six of these EPA protocols refer to leak detection methods mentioned specifically in the regulations. The other one, for Statistical Inventory Reconciliation (SIR) methods, was developed by EPA for a method that qualifies under the "other method" category.

New technologies for leak detection can qualify under this other method category. In order to qualify, new leak detection methods must meet the performance standard given above. These new methods must demonstrate that they meet the performance standards. EPA, in the Forward to the leak detection protocols, has provided ways for this demonstration to be made:

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,

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[1] 40 *CFR* Part 280, Subpart D.

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

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

This last method is expanded on in the EPA Forward. The following section is quoted from that document.[4]

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. . . . 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 volumetric tank tightness testing, for example, this will mean testing under both 0.0 gallon per hour and 0.10 gallon per hour leak rates. In the case of 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 method under at least as many different environmental conditions as the corresponding EPA test procedure.

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

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[3] "Standard Test Procedures for Evaluating Leak Detection Methods: Automatic Tank Gauging Systems," U.S. EPA/530/90-006, Forward, page iv, March, 1990.

[4] *Ibid.*

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.

New technologies currently being brought to the market require development of new protocols. Some of these new technologies are combining the automatic data collection features of Automatic Tank Gauging Systems (ATGS) with the sophisticated statistical data analysis used in Statistical Inventory Reconciliation (SIR) systems. This allows the new systems to monitor the tank continuously, using data collected continually that is reviewed for adequacy. These systems then can operate without interfering with normal tank operation. These new technologies are collectively referred to as "Continuous In-Tank Leak Detection Systems" abbreviated CITLDS, throughout the rest of the document.

Currently there are three types of such continuous systems that are reaching the market. These three types are referred to here as "Continuous Automatic Tank Gauging Systems (Continuous ATGS)," "Continual Reconciliation," and "Automatic Monthly Inventory Control." Other types may be developed in the near future. The basic operation of each of the three current types is described next.

"Continuous ATGS" systems use an ATG probe to collect data continually and combine this with software to identify time intervals when there is no activity in the tank and the data are stable enough for analysis. An algorithm then combines data from a number of such periods until there is enough evidence to make a determination about the leak status of the tank. These systems are designed to meet the monthly monitoring performance standard of detecting a leak of 0.20 gallon per hour or 150 gallons per month with 95% probability and 5% false alarm. These systems typically test only the tank, not the piping.

"Continual Reconciliation" systems being developed combine continuous product level and temperature monitoring from the tank with data from dispensing meters. Data from delivery records may also be included. In addition, these systems may address leaks or unexplained losses of product from the tank vessel, the pressurized lines, or a combination to monitor the tank and line system. These systems allow a combination of monitoring data from a static tank and inventory data from a dynamic tank to be combined in monitoring the system for a leak. These systems are also designed to meet the monthly monitoring performance standard of detecting a leak of 0.20 gallon per hour or 150 gallons per month with 95% probability and 5% false alarm.

"Automatic Monthly Inventory Control" systems emphasize continuous inventory monitoring as a tank management tool, both for business inventory and to meet or replace EPA requirements for monthly (manual) inventory monitoring combined with another leak detection method. These are intended to be business management tools while providing an automatic method of meeting daily inventory record and monthly inventory reconciliation requirements, but are not designed to be stand alone leak detection methods. These systems are, however, designed to satisfy the EPA requirement for manual inventory of identifying a loss of 1% of monthly throughput plus 130 gallons.

All of these systems are designed to operate continuously while the tank is in normal operation. They may use different combinations of data and may be applicable to different performance standards. However, they share the characteristic of monitoring tank data continuously for days, weeks, or months, and then providing leak detection capabilities on demand once the initial data requirements are met.

These systems have common characteristics that distinguish them from other forms of leak detection. They may use many data items, including product height, product temperature, presence or depth of water, the tank chart or geometry, meter readings, delivery records, among others, collected continually. In addition, their requirements for extensive data collected over days or weeks, will require a special approach to their evaluation.

This document presents an evaluation protocol designed for continuous in-tank leak detection systems (CITLDS). It combines approaches from the ATGS and SIR protocols in ensuring that the 5 points quoted above are met. Data required from each type of system are listed in Section 5.

SECTION 2

SCOPE OF APPLICATION

This document presents a standard protocol for evaluation of continuous in-tank leak detection systems (CITLDS). These systems are designed to allow the tank to operate continuously or nearly continuously without interruption for leak detection tests. They typically have some sensors permanently installed in the tank, combined with a microprocessor in a console. In addition, they may be connected to the dispensing meters, allowing for automatic recording and use of dispensing data. There may also be a provision for direct input of data from a keyboard or pad, to allow for entry of delivery receipts, for example.

Currently there are three types of such continuous systems that are reaching the market. These three types are referred to as "Continuous ATGS," "Continual Reconciliation," and "Automatic Monthly Inventory Control." Other types may be developed in the near future. The basic operation of each of these three types is described next.

"Continuous ATGS" systems use an ATG probe to collect data continually and combine this with software to identify time intervals when there is no activity in the tank and the data are stable enough for analysis. An algorithm then combines data from a number of such periods until there is enough evidence to make a determination about the leak status of the tank. This type of system functions like an ATGS except that it does not require that the tank be taken out of service for a set period of several hours whenever a test is to be done. Instead, it uses data from shorter stable time periods and combines the results to estimate a leak rate and perform a test. The system may default to a standard or shut down ATG test (requiring the tank to be out of service for a few hours) at the end of the month if sufficient good quality have not been obtained over the month. These systems are designed to meet the monthly monitoring performance standard of detecting a leak of 0.20 gallon per hour or 150 gallons per month with 95% probability and 5% false alarm. They test the tank vessel itself.

The operation of a Continuous ATGS is described to distinguish it from a regular ATGS. A Continuous ATGS may use the same probe in a tank as a similar ATGS to collect temperature and level measurements and report them to a console. However, whereas an ATGS requires a specified waiting time after a delivery and a further period of no dispensing or delivery operations while it conducts a leak test (a shut down period), the Continuous ATGS is designed to avoid such specified shut downs of normal tank operation. It does this by collecting data continuously. The software identifies segments of stable data, stores these data, and combines numerous such segments to produce a leak rate estimate that is used to determine whether the tank is tight or not. For high use tanks, a period of several days or weeks may be needed for the system to acquire sufficient data to make its determination. Once an adequate data base is obtained, a test can be conducted at any time by operator request. The test is based on the most recent data available. As new data are accumulated, older data are dropped, so that the leak rate estimate and test are based on the most current data. The total duration of the test period and the amount of data actually used in calculations will vary with the tank use pattern, the type of test being run (e.g., monthly or annual), and the quality of the current data.

"Continual Reconciliation" systems being developed combine continuous product level and temperature monitoring from the tank with data from dispensing meters. Data from delivery records may also be included. In addition, these systems may address leaks or unexplained losses of product from the tank vessel, the pressurized lines, or a combination to monitor the tank and line system. These systems allow a combination of monitoring data from a static tank and inventory data from a dynamic tank to be combined in monitoring the system for a leak. These systems are also designed to meet the monthly monitoring performance standard of detecting a leak of 0.20 gallon per hour or 150 gallons per month with 95% probability and 5% false alarm.

Continual reconciliation systems are related to statistical inventory reconciliation (SIR) systems. However, while SIR uses daily inventory records in the statistical analysis, the continual reconciliation systems use much more frequent inventory data. In addition, the continual reconciliation system may use initial data to develop a meter map, identifying meters with the tanks they draw product from. Furthermore, the continual reconciliation system may use data from the first month or so to do a tank calibration for each specific tank, providing a more accurate analysis of the data. Thus, the continual reconciliation systems differ from SIR systems in collecting and using more data from the tank records and in using much more frequent reconciliations as well as collecting some of the data automatically while also allowing for manual input.

"Automatic Monthly Inventory Control" systems emphasize continuous inventory monitoring as a tank management tool, both for business inventory and to meet or replace EPA requirements for monthly (manual) inventory monitoring combined with another leak detection method. These are intended to be business management tools while providing an automatic method of meeting daily inventory record and monthly inventory reconciliation requirements, but are not designed to be stand alone leak detection methods. These systems are, however, designed to satisfy the EPA requirement for manual inventory of identifying a loss of 1% of monthly throughput plus 130 gallons.

The automatic monthly inventory control is designed to replace manual inventory reconciliation. It does so by providing an automated way to acquire the data. A microprocessor then produces the required inventory reconciliation report, including calculation of the daily differences, the monthly reconciliation, and the comparison number of 1% of throughput plus 130 gallons.

This nature of operation of a CITLDS, using data collected continually both when the tank is not actively in use and when dispensing and deliveries occur, means that third-party testing at a specialized test facility is impractical. In fact, because CITLDS systems are explicitly designed to work in the presence of ongoing operations, testing under normal tank operation is a critical part of the evaluation of these leak detection systems.

The aim of this protocol is to provide a test plan to determine whether a vendor's CITLDS meets the EPA performance standards for leak detection. The protocol uses data collected from operating installations with the CITLDS installed in the field. The data from such installations may be collected in a computer file and the file used to test the performance of the method as is done with statistical inventory reconciliation methods. The basic approach assumes that the CITLDS produces an estimated leak rate that can be compared numerically to an induced leak rate. However, if the CITLDS only produces a qualitative (pass or fail) result, the protocol also provides for evaluation on that basis.

This protocol provides calculations to estimate the probability of false alarm, PFA, and probability of detection, PD(R), where R is a specified leak rate (typically 0.10 or 0.20 gallon per hour). If the CITLDS reports quantitative data, the reported leak rates are compared to induced leak rates. The differences are analyzed using a normal probability model for the errors to estimate the PFA and PD(R). If the CITLDS reports qualitative data the PFA and PD(R) are estimated directly as the proportion of incorrect leak determinations under the tight tank condition and the proportion of correct identifications of a leak of specified size, respectively.

Subject to the limitations listed on the Results of Evaluation Form, the results of this evaluation can be used to prove that a CITLDS method meets the requirements of 40 *CFR* Part 280. The Results Form reports the testing conditions. A list of required data elements for each type of CITLDS is given in Section 5.

SECTION 3

SUMMARY

The evaluation protocol for CITLDS calls for an evaluating organization to arrange with the vendor for the CITLDS system to be installed in a number of tanks at different geographical locations. The tanks used for these installations should have some independent evidence that they are tight to prevent any problem with the evaluation being based on data from leaking tanks. Satisfactory evidence that the tanks are tight is provided by indication of a tight tank from an independent leak detection method and confirmation of a tight result from the CITLDS system.

These installations are used to run tests in the tight tank condition and collect data that can be used for simulation of leaks. The geographical dispersion of the tanks should be chosen to provide a variety of temperature conditions for the data base. The tanks should be of a variety of sizes and should include a variety of monthly product throughputs.

The data collected from each tank and used by the CITLDS to perform its test are collected in computer files. For a quantitative CITLDS that reports an estimated leak rate, a minimum of 100 such data files are collected. For a qualitative CITLDS, that only reports a tight or leak indication, at least 240 data files are collected. The evaluating organization will select a number of files at random for the evaluation, at least 45 for a quantitative system and 120 for a qualitative system. For a quantitative system the selected data bases will be randomly divided into sets with different simulated leak rates. For a qualitative system the data bases will be randomly divided into two groups with approximately half of the data bases used as tight tank records and the rest used as leaking tank records with the target leak rate simulated.

Note that while a Continuous ATGS and a continual reconciliation system could be qualitative, the automatic monthly inventory control is inherently quantitative. This is because it is designed to meet the EPA requirement of monthly inventory reconciliation that requires daily calculation of overage or shortage and monthly computation of the cumulative for comparison with the EPA standard of 1% of throughput plus 130 gallons.

Because of the anticipated long duration (days or weeks) of data collection for these systems, it will generally not be practical to physically induce leaks in the tanks by removing product during the entire test period. If this is the case, the evaluation will require that the data collected by the system be logged and stored as a computer file. These records will then be used as the data set. Leaks will be mathematically simulated in some of the tank data records, while others will be used as recorded. The data records will be submitted to the system's software as if the data were being received from an operating tank. The system's algorithm would then provide the same analysis as if it were on line. Methods of simulating the leak must be appropriate to the system and the type of leak and are discussed in Section 6. Of course, if it is feasible, leaks may be physically induced at some of the tank sites by removing product from the tank and the results from the CITLDS compared directly to the amount of product removed.

Some of the testing of CITLDS systems could be done at a specialized test facility. However, an inherent part of these systems is their ability to operate during routine tank operations, particularly at tanks that operate on a 24-hour basis. Some types of CITLDS systems use part of the operations as an inherent part of their test. It is difficult and time consuming to simulate such operations at a test facility. Consequently, the protocol requires that some of the testing must be done using operating tanks with characteristics similar to those of the population for which the system is intended to be used. Limiting testing at a test facility to about 3 weeks of operation and assuming that at most one test could be run per day would suggest a practical limit of at most 15 tests at a specialized facility as part of an evaluation. To demonstrate that the CITLDS works in a variety of situations, testing must be done in a variety of tanks and operating conditions. A limit of at most 15 tests at any one tank is imposed to help assure an adequate distribution of tanks and conditions.

The method of simulating the leaks will depend on the type of CITLDS system. The method of simulating leaks for Continuous ATGS may differ from that for continual reconciliation. One method is appropriate for tank leaks, and another for line leaks. Approaches to leak simulation are described in Section 6.

The data base with simulated leaks is used with the software of the CITLDS to produce the measured leak rates. These measured leak rates are then compared with the simulated leak rates introduced into each data file. The comparison of these measured and actual leak rates is used to estimate the performance of the CITLDS system.

For a quantitative system the comparison is made on the basis of the difference between the estimated and simulated leak rates. These differences are analyzed with a statistical model to estimate the probability of false alarm, PFA and the probability of detection, PD of the target leak rate.

For a qualitative system, the proportion of tight tanks incorrectly identified as leaking is used to directly estimate the PFA. A confidence interval for this proportion is also constructed. Similarly, the PD is estimated directly as the proportion of data bases with a simulated leak that were correctly identified as leaking by the CITLDS.

SECTION 4

SAFETY

The evaluation consists of analysis of data collected from field installations of the CITLDS. Thus most of the evaluation will involve office work and calculations and for this no special safety considerations apply. It is possible that some field data collection may involve operating the CITLDS or dealing with the product stored in the underground storage tanks. Typically such data collection would involve retrieving data from the microprocessor. This might be done via telephone using a modem or might involve a data transfer to another computer or external disk. All appropriate safety protocols for using the CITLDS or related computer equipment should be followed, in particular, the use of electrical connections around potentially flammable liquids should be considered.

The instructions for data collection specified by each vendor of the CITLDS should address the safety issues involved with collecting these data. In addition, the operating procedures for the device should address the safe installation and operation of the device. The intrinsic safety of the device for its intended use is the responsibility of the vendor.

This test procedure only addresses the issue of the method's ability to detect leaks. It does not address testing the equipment for safety hazards. The manufacturer needs to arrange for other testing for 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

The evaluation uses data collected during the operation of the system in the field. A computer and associated data recording and transfer peripherals will be needed. Most likely, the data collected and analyzed by the system will need to be logged and stored for use on a separate computer. Thus, a means of recording or transferring the data base from each tank record from the CITLDS system to an electronic data storage or transfer medium will be needed. A computer system capable of using the data in an analysis will also be needed.

Some of the testing of CITLDS systems could be done at a specialized test facility. However, this protocol requires that some of the testing must be done using operating tanks. The degree to which a test facility may be used depends somewhat on the type of CITLDS. For a continuous ATGS up to 15 tests might be run at a test facility, if the system could complete a test in 1 day. However, a continual reconciliation system would typically require a month of normal operations data for a test. Similarly an automatic monthly inventory control system requires a month of inventory data for its operation. At most one test at a test facility would seem to be a practical limit for these latter two types, and that would require the continuous simulation of an operating tank.

If a special test facility is used, the test tank should be equipped with a submersible pump of the type generally used in pressurized piping systems. Some CITLDS systems also monitor for leaks in pressurized lines. The reason for requiring a submersible pump rather than a suction pump is that submersibles are the type generally found in dispensing operations and is needed to provide a pressurized line. In testing at a specialized facility, this type of pump should be utilized to mimic the real world conditions as closely as possible.

A method of simulating a leak in an operating tank in which the system is installed may be needed. This would require inducing or simulating the leak over an extended period of time, perhaps days or weeks. If physical leak simulation is to be accomplished, it will require a means of removing product from the tank and transferring it to a storage container capable of safely holding enough of the product so that the system can run continuously for a day or so. The amount of product to be removed would be on the order of 5 gallons per day, corresponding to a leak rate of 0.2 gallon per hour. In addition, the leak simulation system must be capable of simulating the leak at a controlled rate and a method of accurately measuring the actual leak simulated must also be available. Further, a means of keeping the fact that a leak was being simulated and the amount of product withdrawn confidential from the vendor would be necessary.

Physical leak simulation can be accomplished by use of a peristaltic pump, controlling the flow rate to be constant. Alternatively, an orifice type simulator can be installed in the tank. The product would have to be regularly or continuously removed from the orifice simulator with some sort of a pump also. With either type of simulator, the product will need to be pumped to a holding tank or container. Installation and use of a leak simulator system at a field site will have to be individually designed to accommodate to the operations at that site.

Because of the extensive data requirements and the long length of time needed for collecting the data, it is anticipated that the evaluation will generally be based on using test data logged by computer from several sites. The data requirements for the data files collected are summarized below for each type of system.

Continuous ATGS

The Continuous ATGS systems must provide certain minimum data elements in their computer file. It is expected that data will be logged frequently, typically every few seconds or at least once per minute. At each time the data recorded in the log must include

Date and time stamp for each record
Product level
Product temperature
Date, time, and amount of each delivery

Note that if the time of delivery, amount of delivery, and the temperature of the delivered product and that in the tank are available by other means, then the temperature data items are not needed in the data record that is logged every few seconds.

In addition, for each tank record basic data about the tank are required. These include the size of the tank, the product in the tank and the thermal coefficient of expansion used, the construction of the tank, and the method of converting from product level to product volume for that tank.

Continual Reconciliation

The Continual Reconciliation systems must provide certain minimum data elements in their computer file. It is expected that product level and meter data will be logged frequently. Delivery of product to the tank will be recorded when it occurs. Each entry must be time stamped to include the date and time. The data recorded in the computer log must include

Date and time stamp for each record
Product level
Temperature of product
Meter reading
Dispensing status
Date, time, and amount of each delivery

Note that if the time of delivery, amount of delivery, and the temperature of the delivered product and that in the tank are available by other means, then the temperature data items are not needed in the data record logged every few seconds.

In addition, for each tank record basic data about the tank are required. These include the size of the tank, the product in the tank and the thermal coefficient of expansion used, the construction of the tank, and the method of converting from product level to product volume for that tank.

Automatic Monthly Inventory Control

Automatic Monthly Inventory Control systems will automatically record data on a daily basis. A computer log should be used to store the data that are recorded automatically by the system. Data that are entered by the operator should be supplied separately to the evaluating organization for entry. The data to be included in the computer log include all those data that are recorded automatically by the system. These include

Date and time stamp for each automatic entry
Product level (if recorded automatically)
Product temperature (if recorded automatically)
Meter readings (if recorded automatically)
Delivery amount (if recorded automatically)

In addition, for each tank record basic data about the tank are required. These include the size of the tank, the product in the tank, the construction of the tank, and the method of converting from product level to product volume for that tank. Note that the product temperature is not required for the reconciliation, but product temperature in the tank before delivery and after delivery or the temperature of the product delivered would be needed to document the temperature conditions of delivery. At least one of the product level or the meter readings must be automatically recorded (both may be). The delivery amounts may be automatically recorded or entered by hand. The date and time recorded for hand entered data should also be available.

SECTION 6

TEST PROCEDURE

Continuous leak detection methods typically require a long period of normal tank operation to conduct the test. Consequently, testing of these systems at a special test facility is unlikely to be practical. The length of the data record required may range from a day to nearly a month or more for an annual tightness test, so physically withdrawing product from the tanks at a constant rate to simulate leaks may be impractical. Further, these systems are generally designed to work with the normal operation of the tank. An adequate test of the system must include its function with normal tank operations.

This evaluation protocol is based on a combination of the alternative method for evaluating an automatic tank gauging system[5] and the protocol for evaluating a statistical inventory reconciliation system.[6] The data base of tank records used in the evaluation should be collected similarly to the alternative method for an ATG. Since it is expected that it will generally not be feasible to physically remove product from a tank over an extended period to induce or simulate a leak, methods similar to those described in the EPA test method for SIR are appropriate. The reporting format is a combination of the relevant items from the ATG and SIR protocols, augmented with some additional data specific to CITLDS.

This protocol must remain flexible so that it can be used for different systems. For a Continuous ATGS type of CITLDS or a Continual Reconciliation type of CITLDS, a single test with a physically simulated leak is recommended, but not required. This may be at an operating tank or at a special test facility. Operation of a Continual Reconciliation CITLDS may make physical simulation of a leak feasible only at a field site. For an Automatic Monthly Inventory Control type of CITLDS, no physical leak simulation is required because of the different performance specification for this system. (It is not a stand-alone leak detection system.)

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[5] "Standard Test Procedures for Evaluating Leak Detection Methods: Automatic Tank Gauging Systems," EPA/530/UST/90-006, March 1990, Section 6.5.

[6] "Standard Test Procedures for Evaluating Leak Detection Methods: Statistical Inventory Reconciliation Methods," EPA/530/UST-90-007, June 1990, Section 6.

This protocol requires two types of testing for a Continuous ATGS. One type of test is based on field data from operating installations. The other type is physical leak simulation, which may be done at an operating installation or at a special test facility. The purpose of the physical leak simulation is to demonstrate that the probe adequately responds to loss of volume from a tank. If the CITLDS system uses probes or measuring devices that have been developed and evaluated as part of a tank tightness test method or an ATGS system, the requirement for physical leak simulation may be satisfied by referencing the appropriate evaluation report. If entirely new measurement technology is being employed, that has not been previously evaluated with an EPA protocol, then a limited series of physical leak simulation tests under controlled conditions is required. These follow the shut down mode of testing for an ATG and are detailed in Section 6.2.2. Testing at a test facility should not require more than 3 weeks. The types of testing appropriate vary with the type of CITLDS. Details of different approaches are in Section 6.2.

Testing done at a special test facility may be done with any fuel type. However, the total series of tests must include at least 50% of the tests run with tanks containing gasoline (unless application is limited to non-gasoline products). In computing the tank size limitation, include tank sizes for all tests, including those at the test facility tank (if a test facility was used) in calculating the 80th percentile.

Tests at a special test facility should simulate dispensing using a submersible pump. The reason for this is that pressurized piping systems using submersible pumps are typical in the field. The submersible also disturbs the product surface and to some extent heats the product during its operation. The conditions at the test facility should mimic those in the field as closely as possible and so should include a submersible rather than a suction pump. The dispensing should follow a pattern typical of a high-throughput tank. A standard dispensing schedule for a 24-hour period is provided in Table 2. This schedule was developed from records from an operating tank and corresponds to a monthly throughput of about 80,000 gallons. The schedule in Table 2 may be repeated on a 24 hour cycle for one test. Additional tests at a special test facility should use different dispensing schedules. These may be obtained by recording the dispensing schedule from one of the operational test sites. Again, a 24 hour dispensing cycle may be repeated for as many days as needed to obtain a completed test. It should be emphasized that the dispensing schedule used at a test facility should be derived from an actual operating schedule and should not be an artificially constructed schedule. A different, but real, pumping schedule should be used for each full test at a special test facility.

6.1 DATA BASE DEFINITION

The CITLDS should be installed in at least 5 sites and in at least 10 different tanks. Sites and tanks should be selected to provide a geographical distribution, climatic variability, and size and throughput ranges as well as a variety of product types. Each tank should have some independent evidence that it is tight. Multiple tests may be run on each tank using data from different times, but no more than 15 tests should be from the same tank system, including a special test facility. If the CITLDS is intended for use on manifolded tank systems as well as single tanks, at least 25% of the data and no more than 75% of the data should be from manifolded tank systems.

A test using a CITLDS consists of a data collection period that may require several days or weeks. This is the period of tank operation needed for the CITLDS to collect enough data from intermittent, stable periods in the tank so that the CITLDS can produce a valid estimate of the leak rate. For the evaluation, a test can be defined as this data collection period, accompanied by the result of the CITLDS test. Test periods for the evaluation need to be non-overlapping periods, so that the results from each test are based on separate data.

For testing at a test facility, a test consists of the time from turning on the CITLDS and initiating a dispensing schedule until the CITLDS has concluded a leak test with a valid result. At that time, the CITLDS should be reset to start a new test. A new simulated leak should be established and the next dispensing schedule started. Each such facility test will become one test record in the final data base used for evaluation.

The test plan should use approximately equal numbers of tight tank tests and each of the nominal leak rates. Slightly more tight tank tests than any given leak rate are recommended. This recommended schedule is better than that of the alternative ATG procedure in that it is more stringent in evaluating the system's performance when there are leaks. Note that tests done at a special test facility will generally have leaks induced.

The procedure for establishing a data base for the CITLDS evaluation calls for recording several data items:

1. The temperature of product in the tank prior to each delivery,

2. The time and date of each delivery,

3. The temperature of product in the tank following each delivery (taken 30 minutes to 1 hour after completion of the delivery,

4. The amount of product delivered at each delivery,

5. The tank size, type of tank, and product,

6. The starting date and time, the duration, and results of each test,

7. The monthly throughput for each test period.

These items need special consideration in view of the continuous operation of the CITLDS system. It is anticipated that the CITLDS will measure or identify each of these items in its normal operation. However, it may be necessary to arrange to specifically include the items in a computer log.

There will typically be multiple deliveries during a test period. The data items 1 through 4 have to be determined for each delivery during the period of the test on each tank. Items 1, 3, and 4 are used to calculate the temperature of the product added to the tank during the delivery. (If available, the temperature of the delivered product could be used instead, but this is typically not available.) The difference between the temperature of the product in the tank and that of the product delivered is to be calculated for each delivery. The standard deviation of the temperature differences between the product in the tank and that just delivered will be calculated and used to document the temperature conditions.

The date and time of each test will be recorded, but these tests may cover data collected over periods ranging from one day to a month. Thus, the date and time will be used to determine the beginning and end of the data used in the test. The product level during the data collection will vary according to normal tank usage. Typically product level will rise from deliveries and fall as product is dispensed during a test period. The tests will thus be done over a range of product levels representing the actual operation of the tank.

This protocol requires determination of the monthly throughput for each tank and reporting of some percentiles of this distribution. The distribution of the throughputs will impose a restriction on the use of the system. Any tests done at a special test facility are included in calculating these percentiles. In addition, the protocol requires that the product delivered to the tanks be at different temperatures from that in the tanks. This is documented by calculating the standard deviation of the differences in temperature between the delivered product and that already in the tanks. This standard deviation is required to be at least 4°F.

All of the EPA protocols require that the test tanks have independent evidence that they are tight. Such evidence should be provided by use of an additional leak detection method besides that being evaluated. This could be an annual tightness test or an operating ATG in the tank or by vapor or liquid monitoring wells at the site. The requirement for evidence that the tanks are tight is primarily a protection for the vendor. If a leaking tank were inadvertently used in part of the evaluation, and the vendor's method indicated a leak, this would appear in the data as a false alarm, or as a large over estimation of a leak rate. Thus, it is in the vendor's interest to ensure that the tanks in the evaluation are tight. This requirement is therefore self-enforcing and regulators should not need any special evidence that it has been met. Thus, if a leaking tank were used as a test tank, the effect would be an apparent deterioration of the performance estimated for the system.

Since CITLDS systems will operate continuously during normal tank operation, it is expected that several days or weeks of data may be required to be collected in order for a leak rate to be estimated. This is especially true if the system operates in a tank with a high throughput. Such tanks are the motivation for the development of CITLDS, since leak detection methods that take the tank out of service are difficult to accommodate in such usage. Consequently, it may not be feasible to physically induce or simulate a leak in all the tanks for the test. The method of introducing leaks into the data mathematically is similar to that provided in the SIR Protocol.[7] A computer program can introduce the selected leak rates into the tank records by computing the level change (in double precision) resulting from the specified leak rate period needed for data collection by the CITLDS (e.g. every 30 seconds) and can alter the tank level reading by this amount cumulatively between deliveries.

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

Step 1: Identify a number of tanks for installation of the CITLDS system. The tanks can be of varying sizes and throughputs, but the sizes and throughputs used in the evaluation will limit the applicability of the results. A minimum of 5 different geographical sites should be used, with a minimum of 10 different tanks. The combination of geographical sites and dates should provide test periods during hot and cold weather conditions as well as mild weather conditions.

Step 2: Install identical CITLDS systems in the tank systems. Collect and record the tank and site data for each tank. Arrange to record the data to document the test conditions for each test. The data requirements were noted above.

Step 3: Operate the CITLDS system to conduct tests on each tank system. It will be necessary to arrange to log the raw data used by the CITLDS for its calculations. These raw data will be used in simulating leaks.

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[7] "Standard Test Procedures for Evaluating Leak Detection Methods: Statistical Inventory Reconciliation Methods," EPA/530 UST-90/007, June, 1990.

Step 4: Create a data base of the leak detection tests conducted by the CITLDS. The data base should include at least 100 tests (for quantitative systems; 240 for qualitative systems) and should be distributed over the tank size, throughput, and test conditions representing the intended population of use. The data base should include manifolded tank systems if the CITLDS is intended for use on such tank systems.

Step 5: At some time during the evaluation period, if the CITLDS has a water sensor, evaluate the water sensor function. This can be done using the procedure described in Section 6.4 of the ATGS protocol.[8]

Step 6: The evaluating organization will take the data base of leak tests conducted on the test tank population and randomly select a subset for use in the evaluation. The subset will be randomly allocated to tight and various leak rates for simulation. As an alternative to selecting a random subset from a larger population of test records, the evaluating organization may work with the vendor in identifying the sites, tank records, and data test period. All tank records from the sites, tanks, and period must be submitted to the evaluating organization for use. This would reduce the number of tank records needed to conduct the evaluation. It should be recognized, that some tank records submitted in this manner may not be usable because of data recording difficulties. Such problems in recording large amounts of data should be expected and should not invalidate the evaluation. However, the evaluating organization would have all of the data for the period and tanks selected, and would review all records to estimate the performance of the CITLDS. The evaluating organization will then simulate the leak rates and produce raw data files altered to include the induced or simulated leak rates. The evaluating organization will operate the CITLDS on these data records. The CITLDS will treat these as ongoing tank records and produce leak rate estimates. The evaluating organization will record the results produced by the CITLDS.

Step 7: The evaluating organization will spot check the data records by plotting fuel level and temperature (if used by the system) versus time for selected records. This review will allow the evaluating organization to examine the dispensing patterns to check for consistency and for typical dispensing patterns. It allows the evaluating organization an additional tool to ensure that the data were not tampered with.

Step 8: If desired, a number of physical leak simulations may be incorporated into the test plan for evaluating a Continuous ATGS. These would

[8] See Note 3.

replace some of the mathematically simulated leaks and may be done at field sites or at a special test facility. The number of tests done at a special test facility may range from 1 to 15. Physical leak simulation is required only for systems that use sensors that have not been previously evaluated.

Step 9: The data will be used to analyze the difference between the leak rates estimated by the CITLDS and those introduced by the evaluating organization. Based on these differences, the PD and PFA will be calculated. If the CITLDS system is qualitative, the proportions of errors will be calculated separately for tight tank records and for those with induced leaks. These proportions will be used to estimate the PD and PFA.

Step 10: The data on test conditions will be summarized and reported together with the limitations on applicability of the CITLDS system that result from the test conditions.

Step 11: If the system uses sensors that have been previously evaluated as part of another (non-continuous) leak detection system, that evaluation report should be referenced to document that physical performance of the sensors. If the system is based on new technology with sensors that have not been evaluated previously, then at least 6 physical leak simulations are required. These can be done in the field as part of Step 7, or they can be run at a special facility with the system operating in a shut-down mode.

Note: In the event that leaks can be physically simulated or induced at the tanks in an appropriate manner, it might not be necessary to log the raw data collected and used by the CITLDS. If leaks are physically simulated by withdrawing product from the tanks, it would be necessary to ensure that the fact of this withdrawal and the size of the leak simulated is kept blind, that is, it is not available for use by the vendor in modifying the system's results. It would also be necessary to ensure that the leak rate is measured accurately.

6.2 TEST SCHEDULE

The data from tank records described above are used for the evaluation. A data base of about twice the number of records to be used in the evaluation from the tanks described above can be used to randomly select a subset for analysis. Alternatively the set of tanks, records, and time can be selected with the evaluating organization and all records for the defined period submitted for evaluation. This will reduce the amount of data needed for the evaluation, while still assuring that the data represent the performance of the system. The data should be stratified by climate condition and by tank throughput and size.

6.2.1 General Test Schedule

Some testing may be done at a special test facility, but some field data tests from operating tanks are also required. This protocol must remain flexible so it can be used for different systems. Thus, a variety of combinations of field tests and tests at a specialized facility is possible. The appropriate mixture differs by the type of CITLDS.

For a Continuous ATGS type of CITLDS, no physical leak simulations are required, provided that the probes and sensors were previously evaluated as part of an ATG system. In that case, the previous evaluation report should be referenced. If the system uses sensors based on new technology with no previous evaluation, then at least 6 physical leak simulations must be run to demonstrate that it does track volume changes. These can be run in a test facility as regular ATG shut-down mode tests. For a Continual Reconciliation type of CITLDS, a single test with a physically simulated leak is recommended, but not required. Operation of a Continual Reconciliation CITLDS may make only a field simulation feasible. For an Automatic Monthly Inventory Control type of CITLDS, no physical leak simulation is required because of the different performance specification for this system. (It is not a stand-alone leak detection system.)

For a quantitative system, after stratification of the data base by tank size and temperature conditions, randomly select 45 tank records for use. The selected records are then randomly assigned average leak rates of nominally 0, 0.10 gallon per hour (gph) or 75 gallons per month, 0.20 gph (150 gallons per month), and 0.30 gph (225 gallons per month), for an evaluation of the CITLDS as a monthly monitoring system able to detect a leak of 0.20 gph or 150 gallons per month. Fifteen (15) tank records are assigned to the tight (zero leak) group and 10 to each of the other leak rates.

It should be noted that the leak rates for monthly monitoring are averages. That is, they are designed to evaluate the system's ability to detect an average leak rate of 0.20 gph or 150 gallons per month as noted in the EPA regulations for other leak detection methods. If the CITLDS is also to be evaluated as to its ability to detect a leak rate of 0.10 gph or 75 gallons per month on a monthly basis, an additional 10 records are needed, to which a nominal leak rate of 0.05 gph (37.5 gallons per month) is to be added. Consistent with the EPA performance standard, all leak rates are to be viewed as monthly average leak rates, with equivalent monthly total gallons lost.

A random number is to be added to each leak rate so that the simulated leaks are not predictable, exact leak rates. Rather, select rates at random with a uniform distribution specific to each nominal leak rate. Use [0.03, 0.07] gph or [22.5, 52.5] gallons per month for the nominal 0.05 gph (37.5 gallons per month); use [0.08, 0.12] gph or [60, 90] gallons per month for the nominal 0.10 gph (75 gallons per month) leak rate; use [0.16, 0.24] gph or [120, 180] gallons per month for the nominal 0.20 gph or 150 gallons per month leak rate, and use [0.25, 0.35] gph or [187.5, 262.5] gallons per month for the nominal 0.30 gph or 225 gallons per month leak rate.

For a qualitative system, after stratification of the data base by tank size and temperature condition, randomly select 120 tank records for use. Randomly select a number between 50 and 70 for the number of records to use as tight. The remainder will have leaks simulated of a size as close as practical to 0.2 gph or 150 gallons per month. Randomly divide the 120 records into the two groups with the size determined above.

A test plan for a quantitative system is provided in Table 1. This plan includes the leak rates used for both the 0.10 gph or 75 gallons per month and the 0.20 gph or 150 gallons per month performance standards. If evaluation to only a single standard is desired, the appropriate 4 nominal leak rates may be used. That is, for an evaluation aimed at documenting the performance of the system in detecting the target leak rate of 0.20 gph or 150 gallons per month the records with induced leak rates of 0.05 gallon per hour or 37.5 gallons per month would be dropped.

The test plan included in Table 1 includes a total of 55 tank records. Fifteen of these are for tight tanks, and 10 are assigned each of the four induced leak rates. (One of the induced leaks could be dropped if evaluation is to a single standard, but since often both levels of performance may be of interest, the full data matrix is recommended to provide for both performance levels within a single set of tests.) Table 1 includes the induced leak rates in ascending order so that the number of each can be clearly seen. In actual practice, the tank records would be identified with tank size, throughput, and temperature condition. Then the records would be assigned induced leak rates at random, so that no pre-specified order would exist. The actual leak rates to be induced would then be constructed from the nominal leak rates by introducing some random variability as described above.

Table 1. **EXPERIMENTAL DESIGN AND DATA FORM**

Test No.	Tank volume (gal)	Monthly throughput (gal)	Season (H,M,C)	Nominal induced leak rate (gal/hr)
1				0
2				0
3				0
4				0
5				0
6				0
7				0
8				0
9				0
10				0
11				0
12				0
13				0
14				0
15				0
16				0.05
17				0.05
18				0.05
19				0.05
20				0.05
21				0.05
22				0.05
23				0.05
24				0.05
25				0.05
26				0.1
27				0.1
28				0.1
29				0.1
30				0.1
31				0.1

Table 1 (Continued)

Test No.	Tank volume (gal)	Monthly throughput (gal)	Season (H,M,C)	Nominal induced leak rate (gal/hr)
32				0.1
33				0.1
34				0.1
35				0.1
36				0.2
37				0.2
38				0.2
39				0.2
40				0.2
41				0.2
42				0.2
43				0.2
44				0.2
45				0.2
46				0.3
47				0.3
48				0.3
49				0.3
50				0.3
51				0.3
52				0.3
53				0.3
54				0.3
55				0.3

A leak from a tank may be simulated as a continuous loss of product at an essentially constant leak rate. However, a different approach is needed to simulate a leak from a pressurized line. Since the line will leak only while it is under pressure, the simulation must introduce a leak only when the line is pressurized. This will require an initial pass through the data to determine when the line is under pressure and for what proportion of time. Then the appropriate leak can be simulated during those periods when the line is under pressure to give the appropriate product loss over the month.

The situation is different for an automatic monthly inventory control system. Such systems reconcile the monthly inventory and compare the result with the EPA action level of 1% of throughput plus 130 gallons. The throughput for each tank record must be determined to give the appropriate threshold in gallons for the month. A few records might be checked by doing the reconciliation calculations manually to confirm that the program does the calculations correctly. Introducing a loss in the inventory mathematically should be exactly reproduced by the computer program, so simulating a leak is not an intrinsic part of the evaluation of automatic monthly inventory control systems. Instead, a series of monthly records for tight tanks using the automatic monthly inventory system is collected. The correct value for an inventory reconciliation for these tanks would be zero. The calculated monthly reconciliations can be used to estimate the accuracy and precision of the automatic monthly inventory control system. These can be expressed in terms of percent of the monthly throughput and the results used with the EPA action level to estimate a probability of false alarm. A loss (in terms of percent of throughput) that should be detectable with probability 95% can also be estimated and reported.

A table similar to Table 1 is provided as a data reporting form. It includes the actual induced leak rates rather than the nominal leak rates, the measured leak rates reported by the CITLDS, and the difference between these. These data are used in the calculations in Section 7.

Several trial runs should be performed prior to selecting the data set for evaluation. These trial runs should document that the leak simulation is working properly and that the transfer of the original data and modified data to the CITLDS for analysis by its algorithm also works properly. The CITLDS program should be run in duplicate on some data sets to document that it gives the same results for the same tank record. The leak inducing program, that is, the program that adds the effect of the simulated leaks to the data sets, should be run twice on some data sets to document that the same leak was induced. The CITLDS algorithm should be run on the resulting pairs of tank records with the induced leak to document that it produces the same leak rate estimate. The leak inducing program should be used with a zero induced leak and the results compared with the unaltered data file to verify that it functions properly. Finally, some large leaks (1 to 10 gph equivalent to 720 to 3,600 gallons per month) should be induced to verify that the program operates properly over a wide range of leak rates. Select 10 tank records at random. (More may be done if desired.) Induce leaks of 1 to 10 gph in these records, with the leak rates assigned at random. These large leak rates are also used to document that the system is capable of detecting a large leak. Their use for this is discussed in Section 7.

If the CITLDS is qualitative in that it only reports results as tight or leaking, the design is modified to include 120 records. To preserve confidentiality, a random number between 50 and 70 is selected for the number of tight tank records. The remainder have the target leak rate (0.2 gph or 150 gallons per month for example) simulated in them. Some records are chosen at random from the selected data base to have simulated leaks induced in them. Once the leaks have been simulated, the CITLDS is used on all data records and the results recorded. In this case, the finding of the CITLDS (tight or leaking) is compared to whether or not a leak was simulated in that data base.

6.2.2 Test Schedule for Tests at a Special Test Facility

This section describes a test schedule for testing a CITLDS at a special test facility. It is primarily for testing a Continuous ATGS CITLDS. However, with suitable instrumentation for metering the dispensing operations, it could be adapted for use with a Continual Reconciliation CITLDS. It is possible that several tests with a Continuous ATGS CITLDS could be conducted at a special test facility, however, it seems likely that a Continual Reconciliation CITLDS would require a fairly long period, perhaps most of a month, to perform its test.

Tests at a test facility should simulate dispensing using a submersible pump. A submersible pump is required since it is the typical type of pump and it disturbs the product level more than a suction pump. Table 2 contains a dispensing schedule for testing at a special test facility. The dispensing schedule was developed from dispensing records for an operating tank, which had a monthly throughput of about 80,000 gallons. The daily total of about 2,600 gallons dispensed corresponds to this monthly total for a 31-day month. This dispensing schedule represents a realistic throughput for a 24-hour operation for which a CITLDS is designed and which can be reasonably achieved at a special test facility. Field data may include higher throughputs. The schedule in Table 2 may be repeated as needed to complete a test. Alternatively, similar dispensing records may be recorded from the field installations and those could be used in place of Table 2.

Table 2. DAILY DISPENSING SCHEDULE FOR TEST FACILITY TESTING

Start of busy period		Duration with pump on (minutes)	Gallons dispensed	Duration of period with pump off (minutes)
Hour	Minute			
0	24.1	0.7	3.94	23.6
0	35.7	1.3	10.26	10.8
0	55.9	2.4	15.76	19.0
2	2.9	1.0	7.89	64.5
2	16.8	0.9	3.94	13.0
2	31.7	1.7	11.82	13.9
3	59.6	0.7	3.94	86.3
4	22.8	3.3	12.32	22.5
4	34.5	1.1	3.93	8.3
5	10.0	1.7	12.61	34.5
5	30.2	0.6	3.94	18.5
5	39.9	3.5	10.42	9.1
5	59.5	1.7	7.33	16.2
6	7.4	5.9	29.93	6.3
6	31.2	1.9	12.06	17.9
6	43.3	1.2	3.94	10.2
6	58.5	0.6	3.94	14.0
7	4.3	1.9	15.17	5.2
7	18.3	10.8	77.98	12.2
7	38.0	12.8	28.69	8.9
7	56.4	1.4	11.10	5.6
8	25.6	1.3	9.45	27.8
8	30.6	5.7	28.46	3.7
8	41.8	1.9	11.82	5.5
8	49.4	1.7	9.20	5.7
8	54.1	4.0	37.39	3.0

Table 2 (Continued)

Start of busy period		Duration with pump on (minutes)	Gallons dispensed	Duration of period with pump off (minutes)
Hour	Minute			
9	2.6	1.5	11.89	4.5
9	31.3	1.8	9.85	27.2
9	36.2	1.0	5.52	3.1
9	41.9	5.6	32.00	4.7
9	51.9	0.6	3.94	4.4
9	59.7	3.8	30.25	7.1
10	10.8	0.6	3.94	7.2
10	13.9	4.8	46.96	2.5
10	23.2	2.4	26.00	4.6
10	29.8	2.8	16.56	4.2
10	35.3	6.0	64.78	2.7
10	49.5	2.9	18.18	8.1
10	55.6	1.0	10.25	3.2
10	56.6	10.0	15.14	0.0
11	17.9	15.8	83.46	11.3
11	36.2	3.4	26.50	2.5
11	49.0	5.4	25.68	9.4
12	0.1	2.1	12.50	5.8
12	17.8	1.3	9.18	15.6
12	28.8	2.4	14.92	9.7
12	33.7	13.0	59.69	2.6
12	58.1	0.8	3.95	11.4
13	4.3	0.8	1.46	5.4
13	12.5	4.6	32.90	7.4
13	19.9	2.2	16.56	2.7

Table 2 (Continued)

Start of busy period		Duration with pump on (minutes)	Gallons dispensed	Duration of period with pump off (minutes)
Hour	Minute			
13	37.3	1.0	9.46	15.2
13	41.7	3.8	32.66	3.4
13	50.8	3.4	7.88	5.3
13	57.7	30.3	164.18	3.5
14	33.0	1.4	11.83	5.0
14	41.6	5.8	31.39	7.2
15	1.1	14.5	111.50	13.8
15	21.6	1.2	9.86	6.0
15	27.2	10.1	84.26	4.3
15	40.2	15.6	58.58	2.9
15	59.8	1.0	6.50	4.0
16	7.8	3.2	11.04	7.0
16	13.9	0.9	6.31	2.9
16	23.9	2.9	17.14	9.1
16	31.5	2.6	26.02	4.7
16	37.1	1.2	9.06	3.0
16	42.5	10.8	53.67	4.1
16	57.8	19.2	87.54	4.6
17	21.1	2.2	10.96	4.1
17	30.4	16.1	137.82	7.1
17	49.5	8.1	37.06	3.0
18	0.7	10.3	49.25	3.1
18	15.7	4.8	30.45	4.7
18	23.2	0.9	5.52	2.7
18	30.8	2.2	11.95	6.7

Table 2 (Continued)

Start of busy period		Duration with pump on (minutes)	Gallons dispensed	Duration of period with pump off (minutes)
Hour	Minute			
18	41.0	2.5	10.24	8.0
18	48.1	1.5	11.50	4.6
18	54.0	2.7	13.01	4.4
19	3.3	12.5	79.79	6.7
19	20.4	2.6	8.62	4.6
19	29.6	4.0	18.52	6.7
19	37.9	0.5	2.37	4.3
19	42.6	17.9	48.19	4.2
20	13.9	1.2	7.10	13.4
20	26.1	4.3	21.96	11.0
20	34.6	1.9	15.76	4.2
20	41.0	1.6	14.83	4.5
20	51.6	3.8	30.76	9.0
21	7.7	4.2	15.05	12.3
21	17.7	2.2	18.13	5.8
21	26.5	15.2	67.79	6.6
21	57.6	1.3	11.04	16.0
22	7.8	6.3	50.46	8.9
22	17.9	4.8	20.72	3.8
22	30.8	4.7	22.99	8.1
22	38.9	0.5	3.17	3.4
22	49.9	2.0	13.44	10.5
22	57.6	2.9	15.76	5.8
23	4.1	1.7	10.83	3.5
23	12.8	2.8	7.09	7.1

Table 2 (Continued)

Start of busy period		Duration with pump on (minutes)	Gallons dispensed	Duration of period with pump off (minutes)
Hour	Minute			
23	19.6	5.7	22.98	4.0
23	35.1	2.4	21.31	9.8
23	42.2	2.1	11.83	4.7
23	54.6	2.9	17.34	10.3
24	0.0	0.5	3.94	2.5

In using this form of testing, the dispensing schedule should be followed continuously for each test. The schedule is reported for the 24-hour period beginning at midnight. In operation, the schedule can be started at any time during the day, by entering the table at the appropriate time and following the schedule from then on. When midnight is reached, return to the top of the schedule and continue with it.

The first two columns of Table 2 have the start of each busy period, that is, the time when the pump is turned on in hours and minutes. The next column has the duration of that busy period, or the length of time that the turbine should run in minutes. The next column contains the amount of product dispensed during that period in gallons, while the last column has the duration of the period with the pump off just prior to the start of the current active period. The time periods are given to the nearest 1/10 of a minute, but following them to the nearest minute is sufficient. Similarly, the gallons dispensed is reported to the nearest 1/100 of a gallon, but dispensing to the nearest gallon is sufficient.

It is important that the duration of the quiet periods not be extended beyond those in the test schedule. The turbine of the pump should run during the entire busy period, even if product dispensing is completed in less time than indicated as the busy period.

As product is dispensed, the product level in the tank will drop and the tank will need to be refilled periodically. Timing of this will depend on the starting level of the tank and the particular test facility. Generally, the level should be allowed to drop below half full, perhaps to about 25% of tank capacity, and then the tank should be refilled to between 75% and 95% full. The dispensing may be continued while the tank is being filled, but this is not necessary. If dispensing is discontinued during filling of the tank, once the filling is completed, the dispensing should be resumed at the appropriate time of day in the schedule shown in Table 2. A delivery is required at least every fourth day, with the amount to be delivered ranging from 1/4 to 3/4 of the tank capacity. Each fill should include temperature conditioning so that the temperature of the delivered product is at least 5°F different from that of the product in the tank. The delivery may be a refilling from another tank, subject to the required temperature differences.

The data in Table 2 are displayed graphically in Figure 1. This dispensing pattern illustrates the activity typical of a busy tank at a service station and indicates the difficulty of a CITLDS finding adequate time to perform its leak detection.

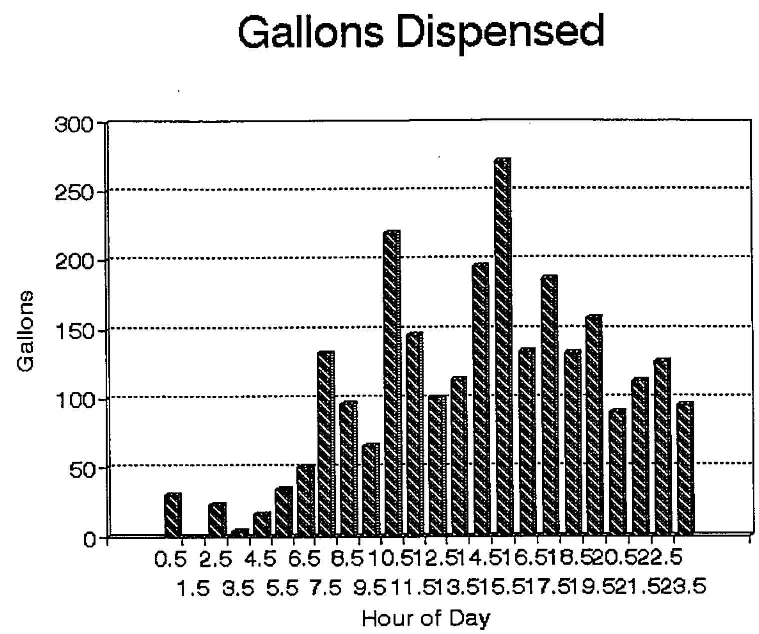

Figure 1. Dispensing Activity by Time of Day.

When physically inducing a simulated leak, either at a field site or a test facility, continue with a constant leak rate until a test is completed. Since a limited number of tests with a physically simulated leak is anticipated, only two leak rates are recommended, 0.1 or 0.2 gallon per hour (75 or 150 gallons per month, respectively). At a test facility, begin with a 0.2-gph (150 gallons per month) leak rate and continue until a test is completed, then change to 0.1 gph (75 gallons per month). When the second test is complete, return to 0.2 gph (150 gallons per month). About half the tests should be done with each leak rate. Since tight tests will be available from the field data, no tight tests need be simulated at the test facility. These physical leak simulations should be used for some of the required leak simulations in Table 1, with the remaining leaks simulated mathematically as described in Section 6.3. As discussed earlier, the actual leak rates should be varied randomly to be within ±30% limits of the nominal rates.

If a system has special requirements, these can be accommodated with appropriate restrictions on the application of the system. A system that is designed for a high volume station that is closed for a specified period each night may be tested and restricted to sites with the required closed period. The test schedule should include the required nightly period between dispensing operations. The schedule in Table 2 may be adapted to a required closed period each night by eliminating dispensing during that period. Amounts dispensed during the day may be proportionally increased to provide the same total gallons dispensed each 24 hours.

6.3 SIMULATING LEAKS

One approach to simulating leaks in a tank would be to install a peristaltic pump system in an operating tank to remove a constant amount of product (e.g., 0.20 gph or 150 gallons per month). The product removed could be pumped into another tank with compatible product. It would be necessary to check the rate periodically to ensure that the pump was removing product at a constant rate and to measure that rate. This physical simulation could be carried out while the CITLDS was operating in that tank. At the end of the test period, the leak rate measured by the CITLDS would be compared to that actually induced by the peristaltic pump. This would provide one test of the required number with simulated leaks. Following the ATG protocol, a total of 18 such tests would be needed in addition to at least 6 tests with zero leak simulated.

Since test durations of days or weeks are anticipated, the physical simulation of leaks is not very practical. Consequently, a mathematical simulation of a leak in the data base is recommended as an alternative.

It is anticipated that most CITLDS's will collect product level and temperature data every few seconds. This will necessitate simulating a leak by altering the reported product level. The change in product level from the simulated leak must be calculated for every period that data were recorded and used to alter the product level cumulatively. The leak simulation process is reset following each delivery, since a new product level is determined at that time, based on the amount of product delivered.

Some CITLDS's may be designed to detect leaks or product loss from either the tank vessel itself or its pressurized lines or both. In the event that the CITLDS is designed to detect leaks from the lines as well as the tank, leak simulation should be designed to verify that the system can, in fact, detect such line leaks. Since leaks from a pressurized line would only occur while the line is pressurized, they will have a different effect on the product level from that of a tank leak. Thus, it will be necessary to induce two different types of leaks in the data record to establish that a CITLDS is capable of detecting leaks from both the tank and its associated pressurized piping.

6.3.1 Simulating Tank Leaks

For simulation purposes, a tank leak is assumed to occur with a constant rate. It is recognized that in reality, tank leak rates can vary with time in response to changes in the product level in the tank, external water table changes, etc. Nevertheless, for a practical evaluation, some set leak must be considered. In many situations a tank leak is reasonably constant, and this is chosen as the type of leak to simulate.

There are two possible approaches to simulating the leak in the data logged by the system. One approach is to calculate the level change resulting from a leak rate for each time interval between data points recorded by the CITLDS. The product level is then modified by this amount at each interval. The second approach is to cumulate the loss in product volume from the latest fill to each data point recorded by the CITLDS. Then the product volume is modified by the cumulative loss at each data point. The product level for the modified volume is then calculated and this modified product level is used to replace the originally recorded product level.

It should be emphasized in this simulation process that the simulation must be consistent with the most accurate tank chart or formula available for the tank from which the data came.

If the system records product height, the product height should be converted to volume with the most accurate method available. Then the volume would be modified to reflect the effect of the loss of product at the desired leak rate. The modified volume would be used to compute the corresponding height of product. This modified product height would be used to replace the original product height in the data file. The CITLDS would then use this modified height in its calculations.

It should be emphasized that the modified file submitted to the CITLDS cannot contain both product height and volume. The reason for this is that to do so might enable the system to compare the recorded volume with its volume conversion. If they did not match the system might be programmed to conclude that a leak had been simulated. It is also possible that an inconsistency between the level and volumes in the file might lead to the algorithm giving an invalid result or identifying the data as bad.

If the CITLDS only records volume and not level, then the leak could be simulated directly in the volume without the conversions between level and volume and back. However, this is regarded as unlikely. Some systems might use other principles for their volume calculation, for example, the buoyant force exerted on a submerged or partially submerged probe. In this event, the leak simulation would consist of altering the recorded force to reflect the effect of the loss of volume consistent with the leak rate.

The following example illustrates the computations for cumulating the volume loss and modifying the product level accordingly. Beginning at the conclusion of each fill, the volume loss for a specified leak rate is cumulated for each time that the CITLDS has logged a data point. These cumulative volume losses are then converted to product level changes. The data file with the product level recorded is then modified to reflect the changed product level that would correspond to the volume lost. The modified file with the product level altered to reflect the effect of the leak is submitted to the CITLDS for analysis. Note that the file would not have both product level and volume in it; the CITLDS would be required to compute the volume from the altered product levels.

The conversion from product volume to product height should be based on the most accurate tank chart or formula available for each specific tank in the data base. If the tank is a horizontal right circular cylinder, as steel tanks generally are, a formula is available to compute the volume of product from the depth of product. Let R denote the radius of the cylinder, L the length of the cylinder, h the product height measured from the bottom of the tank, and let

$$d = R - h$$

denote the distance from the center of the tank to the product level. All dimensions are in inches. Note that d may be positive or negative depending on whether the product level is below or above the midpoint. Then the volume of product in the tank (in gallons) is given by the equation

$$V = (L/231)\,[R^2 \arccos(d/R) - d\sqrt{(R^2-d^2)}\,] \qquad (1)$$

For a given volume, Equation (1) cannot be solved explicitly for h, rather, an iterative solution must be found.

Some fiberglass tanks are composed approximately of a cylindrical center section with hemispherical ends. If L is the length of the cylindrical section, R the radius, and h the depth of product in the tank, with dimensions in inches, then the volume in gallons is given by

$$V = (L/231)\,[R^2 \arccos(d/R) - d\sqrt{(R^2-d^2)}\,] + (\pi/3)h^2\,(3R-h)/231 \qquad (2)$$

Again, Equation (2) cannot be solved explicitly for h given a specified volume, V, but must be solved by iteration.

Alternatively, if the tank geometry differs from these two, another equation may be developed and used, or interpolation may be used in a detailed tank chart to calculate the corresponding heights for the volumes.

Beginning with a data record that includes volume and product height, the data are modified to reflect the loss in volume from a specified leak rate. The volume change is cumulated from the start of the record and this change is made to the volume in the tank. The height data are also changed to reflect the altered volume. Equation (1) or (2) may be used as appropriate to solve for the product height to match the altered volume.

Table 3 is an example of a few of these calculations. In it a leak rate of 0.20 gph equivalent to 150 gallons per month has been simulated intermittently. The first part of the table, where the 0.20 gph (or 150 gallons per month) is simulated, is an example of how a tank leak might be simulated. The entire table, with the intermittent leak rate, is an example of how a line leak might be simulated. The table shows a period of 14 minutes out of 98 when the pump is off and no leak is simulated. If the pump were consistently on this proportion (86%) of the time during the month then the average line leak rate that would be simulated would be about 0.17 gph, which would be result in approximately a loss of 122 gallons over a month. If the pump were on about 50% of the time, then this example would simulate an average leak rate of about 0.10 gph or 75 gallons per month out of the pressurized lines.

It should be noted that the data required to simulate leaks mathematically must have the same information content as exemplified in Table 3. However, the actual format for the data may differ. Thus, Table 3 is an example showing how the leak simulation may be done, but it is not a requirement that it be in exactly this format.

Table 3 contains some sample calculations for a few time intervals using Equation (1) as the formula for the volume. An actual record would be much longer. Equation (1) was solved by iteration for the height corresponding to the modified volumes. The example uses a 10,000-gallon steel tank that is 96 inches in diameter and 324 inches long.

In the example data of Table 3, a leak of 0.2 gph has been induced intermittently. Note that at minutes 31, 32, and 33, the level drops significantly, indicating that dispensing has taken place. The induced leak has been stopped beginning with minute 55. The first part of the file—up to minute 55—is consistent with a tank leak. The entire table with an intermittent leak would be consistent with a line leak. However, the average size of the leak simulated with an intermittent leak depends on the proportion of the time that the leak is simulated. The instantaneous leak rate for simulating a line leak would have to be set after determining the proportion of time that the lines are pressurized. If an average leak rate equivalent to 0.20 gph (150 gallon per month) is to be simulated from lines that are pressurized only 50% of the time, then the instantaneous leak rate to be used would be 0.40 gph (0.2/0.5).

The system would be used in an operating tank to log data, including time and level as shown in the first two columns of Table 3. Other data such as temperature, dispensing activity, etc., used by the system would usually also be present in the log. The volume in the third column of Table 3 would be computed by the system. It is shown in Table 3 to illustrate the effect of the leak simulation. Note that the reported level and corresponding calculated volume in Table 3 include some random noise. After the leak is simulated, the volume is altered, as shown in the adjusted volume column in Table 3. The adjusted volume is used to calculate the corresponding level, shown in the adjusted level column. For the test, the column of adjusted level data would replace the data in the original level column. The resulting modified file would be submitted to the system's software for analysis. No volume data would be supplied, rather, the system would use the level to recompute the volume.

Table 3. EXAMPLE LEAK SIMULATION

Time (min)	Reported level	Reported volume	Adjusted level	Adjusted volume	Comments
0	40.0000	4003.9741	40.0000	4003.9741	Leak On
1	40.0001	4003.9874	40.0001	4003.9841	
2	39.9999	4003.9608	39.9998	4003.9542	
3	40.0001	4003.9874	40.0000	4003.9774	
4	40.0001	4003.9874	40.0000	4003.9741	
5	40.0001	4003.9874	40.0000	4003.9707	
6	40.0001	4003.9874	39.9999	4003.9674	
7	40.0000	4003.9741	39.9998	4003.9508	
8	40.0001	4003.9874	39.9999	4003.9607	
9	39.9999	4003.9608	39.9997	4003.9308	
10	40.0001	4003.9874	39.9998	4003.9541	
11	40.0001	4003.9874	39.9998	4003.9507	
12	40.0001	4003.9874	39.9998	4003.9474	
13	40.0001	4003.9874	39.9998	4003.9441	
14	40.0000	4003.9741	39.9996	4003.9275	
15	39.9999	4003.9608	39.9995	4003.9108	
16	39.9999	4003.9608	39.9995	4003.9075	
17	40.0001	4003.9874	39.9997	4003.9307	
18	39.9998	4003.9476	39.9993	4003.8876	
19	39.9998	4003.9476	39.9993	4003.8842	
20	40.0000	4003.9741	39.9995	4003.9075	
21	40.0000	4003.9741	39.9995	4003.9041	
22	40.0000	4003.9741	39.9994	4003.9008	
23	40.0001	4003.9874	39.9995	4003.9107	
24	39.9999	4003.9608	39.9993	4003.8808	
25	40.0000	4003.9741	39.9994	4003.8908	
26	40.0001	4003.9874	39.9994	4003.9007	
27	40.0000	4003.9741	39.9993	4003.8841	
28	40.0000	4003.9741	39.9993	4003.8808	
29	40.0000	4003.9741	39.9993	4003.8775	

Table 3 (Continued)

Time (min)	Reported level	Reported volume	Adjusted level	Adjusted volume	Comments
30	40.0000	4003.9741	39.9992	4003.8741	
31	39.9549	3997.9874	39.9541	3997.8841	6 Gal. Sold
32	39.8944	3989.9608	39.8936	3989.8542	8 Gal. Sold
33	39.8869	3988.9608	39.8861	3988.8508	1 Gal. Sold
34	39.8871	3988.9850	39.8862	3988.8717	
35	39.8871	3988.9870	39.8862	3988.8704	
36	39.8872	3988.9945	39.8863	3988.8745	
37	39.8870	3988.9803	39.8861	3988.8570	
38	39.8870	3988.9789	39.8861	3988.8522	
39	39.8869	3988.9663	39.8860	3988.8363	
40	39.8870	3988.9789	39.8860	3988.8456	
41	39.8871	3988.9901	39.8861	3988.8535	
42	39.8870	3988.9791	39.8860	3988.8391	
43	39.8870	3988.9770	39.8859	3988.8337	
44	39.8870	3988.9717	39.8859	3988.8250	
45	39.8872	3988.9949	39.8860	3988.8449	
46	39.8870	3988.9733	39.8858	3988.8200	
47	39.8870	3988.9740	39.8858	3988.8174	
48	39.8870	3988.9774	39.8858	3988.8174	
49	39.8870	3988.9712	39.8857	3988.8079	
50	39.8869	3988.9615	39.8857	3988.7948	
51	39.8868	3988.9441	39.8855	3988.7741	
52	39.8869	3988.9629	39.8856	3988.7896	
53	39.8870	3988.9734	39.8857	3988.7968	
54	39.8869	3988.9630	39.8856	3988.7830	
55	39.8869	3988.9574	39.8855	3988.7741	Pump Off
56	39.8869	3988.9574	39.8855	3988.7741	Leak Off
57	39.8870	3988.9767	39.8856	3988.7934	
58	39.8871	3988.9857	39.8857	3988.8023	
59	39.8869	3988.9627	39.8855	3988.7794	

Table 3 (Continued)

Time (min)	Reported level	Reported volume	Adjusted level	Adjusted volume	Comments
60	39.8871	3988.9908	39.8857	3988.8075	
61	39.8870	3988.9806	39.8856	3988.7972	
62	39.8870	3988.9785	39.8856	3988.7951	
63	39.8870	3988.9758	39.8856	3988.7925	
64	39.8870	3988.9737	39.8856	3988.7904	
65	39.8870	3988.9778	39.8856	3988.7945	
66	39.8869	3988.9650	39.8855	3988.7817	
67	39.8870	3988.9754	39.8856	3988.7921	
68	39.8870	3988.9791	39.8856	3988.7958	Pump On
69	39.8871	3988.9885	39.8854	3988.8019	Leak On
70	39.8871	3988.9843	39.8856	3988.7943	
71	39.8868	3988.9486	39.8854	3988.7552	
72	39.8869	3988.9638	39.8854	3988.7672	
73	39.8870	3988.9737	39.8855	3988.7737	
74	39.8868	3988.9455	39.8853	3988.7421	
75	39.8867	3988.9413	39.8852	3988.7346	
76	39.8868	3988.9526	39.8853	3988.7426	
77	39.8868	3988.9501	39.8852	3988.7368	
78	39.8871	3988.9812	39.8854	3988.7646	
79	39.8870	3988.9750	39.8854	3988.7550	
80	39.8870	3988.9691	39.8853	3988.7457	
81	39.8869	3988.9595	39.8852	3988.7328	
82	39.8869	3988.9595	39.8852	3988.7295	
83	39.8869	3988.9615	39.8851	3988.7282	
84	39.8869	3988.9614	39.8851	3988.7248	
85	39.8869	3988.9674	39.8851	3988.7274	
86	39.8868	3988.9532	39.8850	3988.7098	
87	39.8868	3988.9434	39.8849	3988.6967	
88	39.8869	3988.9657	39.8851	3988.7157	
89	39.8870	3988.9769	39.8851	3988.7236	

Table 3 (Continued)

Time (min)	Reported level	Reported volume	Adjusted level	Adjusted volume	Comments
90	39.8870	3988.9765	39.8851	3988.7198	
91	39.8871	3988.9894	39.8852	3988.7294	
92	39.8868	3988.9460	39.8848	3988.6827	
93	39.8868	3988.9506	39.8848	3988.6839	
94	39.8870	3988.9707	39.8849	3988.7007	
95	39.8869	3988.9567	39.8848	3988.6834	
96	39.8868	3988.9545	39.8848	3988.6778	
97	39.8868	3988.9466	39.8847	3988.6666	
98	39.8868	3988.9538	39.8847	3988.6704	

The leak simulation described above can be used to modify the data file for the whole record. Care must be taken to ensure that the modified product level does not drop too low in the tank. In practice, the amount of product delivered would depend on the level of product in the tank and would be selected to keep the inventory of product on hand at the desired level.

For CITLDS's that use the product level, calculated volume, and temperature, but do not use the metered amounts or the deliveries, the modified level can be reset to match the recorded level after each delivery. That is, if the algorithm is based on an intermittent use of ATG data, a new baseline of level and volume is established with each delivery. The leak simulation can be based on cumulating the product lost from the tank starting after each delivery. This may be more convenient than cumulating losses over the entire period and should ensure that the modified product level remains within normal limits. Note that the cumulative loss from a 0.3-gph leak would approach 225 gallons over a month. For most tank operations, at least in 8,000 gallon tanks or larger, a product loss of 225 gallons would still leave the tank level within normal inventory limits.

An additional type of leak simulation is used to demonstrate that the system does not preferentially use data from low product levels in the tank. For this type of simulation, a variable leak rate is used. Each tank record that has a mathematically induced leak simulated, as described above, will also have a variable induced leak of the same average rate simulated. If all leak simulations were physical leak simulations, the data from the tight tank records will be used to compare a constant and variable leak. These will be simulated mathematically using an average leak rate of the performance standard, e.g., 0.2 gph or 150 gallons per month. The pairs of results with a constant and a variable simulated leak will be compared to document that the system adequately measures leaks throughout the tank. That is, this comparison is used to show that the system does not underestimate the leak by preferring data from low product levels.

The variable leak is simulated by the following process. The square root of the product height is calculated at each time increment. These values are averaged over the record. Then at each time interval, the average leak rate to be simulated is multiplied by the ratio of the square root of the product height at that time interval divided by the average of these square roots. The simulation of the mathematical leak then proceeds as described above, with the exception, that the leak rate is varied at each time increment according to the product level. This description assumes that the time increments in the record are constant. If the time interval between recording of data varies, then the average of the square roots of the product height must be a time-weighted average.

6.3.2 Simulating Leaks in Manifold Tank Systems

If a leak is simulated in a manifolded tank system, the leak rate to be simulated must be divided among the tanks in the system. That is, the leak rate to be simulated is divided by the number of tanks in the system. Then the resulting leak rate is simulated in each tank of the system separately and the resulting data record is used in the evaluation. For example, if a leak rate of 0.20 gallon per hour is to be simulated for a 2-tank manifold, this can be done by simulating a leak rate of 0.10 in each of the 2 tanks.

This approach assumes that while a loss or leak may occur from only one of the tanks in the manifold, the siphon would result in product transfer to make the volume loss appear from the combined tank system.

6.3.3 Simulating Line Leaks

The EPA performance standard for monthly monitoring of pressurized lines is that the system be able to detect a loss of 0.2 gph or 150 gallons per month at normal operating pressure with at least 95% probability, while operating at no more than a 5% probability of false alarm. Since a CITLDS monitors the tank and line system continuously for leak detection, the monthly monitoring standard is appropriate. Since CITLDS systems are inherently continuous, they are not appropriate for conducting annual line tests, although they might be capable of meeting the leak rate standard for such tests.

In contrast to a tank leak, a line leak will only occur when the pump is running for dispensing product, meaning that the line is pressurized. Thus, in order to simulate a line leak, the data base must include information about when the lines are pressurized. The appropriate leak rate will then be introduced in the data only for those periods when the lines are pressurized. Note that the stated equivalency of the 0.20 gallon per hour leak rate and the 150 gallons per month implies that the hourly leak rate is an average leak rate. All leak rates should be considered both as hourly averages and the equivalent total loss per month. With line leaks that occur only while the line is pressurized, the gallons per month is the appropriate figure to use in simulating leak rates.

As with the tank leaks, there are two different experimental designs, depending on whether the CITLDS is quantitative or qualitative in the manner in which it reports line leaks. If the CITLDS is quantitative and reports an estimated leak rate, then the line leak simulation would include zero and 3 leak rates including the target leak rate. If the CITLDS is qualitative and reports only the presence or absence of a line leak, then only zero and the target leak rate are included in the design.

For the monthly standard, the recommended leak rates for a quantitative system are 0.10 gph (72 gallons per month), 0.20 gph (144 gallons per month), and 0.30 gph (216 gallons per month). Note that these gallons per month are based on 30-day months and so are slightly smaller (hence more stringent) than the regulations which state that a 0.20-gph leak or 150 gallons per month is to be detected.

The data record must include the information about when the line is pressurized. The first step in simulating the leak is to determine the proportion of the time that the lines are pressurized. The second step is to calculate the monthly total loss corresponding to the leak rate to be simulated. This is then converted to an average leak rate when the line is pressurized. For periods of time when the line is pressurized, the leak is simulated just as for a tank leak but using the leak rate calculated for the period when the line is pressurized. When the line is not pressurized, no leak is simulated. Thus, the difference in leak simulation for tanks and lines is that the line leak is introduced only when the line is pressurized. Otherwise, both are assumed to result in a constant loss of product from the tank that is not accounted for in metered dispensing. If the ability of the system to detect both line and tank leaks is being investigated, the same records with zero leak (tight condition) can be used, but separate records with induced or simulated line and tank leaks are required.

Table 3 is an example of a leak simulated in level and volume data. For purposes of illustration, the leak rate used there was 0.2 gallon per hour. The leak rate was simulated intermittently, with the comments column of the table showing when the pump was off, dropping the line pressure and stopping the leak. The example has a brief interval of product dispensing and two periods with the pump on, pressurizing the line, separated by a period when the pump was off, when no leak occurred. In this limited data, the pump was on about 85% of the time, implying that the average leak was about 0.17 gallon per hour. For line leaks, if the line was pressurized about 50% of the time, this simulation, carried out over the month, would result in an average leak rate of about 0.1 gallon per hour (72 gallons over the month).

For the monthly standard the target leak rate is 0.20 gph (150 gallons per month). While approximately 60 records with induced leaks and 60 tight records would be used, if both tank and line rates are being induced, again only one set of tight tank records is necessary, requiring a total of 180 records rather than the 240 that would be needed if the tight records are not used for both the tank and line comparison.

6.3.4 Simulating Leaks When the CITLDS Uses Meter or Inventory Data

A CITLDS may compare the tank inventory resulting from a product level measurement to the book inventory resulting from accounting for product sales and deliveries as part of its leak detection algorithm. If so, then it is necessary to accumulate the product loss from a simulated leak over the entire period. That is, for this type of algorithm, the product level and volume cannot be reset when a delivery occurs, but rather, the product loss must accumulate over the entire data period.

If a line leak is being simulated with this type of algorithm, the leak would occur only during periods when the pump is on so that the line is pressurized. However, the effect of the leak would be cumulative over the data period even though product loss is intermittent.

In general, in order to simulate leaks appropriately, some knowledge of the algorithm the CITLDS uses is necessary. The evaluating organization will need to know what data are used by the CITLDS. A general understanding of how these data are used is needed to determine what method of simulating the leak is most appropriate.

A leak will result in an unexplained loss of product from the tank and a resulting drop in level. This would occur throughout the period of the leak. The simulation should mimic this loss. Care must be taken to ensure that the modified tank level and volume are consistent and that they are consistent with all other data in the test log file. Generally, only the modified level should be in the file with the leak simulated. The CITLDS should be required to compute the volume from the product level. This will ensure that the simulated data are not inconsistent with the CITLDS algorithm.

6.3.5 Data for Automatic Monthly Inventory Control

Automatic monthly inventory control CITLDS systems are designed to meet the EPA requirement of manual inventory reconciliation. This EPA requirement requires that operators of tanks physically measure the inventory in the tank each operating day. This measurement produces the "stick" amount in the tank. A "book" amount is calculated by taking the previous stick inventory value, adding any deliveries, and subtracting sales to get a book inventory. The book amount must be compared daily to the amount of product in the tank measured by sticking the tank. In addition, the daily differences must be reconciled monthly. If the cumulative monthly difference between the stick and book values of the inventory exceeds 1% of the monthly throughput plus 130 gallons, some action must be taken to determine the reason for the discrepancy.

The automatic monthly inventory control system is designed to automate the collection of at least some of the required data, automatically do the calculations of the daily differences, compute the monthly reconciliation, compute the EPA action level, and make the comparison.

The data for evaluating automatic monthly inventory control systems will consist of inventory data for several tanks recorded by the system. In addition, any data entered manually will be recorded and provided separately. This protocol requires that an automatic monthly inventory control system record some part of the required inventory data automatically. Note that there is no need to simulate leaks in the inventory reconciliation data. By the way in which inventory reconciliation is calculated, any simulated leak would be exactly reproduced in the calculations. The inventory reconciliation for a tight tank should ideally be zero. Differences from zero result from a variety of effects, including sticking errors, meter errors, delivery differences, and temperature effects. The degree to which an automatic monthly inventory control system can reduce such errors is a measure of its quality. Thus, the data base will be inventory records from tight tanks and the system will be evaluated based on its ability to automate the calculations and reduce the various errors.

Because of the requirement for calculation of daily differences, automatic monthly inventory control must inherently be quantitative. Its evaluation will be based on 45 monthly records.

Several levels of automatic inventory calculation are possible. The most automated would log tank inventory from level data, sales data from meters, and delivery from ATGS delivery reports. A slightly less automated alternative might be to enter delivery ticket data manually.

The next level would include either tank inventory data or meter data recorded automatically, with the other entered manually. Delivery ticket information would be entered manually.

The data logged by the system will include tank level data (from which volumes will be calculated) representing physical or stick inventory and meter data sales. In addition the date and time of each entry will be recorded. Delivery tickets will be recorded along with the date and time of each delivery.

The inventory records for a number of months for a number of tanks will comprise the evaluation data base. The inventory reconciliation will be calculated by the system software for each month and tank. These differences in gallons per month should ideally be zero.

The throughput for each inventory record will be calculated. The monthly difference in gallons for each tank will be calculated and expressed as a percentage of the monthly throughput. The data analysis will calculate the mean and standard deviation of the reconciliation numbers in percent. A t-test will be used to test for bias (mean zero). The standard deviation of the percent of throughput numbers will be used to prepare a table of estimated probability of false alarm by dividing the EPA action level (1% of throughput plus 130 gallons) expressed as a percent of several different monthly throughput levels by the standard deviation. An estimated detectable leak (in percent of throughput) will be reported for each throughput level by adding 1.65*SD to the action level. The numerical value 1.65 is the upper 95% level of the normal distribution.

The mean and standard deviation will be reported. In addition, the results report will include the estimated probability of false alarm and the estimated leak rate that can be detected with 95% probability, expressed as a percent of throughput. A copy of the inventory system's report form will be included as part of the required report, showing how the system reports the daily differences, monthly reconciliation, action level, and decision.

6.4 SUMMARY OF THE DATA BASE REQUIREMENTS

- Data from at least 10 different tanks from at least 5 different sites are required (one site may be a special test facility).
- A total of 100 records is required for evaluation of a quantitative CITLDS; 240 records are required for evaluation of a qualitative CITLDS.
- A total of 45 data sets will be selected at random from 100 records for evaluating a quantitative CITLDS; 120 data sets selected at random for evaluating a qualitative CITLDS. (More may be used.)
- At least 1 physical simulation of a leak is recommended for Continuous ATGS (either at a field site or special test facility). This provides 1 of the 45 or 120 required test records.
- If the physical sensors of the system were part of a system with a previous evaluation, that evaluation report may be included by reference. If no previous evaluation of the measurement system has been done, then a series of at least 6 physical leak simulations is required. These may be full CITLDS tests or they may be applied in a shut-down ATG test mode.
- At least half the tank records used in the evaluation should be from tanks containing gasoline unless the system is limited to other products.
- At least 75% of the tank records used in the evaluation must be from tanks that operate on a 24-hour basis unless the system is restricted to non-24-hour sites.

- If designed for use on manifolded tank systems, at least 25% (and no more than 75% unless the evaluation is only for manifolded systems) of the tank systems used in the evaluation data must be from manifolded systems.

- If designed for use on tank systems with blending pumps, which draw product from two tanks with different grades to achieve a mid-grade product, and if the system relies on level changes to identify dispensing, then at least 25% (and no more than 75%) of the tank systems used in the evaluation data must be from systems with such blending pumps.

- The tank records should be distributed over the tank sizes and throughputs of the tank population for which the CITLDS is intended to be used. These distributions imply restrictions on the use of the system.

- The standard deviation of the differences in temperature between the product in the tank and that delivered must be at least 4°F.

- Multiple records from each tank from non-overlapping periods may be used, but no more than 15 records from any one tank system (including a test facility) may be used.

- The evaluating organization spotchecks the data to ensure that representative data are used. This includes plotting level changes over time and checking to ensure the records are for continuous periods for each task. Other data quality checks are described in Section 6.2.1.

- The mathematical simulations are done by the evaluating organization, and the evaluating organization operates the CITLDS program or system on the data records without the vendor.

SECTION 7

STATISTICAL ANALYSIS

The data reported in the Reporting Form For Leak Rate Data are used to calculate the performance estimates. The method of data analysis for a quantitative system is basically the same as in the ATG, volumetric tank tightness test, and SIR protocols. The data analysis for qualitative systems is the same as in the SIR and non-volumetric tank tightness test protocols. However, additional calculations are required to demonstrate that the performance is not adversely affected by larger tank sizes, larger throughputs or the inclusion of manifolded tank systems in the data. Separate subsections are provided describing the data analysis for quantitative and qualitative methods.

7.1 BASIC STATISTICS FOR QUANTITATIVE SYSTEMS

The n pairs of estimated and induced leak rate data are used to calculate the mean squared error, MSE, the bias, and the variance of the CITLDS as follows.

Inconclusive or Invalid Results

It is possible, but unlikely, that a data record might not produce a valid result; that is, that the leak detection software of the CITLDS determines that an operational problem has occurred meaning that the data are inadequate so no valid leak rate can be estimated, and consequently that the test is not valid. If this should happen, the result will be noted and reported as an invalid result. The number and percent of any such results will be reported on the results form.

A minimum number of valid tests is required for the evaluation. For systems that report quantitative results, a minimum of 32 valid tests (out of the planned 45) is required. Further, no more that 30% of the results may be invalid in each nominal leak rate group. For systems that report on a qualitative basis, at least 90 valid tests (out of the planned 120) are required.

Mean Squared Error

The mean squared error, MSE, is given by

$$MSE = \sum_{i=1}^{n} (L_i - S_i)^2/n \qquad (3)$$

where L_i is the estimate leak rate reported by the CITLDS system and S_i is the actual induced leak rate, for i from 1 to n for the different data bases. The bias, B, is estimated by

$$B = \sum_{i=1}^{n} (L_i - S_i)/n \qquad (4)$$

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

Variance and Standard Deviation

The variance is found from the formula

$$\sigma^2 = \sum_{i=1}^{n} [(L_i - S_i) - B]^2/(n-1) \qquad (5)$$

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

Test for Zero Bias

To test whether the CITLDS system has a bias that is statistically significantly different from zero, the following statistical test on the bias, B, calculated above is performed. Compute the t-statistic

$$t = \sqrt{n}\ B/SD \qquad (6)$$

From a t-table, obtain the critical value corresponding to a t with (n–1) degrees of freedom and a two-sided 5% significance level. For example, with n = 45, there are 44 degrees of freedom and the two-sided 5% significance level leads to a critical value of 2.015. Denote this value by t_c. Compare the absolute value of t to t_c. If the absolute value of the calculated t is less than the critical value, the bias is not significantly different from zero and the system is assumed unbiased. If the absolute value of the calculated value of t exceeds the critical value then the method has a significant bias. If the bias, B, is positive, the system systematically over estimates the leak rate. If B is negative, the system under estimates the leak rate.

7.2 PROBABILITY OF A FALSE ALARM, PFA

The probability of a false alarm, PFA, is the probability that the measured leak rate will exceed the threshold or criterion for indicating a leak when the tank is actually tight. Generally, if the estimated leak rate exceeds a specified leak rate or threshold, C, (for example 0.12 gallon per hour), the tank is judged by the CITLDS to be leaking. If C denotes the criterion or threshold for indicating a leak, B, the estimated bias of the system, SD, the standard deviation, then the probability of a false alarm can be written as:

$$PFA = P\{ t > (C-B)/SD \}, \qquad (7)$$

where the probability is calculated from a t-distribution with the number of degrees of freedom associated with the standard deviation, which would be 54 if the full set of 55 tests is used. This formula assumes that the errors are approximately normally distributed. If the bias, B, was not significantly different from zero, B is taken to be zero.

7.3 PROBABILITY OF DETECTING A LEAK RATE OF 0.20 GALLON PER HOUR, PD

The probability of detection, PD, is the probability that the system will correctly identify a leak of specified size. In general for a leak rate of size R, PD is given by:

$$PD = P\{ t > (C-R-B)/SD \}, \qquad (8)$$

where C, B, and SD are as before, and the probability is calculated from the t-distribution with degrees of freedom corresponding to the SD, which would be 44 if the usual set of 45 records is used. The degrees of freedom would be 54 if the full set of 55 tests is used.

7.4 MEAN AND STANDARD DEVIATION OF THE TIGHT TANK TESTS

The tests conducted under the condition of no leak (tight tank) provide direct estimates of the performance of the system on a tight tank. Calculate the mean and standard deviation for the tests on the tight tank records by using the formulas above restricting the data to the data from the tight tank records. The sample size, n, will also be reduced, to 15 if there are 15 records with no induced leak, for example.

7.5 STATISTICS FOR QUALITATIVE CITLDS

The basic results of the CITLDS report are that the tank is tight or leaking. As noted above there is a possibility that some results might be invalid. These results can be tabulated in Table 4 to summarize the results.

Table 4. SUMMARY OF RESULTS FROM QUALITATIVE CITLDS EVALUATION

Actual Status	Reported			
	Tight	Leaking	Invalid	Total
Tight	T_1	L_1	X_1	N_1
Leaking	T_2	L_2	X_2	N_2

The numbers in Table 4 are used to directly estimate the PFA and PD. The number of tight tanks incorrectly identified as leaking, divided by the total number of tight tanks estimates the PFA. That is

$$PFA = L_1/N_1, \tag{9}$$

where the letters in the cells of Table 4 denote the number of results in the category indicated by the cell label.

Similarly, the PD is estimated by the number of leaking tank records correctly identified as leaking or,

$$PD = L_2/N_2. \tag{10}$$

In Table 4, N_1 is the number of tank records from tight tanks and N_2 is the number of tank records with induced leaks. These numbers are approximately 60, but are actually a random value between 50 and 70, for each evaluation.

The proportion of records declared invalid must also be reported separately for the tight and leaking records as well as for all records. These proportions are calculated as

$$PI(Tight) = X_1/N_1, \tag{11}$$

$$PI(Leak) = X_2/N_2, \tag{12}$$

and

$$PI(All) = (X_1 + X_2)/(N_1 + N_2) \tag{13}$$

for the proportion of invalid records among tight, leaking, and all records, respectively. The proportion of invalid records among all tank records provides an estimate of the proportion of tanks in a population represented by the evaluation data base for which this method cannot be used.

In order for the method to meet the EPA performance standard, PFA must be less than or equal to 0.05 (5%) and PD must be at least 0.95 (95%). If the number of records (either tight or leaking) were 60, the CITLDS could make at most 3 mistakes out of the 60 records and still meet these requirements. It is possible that the system might not make any errors, giving an estimated PFA of 0 or an estimated PD of 1. Since no system is expected to have zero errors in practice, it is important to calculate a confidence interval for the discrete proportion of false alarms or detections to give an indication of what range should be expected for the PFA or PD in practice.

If no errors occur in the evaluation data base, the confidence limit for PFA is found from

$$UL = 1 - \alpha^{1/N_1} \tag{14}$$

where $(1 - \alpha)$ is the confidence coefficient, which is generally set at 0.95. For one or more errors, the confidence limits are calculated from confidence limits for the parameter of a binomial distribution. These can be found in *CRC Handbook of Tables for Probability and Statistics*,[9] for example.

If no errors occur in the evaluation in detecting leaks, a lower confidence bound for PD can be calculated from

$$LL = \alpha^{1/N_2}, \tag{15}$$

where again $(1-\alpha)$ is the confidence coefficient, usually set at 0.95. For one or more errors in detecting leaks, the confidence limits for the binomial are used.[10]

7.6 CALCULATIONS FOR AUTOMATIC MONTHLY INVENTORY CONTROL

There are differences in the calculations for automatic monthly inventory control systems. The data are the results of the monthly inventory reconciliation, so no differences between the measured and reported leak rates are calculated. The calculated cumulative monthly difference between the book and stick inventory

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[9] Beyer, William H., editor, *Handbook of Tables for Probability and Statistics*, The Chemical Rubber Co. 1966, p.65.

[10] *Ibid.*

in gallons should be converted to a percent of the throughput by dividing each such difference by the monthly throughput for that tank and multiplying by 100. These numbers are the basis for the evaluation.

Calculate the mean, standard deviation, variance, and mean squared error by applying the formulas in Section 7.1. The system can be tested for significant bias by applying the test for zero bias also found in Section 7.1. The calculation of the probability of false alarm is different, however. Also, since the EPA specifies an action level, the probability of detection is not calculated. Rather, using the EPA action level, a leak detectable with probability 95% is calculated.

The action level specified by the EPA is 1% of the monthly throughput plus 130 gallons. For each tank record calculate the percent of throughput represented by 130 gallons. That is, divide 13,000 by the monthly throughput for each tank record. Calculate the arithmetic mean of these numbers. The average action level, C, for the evaluation data set is taken as 1% plus this average.

Calculation of PFA

Calculate the ratio of the average action level calculated above to the standard deviation

$$Z = C/SD. \tag{16}$$

Then PFA is given by

$$PFA = P[X > Z], \tag{17}$$

where X is a standard normal random variable. (The t distribution could be used, but the number of degrees of freedom should be greater than 40, so the normal approximation is recommended.)

Calculation of Detectable Loss

The loss, expressed as a percent of throughput, that should be detectable with 95% probability, is calculated next. This loss, DL, is given by

$$DL = C + 1.645\ SD, \tag{18}$$

where SD is the standard deviation, C is the threshold, and 1.645 is the upper 95th percentile from the standard normal distribution. Note that C and SD and hence DL are in percent of monthly throughput of the tank.

7.7 OTHER DATA ANALYSIS AND LIMITATIONS

There are a number of factors that can influence the results of the tests performed by a CITLDS. This section contains additional statistics that should be calculated and reported about the conditions of the test data set. These conditions should be summarized in the same way whether the system is qualitative or quantitative. Statistics are calculated for the size of the tanks used in the evaluation, the monthly throughput of product for these tanks, and the temperature differences between product in the tanks and product deliveries. The test conditions or characteristics of the data base impose restrictions on the application of the system. These limitations are described in this section. Some of these statistics become the basis for limitations on the application of the system. These limitations are described next.

Tank Size

The size of the tank is an important consideration. The distribution of tank sizes should be as nearly uniform as practical. In particular, the data base should not emphasize small tanks. The test data should represent the population of tanks for which the system is intended to be used. The results of an evaluation can be extended to tanks 50% larger than the 80th percentile of the tank sizes in the data set used in the analysis.[11] The tank sizes used in the data base should be reported Table 1.

These tank sizes are to be ordered from least to greatest and various percentiles determined. The smallest, 25th, 50th (median), 75th, and 80th percentile, and the largest tank size are reported on the results form. To find a tank size for a given percentile, take the percentile as a percentage of the sample size, and count up from the smallest tank size until that number of tank sizes is reached. For example, for the 25th percentile, with n=55 records, take 25% of 55 to get 13.75. Fractions are moved up to the next integer, 14 in this case. The 25th percentile is the 14th tank size in the set of ordered tank sizes, counting from smallest to largest. If the result of taking a percent of the sample size is not an integer, use the next larger integer.

In particular, the 80th percentile determines a limitation on tank size. If there are 55 records, the 80th percentile is the 44th tank size counting from the smallest to the largest. If a different number of records is used, the 80th percentile is the tank size corresponding to the integer greater than or equal to 0.8n, where n is the number of records, again counting from the smallest tank size to the largest.

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[11] See notes 5 and 6.

The maximum permissible tank size is calculated as 1.5 times the 80th percentile of tank sizes used in the evaluation. That is, the tank size for each record used in the evaluation is listed. These sizes are then ordered from least to greatest. The 80th percentile is the size such that 80% of the tank sizes are less than or equal to this size. The 80th percentile is computed and multiplied by 1.5 to give the calculated size limitation.

To justify the extrapolation to the larger tanks sizes, the results for smaller tanks and larger tanks must be shown to be similar. To make this comparison, divide the data records into two groups based on tank size. The two groups should be of nearly equal size, but if there are many records at one tank size, e.g., 10,000 gallons, it may not be possible to make the two groups exactly equal. For quantitative systems the number in each group is not particularly critical, but for qualitative systems there must be at least 21 tight records and 21 records with simulated leaks in each group.

For quantitative systems, calculate the mean and standard deviation separately for the two tank size groups. This can be done by using the formulas in Sections 7.1 through 7.4 separately on the two tank size groups. Use a two-sample F test to test whether the variances of the two groups are equal. Calculate

$$F = (SD_1/SD_2)^2, \tag{19}$$

where SD_1 and SD_2 are the standard deviations calculated from the two groups. In forming the F ratio, use the standard deviation with the larger calculated value in the numerator. Compare the calculated value of F to the 95th percentile of an F-distribution with $(n_1 - 1)$ degrees of freedom in the numerator (corresponding to SD_1) and $(n_2 - 1)$ degrees of freedom in the denominator (corresponding to SD_2). The sample sizes are n_1 and n_2, respectively. If the calculated value of F is less than the tabled value, there is no significant evidence that the two population variances are different. In this case, there is justification for extrapolating to tank sizes larger than those in the data base.

If the calculated value of F exceeds the tabled value, the two variances are significantly different at the 5% significance level. This is evidence that the performance of the system is affected by tank size. Assuming that the standard deviation for the larger tank sizes is the larger, this indicates that the performance of the system is worse for larger tanks. The tank size limit should be reduced to the smaller of the largest tank in the data or 1.25 times the 80th percentile.

If the standard deviations are not significantly different, test to see if the bias is different for the two groups of tank sizes. Use a two-sample t-test to test whether there is any significant difference in the bias. Calculate

$$t_b = (B_1 - B_2)/(S_p\sqrt{(1/n_1 + 1/n_2)}), \qquad (20)$$

where S_p is the pooled standard deviation of the two groups and is calculated from

$$S_p = \sqrt{[(n_1 - 1)\ SD_1^2 + (n_2 - 1)\ SD_2^2]/(n_1 + n_2 - 2)} \qquad (21)$$

Compare t_b to a two-sided 5% critical value from a t-distribution with (n_1+n_2-2) degrees of freedom. If the absolute value of t_b does not exceed the critical value then there is no evidence that the bias is different for different tank sizes. In this case, extrapolation to 1.5 times the 80th percentile of tank sizes is justified.

If the absolute value of t_b does exceed the percentile from the t-table, then the system has a significantly different bias for the different tank sizes. The tank size limit should be reduced to the smaller of the largest tank in the data or 1.25 times the 80th percentile.

For qualitative systems, at least 21 tight and 21 simulated leak records are required in each group. Compute the PFA and PD as described in Section 7.5 separately for each group. If both groups meet the performance standard, extrapolation to the larger tank size (1.5 times the 80th percentile) is justified. If one of the groups does not meet the performance standard, but the combined data do meet the performance standard, then the tank size limit should be reduced to the smaller of the largest tank in the data or 1.25 times the 80th percentile.

If a significant difference was found, note this and the reduced tank size extrapolation in the other limitations section of the results form.

Monthly Throughput

The volume of product dispensed from the tank in a month is referred to as the monthly throughput. This could be an important factor in that the higher the monthly throughput the fewer and shorter the periods of quiescence for a tank. This would affect the time needed to get a valid test, the relative noise levels of the test, and the amount of data available for the test. Again to the extent practical, the test data base should represent the distribution of monthly throughputs for the population of tanks for which the system is intended to be used. As with the tank sizes, the distribution of throughputs should be approximately uniform.

The monthly throughputs for the tank records in the data base should be determined and reported in a form such as Table 1. If a test is for less than a month, the throughput for the duration of the test should be determined from the record and scaled up to one month.

The maximum allowable monthly throughput is calculated as 1.5 times the 80th percentile of the throughputs in the evaluation data. The monthly throughput for each record used in the evaluation is calculated. For records that are less than one month, determine the recorded throughput for that record. Divide the throughput by the number of days in the record (use fractions if appropriate), then multiply by 31 to get the equivalent monthly throughput. Order these monthly throughputs from least to greatest and compute the 80th percentile. Multiply this by 1.5 to determine the throughput limit for the system.

To justify the extrapolation to the larger throughputs, the results for smaller throughputs and larger throughputs must be shown to be similar. To make this comparison, divide the data records into two groups based on monthly throughput. The two groups should be of nearly equal size. For quantitative systems the number in each group is not particularly critical, but for qualitative systems there must be at least 21 tight records and 21 records with simulated leaks in each group.

For quantitative systems, calculate the mean and standard deviation separately for the two throughput groups. This can be done by using the formulas in Sections 7.1 through 7.4 separately on the two throughput groups. Use a two-sample F test to test whether the variances of the two groups are equal. Calculate

$$F = (SD_1/SD_2)^2, \tag{22}$$

where SD_1 and SD_2 are the standard deviations calculated from the two groups. In forming the F ratio, use the standard deviation with the larger calculated value in the numerator. Compare the calculated value of F to the 95th percentile of an F-distribution with $(n_1 - 1)$ degrees of freedom in the numerator (corresponding to SD_1) and $(n_2 - 1)$ degrees of freedom in the denominator (corresponding to SD_2). The sample sizes are n_1 and n_2, respectively. If the calculated value of F is less than the tabled value, there is no significant evidence that the two population variances are different. In this case, there is justification for extrapolating to throughputs larger than those in the data base.

If the calculated value of F exceeds the tabled value, the two variances are significantly different at the 5% significance level. This is evidence that the performance of the system is affected by throughput. Assuming that the standard deviation for the larger throughputs is the larger, this indicates that the performance of the system is worse for higher throughput tanks. The throughput limit should be reduced to the smaller of the largest throughput in the data or 1.25 times the 80th percentile.

If the standard deviations are not significantly different, test to see if the bias is different for the two groups of throughputs. Use a two-sample t-test to test whether there is any significant difference in the bias. Calculate

$$t_b = (B_1 - B_2)/(S_p\sqrt{(1/n_1 + 1/n_2)}), \tag{23}$$

where S_p is the pooled standard deviation of the two groups and is calculated from

$$S_p = \sqrt{[(n_1 - 1)\ SD_1^2 + (n_2 - 1)\ SD_2^2]/(n_1 + n_2 - 2)} \tag{24}$$

Compare t_b to a two-sided 5% critical value from a t-distribution with (n_1+n_2-2) degrees of freedom. If the absolute value of t_b does not exceed the critical value then there is no evidence that the bias is different for different throughputs. In this case, extrapolation to 1.5 times the 80th percentile of throughputs is justified.

If the absolute value of t_b does exceed the percentile from the t-table, then the system has a significantly different bias for the different throughputs.

For qualitative systems, a minimum of 21 tight and 21 simulated leak records is required in each group. Compute the PFA and PD as described in Section 7.5 separately for each group. If both groups meet the performance standard, extrapolation to the higher throughput (1.5 times the 80th percentile) is justified. If one of the groups does not meet the performance standard, but the combined data do meet the performance standard, then the throughput limit should be reduced to the smaller of the highest monthly throughput in the data or 1.25 times the 80th percentile.

If a significant difference in the performance for different throughputs was found, note this fact and the reduced throughput limit in the other limitations section of the results form.

Large Leak Rate Calculations

Ten (or more) large leak rates in the 1 to 10 gallons per hour range were simulated to demonstrate that the system can detect such rates. These are not used in the computation of the PD and PFA and associated statistics. However, they are used to qualify the system. The system must give a leak result or fail indication for all of these rates. Report the number of large leaks and the proportion correctly identified as leaks on the results form.

The large leak rate tests and calculations are not required for the Automatic Monthly Inventory Control systems because these are not stand-alone leak detection systems.

Comparison of Variable and Constant Leak Rate Pairs

Variable leaks will be simulated on all tank records for which mathematical leaks were simulated. In the (unlikely) event that physical leak simulations were used for all the leak simulations, the tight tank records will be used with both a constant and a variable leak rate. Approximately equal numbers of each nominal leak rate will be used.

It should be emphasized that these variable and constant leak rate simulation pairs are done on the same basic tank record data.

The result will be pairs of leak rate estimates by the system. One member of the pair will be the leak rate estimated for a data record with a constant leak rate simulated. The other member of the pair will be the leak rate estimated by the system when a variable leak rate with the same average rate or overall product loss was simulated.

Form the differences between these pairs of estimated leak rates under constant and variable leak rates (on the same data record). Subtract the reported leak rate with the constant simulated leak rate from the reported leak rate with a variable simulated leak rate. Calculate and report the mean, standard deviation, minimum, and maximum of these differences. Note that these differences are not used on computing the PD and PFA.

In order for the system's performance to be acceptable, the mean of these differences must be greater than or equal to zero. This is reported on the results form.

For qualitative systems to qualify, the system must identify at least as many leaks with the variable leak rate simulation as it does with the constant leak rate simulation. That is, the proportion of leaking records that the system correctly identifies must be at least as large with the variable leak rate as it is with the constant leak rate. To meet the EPA standard, this proportion must be at least 95%. If there are 60 records with induced leaks, at most 3 could be misclassified as tight and still meet the 95% criterion.

This requirement does not apply to Automatic Monthly Inventory Control systems, since leak rates are not simulated for these systems. Also, these are not stand-alone leak detection systems.

Manifolded Tanks with a Siphon

If the system is to be used for manifolded tanks as well as single tanks, the evaluation must contain between 25% and 75% data from manifolded tank systems. For this purpose manifolded tanks are those connected with a free-flowing siphon. Blending pumps are considered later.

To justify the use of the system for both types of tank systems, the results for single tanks and manifolded tanks must be shown to be similar. To make this comparison, divide the data records into two groups based on whether the tanks are single or manifolded. For quantitative systems the number in each group is not particularly critical, but for qualitative systems there must be at least 21 tight records and 21 records with simulated leaks in each group.

For quantitative systems, calculate the mean and standard deviation separately for the two groups. This can be done by using the formulas in Sections 7.1 through 7.4 separately on the two groups. Use a two-sample F test to test whether the variances of the two groups are equal. Calculate

$$F = (SD_1/SD_2)^2, \quad (25)$$

where SD_1 and SD_2 are the standard deviations calculated from the two groups. In forming the F ratio, use the standard deviation with the larger calculated value in the numerator. Compare the calculated value of F to the 95th percentile of an F-distribution with $(n_1 - 1)$ degrees of freedom in the numerator (corresponding to SD_1) and $(n_2 - 1)$ degrees of freedom in the denominator (corresponding to SD_2). The sample sizes are n_1 and n_2, respectively. If the calculated value of F is less than the tabled value, there is no significant evidence that the two population variances are different. In this case, there is justification for using the system on both single and manifolded tank sizes.

If the calculated value of F exceeds the tabled value, the two variances are significantly different at the 5% significance level. This is evidence that the performance of the system is affected by the presence of a manifolded system. In this case, continue the computation of the PD and PFA separately for the single and manifolded tank groups. If both groups meet the performance standards the system may be used on both single and manifolded tank systems, however the difference in performance should be reported. If only one group meets the performance standards, then the use of the system must be limited to the group (single tanks or manifolded tanks) for which the performance standards are met.

If the standard deviations are not significantly different, test to see if the bias is different for the two groups of tanks. Use a two-sample t-test to test whether there is any significant difference in the bias. Calculate

$$t_b = (B_1 - B_2)/(S_p\sqrt{(1/n_1 + 1/n_2)}), \tag{26}$$

where S_p is the pooled standard deviation of the two groups and is calculated from

$$S_p = \sqrt{[(n_1 - 1)\ SD_1^2 + (n_2 - 1)\ SD_2^2]/(n_1 + n_2 - 2)} \tag{27}$$

Compare t_b to a two-sided 5% critical value from a t-distribution with (n_1+n_2-2) degrees of freedom. If the absolute value of t_b does not exceed the critical value then there is no evidence that the bias is different for single tanks compared to manifolded tanks. In this case, use of the system for both types of tanks is justified.

If the absolute value of t_b does exceed the percentile from the t-table, then the system has a significantly different bias for the different tank sizes. In this event, continue the computation of the PD and PFA separately for the single and manifolded tank groups. If both groups meet the performance standards the system may be used on both single and manifolded tank systems, however the difference in performance should be reported. If only one group meets the performance standards, then the use of the system must be limited to the group (single tanks or manifolded tanks) for which the performance standards are met.

For qualitative systems, compute the PFA and PD as described in Section 7.5 separately for each group. If both groups meet the performance standard, extrapolation to both types of tanks is justified. If one of the groups does not meet the performance standard, but the other does, then the results must be limited to the class of tanks for which the system meets the performance standards.

If manifold tank systems are included, limit the use to the number of tanks in the manifold plus 1. For example, if 25% of the data are from manifold tanks with two tanks in the manifold, limit the application to manifold systems with no more than 3 tanks. To qualify for larger numbers of tanks in the manifold, at least 20% of the records should be from tank systems with the larger number of tanks in the manifold and at least 25% of the tank records from manifolded tanks. Again, the distribution of the number of tanks in the manifolded systems should represent the intended use of the system. However, use of the system should not be extended to more difficult cases without justification based upon adequate data in the evaluation.

If differences in performance were found for manifolded as compared to single tanks, report this fact on the results form. There is an additional table provided there to report the PFA and PD separately for the single and manifolded tank systems. Report the combined PFA and PD in the main part of the results, if pooling the results is appropriate as described above.

Tanks with Blending Pumps

Some tank systems have dispensers that blend the product from two tanks to obtain a mid-grade product. This feature must be considered together with the operation of the CITLDS.

If the CITLDS system uses the change in level in the tank to identify a dispensing operation from that tank, then at least 25% of the records in the evaluation data base must be from systems of that type. To demonstrate that the system can correctly identify a dispensing operation as distinct from a large leak, large leaks, in the range of from 1 to 10 gallons per hour must be simulated in the data from the blending pump systems. The system must correctly identify these as leaks. These simulations should be run on all blending pump data. The results should indicate a fail or identify a leak. However, the results are not used in the calculation of the PD and PFA. In simulating the large leaks, a leak can be simulated from a single tank, as that would probably be the most common occurrence of a leak in practice.

The Automatic Monthly Inventory Control systems are not evaluated with induced leak rates, and so are exempted from this consideration.

Product Level Operating Limits

The minimum product level and maximum product during a test period are to be determined for each tank record. The overall minimum product level and the overall maximum product level are reported as limits on the performance of the system. The system has not been demonstrated to work outside of these product level limits.

Report these minimum and maximum product levels on the results form in the space provided.

Additional Large Leak Rate Tests

To demonstrate that the system is capable of detecting large leaks as well as those approximately the size of the detection limit in the performance standards, supplemental tests are run. Select equal numbers of leak rates from 1 to 10 gallons per hour. Randomly assign these to the tank records and simulate these large leak rates. Apply the system to those leak rates. The system must fail the tank, indicate a leak for all of these large leak rates, or provide some type of warning to estimate the problem under the large leak conditions. The large leak rate data are only used in this qualitative fashion. They are not used in calculation of PD and PFA.

The Automatic Monthly Inventory Control systems are exempted from this test and requirement, since they are not evaluated with induced leak rates.

Supplemental Testing for Sensors not Previously Evaluated

If a CITLDS system is based on new technology, not previously evaluated, supplemental tests using physical leak simulation are required to demonstrate that the sensors do track product level changes. Two approaches are possible. If physical leak simulations are part of the experimental design, then no special calculations are needed as they will be included in the estimation of the performance. However, an alternative is to demonstrate that the sensors do adequately track volume changes through a limited set of 6 tests with the system testing in a shut down mode. If this option is used, then the mean and standard deviation of the difference between the measured and induced leak rates for the 6 tests with physical leak simulations are calculated. The standard deviation is required to be less than or equal to 0.061 gallon per hour to demonstrate that the system adequately tracks the physical loss of product.

The Automatic Monthly Inventory Control systems are exempted from this requirement.

Temperature

The difference in temperature between the product delivered and that in the tank can affect a test. In some instances the CITLDS delays the start of the test until temperature equilibrium has been achieved. The tank records are used to obtain the product temperature and volume just prior to each delivery. The amount of delivery can be obtained from the inventory file. The temperature and volume of the product 30 minutes after the delivery is also obtained from the data files. From the amount of product in the tank at the initial average temperature, the amount of delivery, and the amount and average temperature of the product in the tank after the delivery, the temperature of the product delivered is calculated using the formula:

$$T_d = (V_2T_2 - V_1T_1)/V_d, \qquad (28)$$

where T_i and V_i denote the temperature and volume at times i, where i=1 denotes the initial and i=2 the final temperature and volumes. The subscript d denotes the delivery. Of course, if the temperature of the delivered product is available, it can be used directly to compare to the temperature of the product in the tank, but this temperature is not often available.

Once the temperature differences between the product delivered and the product in the tank are determined, find the smallest and largest difference (including the sign). In addition, find the mean and standard deviation of the temperature differences. These are reported on the results form.

Test Duration

The amount of time the system must collect data before it has a valid test is of importance. This required time may be a function of the tank size and the throughput. From the test data, find the length of time from the initiation of the test until the CITLDS system completed the test. Record these data on the Reporting Form for Leak Rate Data. Also determine and report the mean and standard deviation of the test durations. The evaluating organization should note any special conditions that might affect the time needed for the system to complete a test under the comments section on the Results Form.

7.8 SUMMARY OF THE DATA ANALYSIS REQUIREMENTS AND LIMITATIONS

- At least 32 valid test results are required for a quantitative system; at least 90 valid results are required for a qualitative system. No more than 30% may be invalid an any leak rate group.

- The records must be divided into groups at the median tank size. The results for the small and large tanks must be compared. If no significant differences are found, the system is qualified for tanks up to 1.5 times the 80th percentile of the tank sizes used in the evaluation. If the results are different, extension is limited to the smaller of 1.25 times the 80th percentile, or the maximum tank size in the evaluation.

- The throughputs for the data records are to be divided at the median. A comparision of results for the small and large throughput records is done. If no statistical significant difference is found, the system is qualified for throughputs up to 1.5 times the 80th percentile of the throughputs in the evaluation. If there are differences, the limitation is 1.25 times the 80th percentile or the largest throughput in the data, whichever is less.

- At least 10 large leak rate (1 to 10 gph) simulations are required. The system must correctly indicate a leak on all 10.

- All tank records with mathematically simulated leaks will have a variable leak rate simulated as well as the constant leak rate. The average leak rates will be the same. (At the minimum, the 15 tight tank records will be used.) The average difference between the leak rate reported for the variable leak and the constant leak will be calculated and must be greater than or equal to zero. If a qualitative system is used, the proportion of leaks identified with the variable rate simulation must be greater than or equal to the proportion identified with the constant leak rate simulation.

- If manifold data are included in the evaluation, the results for single tanks and manifold tanks are compared. If a significant difference is found, PD and PFA results are calculated and reported separately. If only one group meets the performance standard, application of the system is restricted to that group.

- If the system is used on blending pumps and blending pumps are part of the data base, large leak rates (1 to 10 gph) are simulated in the data from blending pumps. The system must indicate a leak on all such large leak rates.

- The minimum and maximum product level is calculated and reported for the data set used in the evaluation. These become limitations on the use of the system.

- The difference in temperature of the product delivered and already in the tank is calculated for each delivery. The standard deviation of those differences is found and reported. It must be at least 4°F. The system is qualified whenever temperature differences are less than 1.5 times the standard deviation reported.

- If the system uses sensors that have been previously evaluated, the previous evaluation must be referenced. Alternately physical leak simulations are required, which may be done with a minimum of 6 shut-down mode tests at a test facility.

SECTION 8

REPORTING

This section describes the reporting of the results. As a minimum, the report must include the completed results form, the description form, and the appropriate data reporting form. In addition, a sample report is required from automatic inventory control systems. This form will be specific to each system and can consist of a photocopy of the result that the system reported for one of the tank inventory records used. If necessary, any identifying information about company or location can be blanked out. Instructions for completing each standard form are included in this section.

Results Form

The results form is designed to be provided to each installation using the CITLDS. It provides the documentation that the CITLDS has been evaluated and shown to meet the EPA requirements. First enter the name, version number, and vendor's name, address, and telephone number. The name and version are repeated on each page.

The evaluation results consist of several sections. Review each section to determine which are applicable and complete those sections. Place a check mark or "X" in the box(es) indicating inapplicable sections and leave these blank otherwise.

The first section reports quantitative results from a tank leak simulation. Report the mean and standard deviation in the blanks provided. Enter the system's threshold and calculated probabilities of false alarm and detection in the appropriate cells of the table. The method of calculation is described in Sections 7.1 to 7.3. Indicate the size of the leak detected to correspond to the probability of detection. If the system uses more than one threshold for different levels of operation, use one line for each and enter the corresponding size of the leak rate detected for each.

If any results were invalid, enter the appropriate numbers and percentages as indicated. If there were no invalid results, enter zero.

If the system has a water detection function, enter the appropriate results. If not, enter "NA" in the blanks.

If line leaks were simulated and quantitative results reported, complete the next section. Make the same entries as before, based on the data from the line leak simulations.

The next section is applicable for qualitative results from tank leak simulations. Report the number of records in each category as indicated in the table. Report the estimated PFA and PD resulting from the calculations described in Section 7.5. Include reporting of any invalid records.

The next section reports results from qualitative systems using line leak simulations. Report the data as before, but based on data resulting from simulated line leaks.

The next section is the results from an automatic monthly inventory control system. If this section is applicable, enter the mean and standard deviation of the results expressed in percent of throughput. Enter the threshold as calculated in Section 7.7, along with the probability of false alarm and the size of a leak detectable with a PD of 95%.

The next section reports test conditions. Test condition requirements are summarized in Section 6.4. Analysis requirements relating test conditions to limitations are summarized in Section 7.8. In the first table, enter the percentiles of the tank sizes used in the evaluation. In the second table, enter the percentiles of the monthly throughputs.

Following these tables, enter the range of temperature differences and the standard deviation. The results are limited to conditions when the temperature difference is not more than 1.5 times the standard deviation of temperature differences observed in the evaluation. Follow this with the range of tank levels observed in the data. Finally, report the minimum and maximum duration of the tests and the mean.

The results of the variable versus constant leak rate calculations are reported next. If the system is quantitative, report the average difference between the estimated leak rates for the variable and constant induced leak rates. This system must estimate a larger leak rate on the average for the variable leak rate records to meet the performance standards. If the system is a qualitative one, report the number of records identified as leaking with variable induced leaks and the number identified as leaking with constant leak rates. The number identified with variable leak rates must be at least as large as the number identified with constant induced leak rates.

The overall result is indicated by marking the appropriate box with a check or "X" according to whether the system meets the EPA performance standards for monthly monitoring. Also mark the appropriate box or boxes to indicate whether the evaluation showed that the system met the performance for leaks simulated from tanks, lines, or both. If both, mark both the tank and line boxes. If the system meets the performance standards for only one of the types of leaks, mark that the system does meet the performance standard and mark only the box corresponding to the type of leak for which the system was shown to work.

The limitations sections indicates the conditions under which the system should be used. The tank volume to be indicated is one and one-half times the 80th percentile of the tank sizes in the evaluation data, unless data analysis indicates a smaller limit is needed. The monthly throughput is limited to 1.5 times the 80th percentile of the throughputs observed in the evaluation data, unless the analysis indicates a smaller limit. Enter the minimum number of days for a valid result for the length of the data records. Enter the minimum and maximum product height used in the evaluation as limits on the product height range. Use the blank lines to enter any other restrictions, conditions, or explanations. Always enter whether the evaluation is valid for tank leaks, line leaks, or both, or whether it is an automatic inventory control system only.

In the certification of results, indicate whether there were any deviations from the data base definitions summarized in Section 6.4 and whether there were any deviations from the computations summarized in Section 7.8. Finally, provide the name and address of the evaluating organization, together with the individual who directed the testing.

Description Form

This form is provided to provide a summary description of the system. Enter the name and version number of the product. Mark the appropriate boxes for each question. Use the white space to provide any explanations for questions that are not completely applicable or that require elaboration.

Reporting Form for Quantitative Leak Rate Data

Use this form to summarize the data used in the evaluation for a quantitative system. Report the system name and version. Indicate at the top of the form whether it is reporting tank or line leak simulations. Enter the data as indicated in each column. Use as many pages as necessary.

If both tank and line leaks were simulated, complete a separate form for the tank and line leak data. Indicate at the top which type of leak was simulated.

Reporting Form for Qualitative Leak Rate Data

If the system is qualitative, use this form to report the evaluation data. Enter the system name and version at the top. Indicate whether a tank or line leak has been simulated. Use as many pages as needed. If both a tank and line leak were simulated, use a separate form for each type of leak rate data. Complete the data called for in each column for each record used.

Reporting Form for Automatic Inventory Data

Use this form to summarize the data from an evaluation of an automatic inventory control system. Give the system name and version at the top. Complete the form by entering the indicated data for each inventory record used in the evaluation.

STANDARD REPORTING FORMS

Results of U.S. EPA Alternative Protocol Evaluation

Description

Reporting Form for Quantitative Leak Rate Data

Reporting Form for Qualitative Leak Rate Data

Reporting Form for Automatic Inventory Data

Results of U.S. EPA Evaluation

Continuous Leak Detection System (CITLDS)

This form tells whether the continuous leak detection system (CITLDS) 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 proposed Continuous Leak Detection System Evaluation Protocol. This protocol is deemed equivalent in stringency to the EPA Evaluation Protocols. 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.

CITLDS Description

Name ______________________________

Version Number ______________________________

Vendor ______________________________

(street address)

____

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

Evaluation Results

Quantitative Results For Tank Leak Simulation (Complete this section based on the tank leak simulation data if the CITLDS reports a leak rate. If this section is not applicable, check here ☐ and leave the section blank.)

This CITLDS declares a tank to be leaking when the measured leak rate exceeds a threshold. The threshold, probability of false alarm, PFA, and probability of detection, PD, of detecting an average leak rate of 0.20 gallon per hour or 150 gallons per month, are given in the table below.

The mean difference between the measured and reported leak rate was ________ gph. The standard deviation was _______ gph.

Threshold	Probability of False Alarm (FA)	Probability of Detection (PD) of leak ___ gph

Any results that were invalid due to operational difficulties are to be reported. If the data included any invalid results, record that fact here. If not, indicate that. There were _____ invalid results out of ______ records in the data, or _____%. This means that the system may not provide a conclusive test result _____% of the time.

If the CITLDS has a water detection function, complete the following:

The minimum water level (threshold) in the tank that the CITLDS can detect is _______ inch. The minimum change in water level that can be detected by the CITLDS is _______ inch.

Quantitative Results for Line Leak Simulation (Complete this section based on the line leak simulation data if the CITLDS reports a leak rate. If this section is not applicable, check here ☐ and leave the section blank.)

Name of CITLDS ______________________________

Version ______________________________

This CITLDS declares a tank system to be leaking when the measured leak rate exceeds a threshold. The threshold, probability of false alarm, PFA, and probability of detection, PD, of detecting an average leak rate of 0.20 gallon per hour or 150 gallons per month, are given in the table below.

The mean difference between the measured and reported leak rate was ________ gph. The standard deviation was ______ gph.

Threshold	Probability of False Alarm (FA)	Probability of Detection (PD) of leak ___ gph

Any results that were invalid due to operational difficulties are to be reported. If the data included any invalid results, record that fact here. If not, indicate that. There were _____ invalid results out of ______ records in the data, or _____%. This means that the system may not provide a conclusive test result _____% of the time.

Qualitative Results for Tank Leak Simulation (Complete this section based on the tank leak simulation data if the CITLDS reports on a pass/fail basis. If this section is not applicable, check here ☐ and leave the section blank.)

	Reported			
Actual Status	Tight	Leaking	Invalid	Total
Tight				
Leaking				

The estimated PFA was ______ with a 95% confidence interval from ______ to ______.

The estimated PD for detecting a leak rate of 0.20 gallon per hour (150 gallons per month) was _____ with a 95% confidence interval from ______ to ______.

Any results that were invalid due to operational difficulties are to be reported. If the data included any invalid results, record that fact here. If not, indicate that. There were _____ invalid results out of ______ records in the data, or _____%. This means that the system may not provide a conclusive test result _____% of the time.

Qualitative Results for Line Leak Simulation (Complete this section based on the line leak simulation data if the CITLDS reports on a pass/fail basis. If this section is not applicable, check here ☐ and leave the section blank.)

	Reported			
Actual Status	Tight	Leaking	Invalid	Total
Tight				
Leaking				

The estimated PFA was ______ with a 95% confidence interval from ______ to ______.

Name of CITLDS ______________________________

Version ______________________________

The estimated PD for detecting a leak rate of 0.20 gallon per hour (150 gallons per month) was _____ with a 95% confidence interval from _____ to ______.

Any results that were invalid due to operational difficulties are to be reported. If the data included any invalid results, record that fact here. If not, indicate that. There were _____ invalid results out of ______ records in the data, or _____%. This means that the system may not provide a conclusive test result _____% of the time.

Automatic Monthly Inventory Control Results (If the system is an automatic monthly inventory control system, enter the results in this section. If there is no monthly inventory control function, check here ☐ and leave this section blank.)

The mean of the monthly inventory reconciliations was ______ gallons per month. The standard deviation was ______ gallons per month. Using the EPA action level of 1% of throughput plus 130 gallons gave the estimated false alarm rate reported below. Also reported is the smallest loss that could be detected with 95% probability using the EPA threshold.

Threshold	Probability of False Alarm (FA)	Size of leak detected with a (PD) of 95%.

Test Conditions During Evaluation

The data evaluation set included data from tanks of the following sizes:

	Min.	25	Median 50	75	80	Max.
Percentile of Records						
Tank Size (gal)						

The tanks had various monthly throughputs:

	Min.	25	Median 50	75	80	Max.
Percentile of Records						
Monthly throughput (gal)						

The temperature difference between product added to fill the tanks 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 ranging from ______ % to _____ % full.

The duration of the CITLDS tests ranged from ______ to ______, with an average duration of ________ (specify appropriate time units, e.g., day or hours).

The system correctly identified ___ leaks of ___ simulated leaks in the 1 to 10 gph range. Note: must be 100% in this range to be acceptable.

Name of CITLDS ____________________

Version ____________________

For a quantitative system, enter the average difference between the estimated leak rate with a variable simulated leaks minus the estimated rate with a constant simulated leak was _____ gph. This difference must be greater than or equal to zero for the system to be acceptable. For a qualitative system, enter the number of leaks identified with variable leak rates _____ and the number identified with constant leak rates _____. The number with variable leak rates must be at least as large as the number with constant leak rates.

Based on the results reported on pages 1 and 2 of this form, the reported method ☐ does ☐ does not meet the **federal** performance standards established by the U.S. Environmental Protection Agency of an average leak rate of 0.20 gallon per hour or 150 gallons per month from ☐ a tank ☐ or lines (mark applicable boxes) at PD of 95% and PFA of 5%.

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 CITLDS are followed.
- The tank contains a product identified on the method description form.
- The tank is no larger than _____ gallons.
- The data records cover _____ days or more.
- The monthly throughput is ________ gallons or less.
- The difference in temperature between product in the tank and that delivered is ______°F or less.
- The system ☐ may or ☐ may not be used for manifolded tank systems. If the system may be used for manifolded tank systems, check here if there was no significant difference in performance between single and manifolded tank systems. If there was a significant difference, enter the PD and PFA for the two types of systems here:

System	PFA	PD
Single Tanks		
Manifolded Tank Systems with up to ____ tanks.		

- The minimum product level for the system is _____% of the tank volume. The maximum product level for the system is _____% of the tank volume.

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

____

____

____

> **Safety disclaimer: This test procedure only addresses the issue of the method's ability to detect leaks.**

Certification of Results

I certify that the results presented on this form are those obtained during the evaluation. I also certify that the evaluation was performed according to the proposed test procedure for Continuous Leak Detection Systems. In particular, the requirements summarized in Section 6.4 for the data base and in Section 7.8 for the data analysis were followed. Any exceptions are noted below:

- Exceptions to Sections 6.4 and 7.8. If none, state "None."

____

____

____

This test procedure is deemed equivalently stringent to EPA published evaluation protocols.

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

Reporting Form for Leak Rate Data
Continuous Leak Detection System (CITLDS)
Quantitative System

CITLDS Name and Version:

Evaluation Period:

Page ______ of ______

Test No.	Date Test Began (DMY)	Duration of Test (indicate units)	Tank Volume (gal)	Monthly Throughput (gal)	Season (H, M, C)	Nominal Leak Rate (gal/hr)	Induced Leak Rate (gal/hr)	Measured Leak Rate (gal/hr)	Measured-Induced Leak Rate (gal/hr)	Notes

Page ______ of ______

Test No.	Date Test Began (DMY)	Duration of Test (indicate units)	Tank Volume (gal)	Monthly Throughput (gal)	Season (H, M, C)	Nominal Leak Rate (gal/hr)	Induced Leak Rate (gal/hr)	Measured Leak Rate (gal/hr)	Measured-Induced Leak Rate (gal/hr)	Notes

Page ______ of ______

Test No.	Date Test Began (DMY)	Duration of Test (indicate units)	Tank Volume (gal)	Monthly Throughput (gal)	Season (H, M, C)	Nominal Leak Rate (gal/hr)	Induced Leak Rate (gal/hr)	Measured Leak Rate (gal/hr)	Measured-Induced Leak Rate (gal/hr)	Notes

CITLDS - Quantitative Data Reporting Form

MRI-CTRD\R3453-03.R3

Description
Continuous Leak Detection System

This section describes briefly the important aspects of the continuous leak detection system (CITLDS). It is not intended to provide a thorough description of the principles behind the system or how the equipment and software work.

CITLDS Name and Version

____

Product

> Product type

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

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

What product level is required to conduct a test?

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

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

- ☐ yes
- ☐ no

Does the CITLDS 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

What data does the CITLDS collect and analyze for its test? (check all that apply)

- ☐ product level
- ☐ product temperature
- ☐ time
- ☐ product deliveries
- ☐ dispensing records
- ☐ other (specify) ______________________________

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 typical time required for the CITLDS to acquire enough data for a valid test?

__________ days.

What factors influence the time required for the CITLDS to acquire and analyze enough data for a valid test?

____

____

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 CITLDS 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 CITLDS 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 CITLDS 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) ____________________

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

How does the CITLDS compensate for the effects of product evaporation on product level following dispensing of product from the tank?

- ☐ wait a specified period of time after dispensing before beginning test
- ☐ watch the data trends and begin test when decrease in product level has stopped
- ☐ other (describe briefly) ______________________________
- ☐ no compensation

> 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 (gallons 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) ____________________

Is the leak status reported in terms of a leak rate (e.g., gal/h or gal/day)?

- ☐ yes
- ☐ no
- ☐ If the answer to the above question is "No", how are the results reported?

Explain ____________________

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

- ☐ 0.05 gallon per hour
- ☐ 0.10 gallon per hour
- ☐ 0.15 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
Continuous Leak Detection System (CITLDS)

Qualitative System

CITLDS Name and Version:

Evaluation Period:

Page ______ of ______

Test No.	Date Test Began (DMY)	Duration of Test (indicate units)	Tank Volume (gal)	Monthly Throughput (gal)	Season (H, M, C)	Leak Rate Induced (Y/N)	Test Result (Tight or Leaking)	Correct Call (Y/N)	Notes

Page ______ of ______

Test No.	Date Test Began (DMY)	Duration of Test (indicate units)	Tank Volume (gal)	Monthly Throughput (gal)	Season (H, M, C)	Leak Rate Induced (Y/N)	Test Result (Tight or Leaking)	Correct Call (Y/N)	Notes

CITLDS - Qualitative Data Reporting Form

Page ______ of ______

Test No.	Date Test Began (DMY)	Duration of Test (indicate units)	Tank Volume (gal)	Monthly Throughput (gal)	Season (H, M, C)	Leak Rate Induced (Y/N)	Test Result (Tight or Leaking)	Correct Call (Y/N)	Notes

CITLDS - Qualitative Data Reporting Form

Reporting Form for Data
Automatic Inventory Control System

CITLDS Name and Version:

Evaluation Period:

Page ______ of ______

Test No.	Date Test Began (DMY)	Duration of Test (indicate units)	Tank Volume (gal)	Monthly Throughput (gal)	Season (H, M, C)	Monthly Reconciliation as a Percent of Throughput	Notes

Page ______ of ______

Test No.	Date Test Began (DMY)	Duration of Test (indicate units)	Tank Volume (gal)	Monthly Throughput (gal)	Season (H, M, C)	Monthly Reconciliation as a Percent of Throughput	Notes

CITLDS - Automatic Inventory Control Data Reporting Form

Page ______ of ______

Test No.	Date Test Began (DMY)	Duration of Test (indicate units)	Tank Volume (gal)	Monthly Throughput (gal)	Season (H, M, C)	Monthly Reconciliation as a Percent of Throughput	Notes

CITLDS - Automatic Inventory Control Data Reporting Form

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