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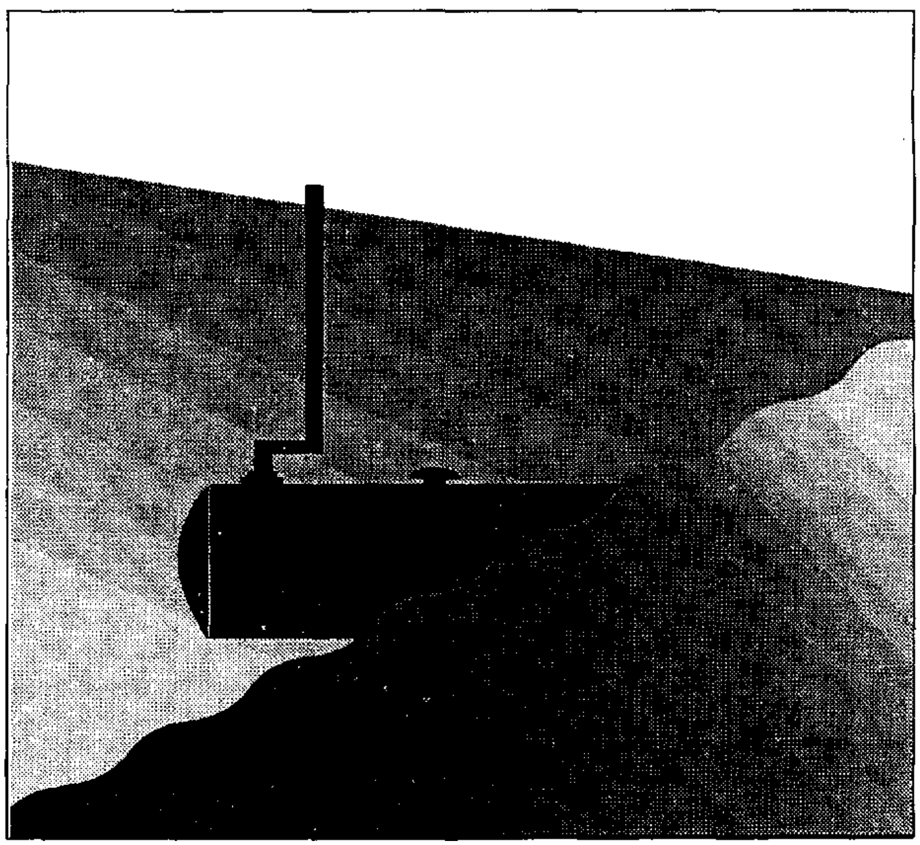
EPA

Standard Test Procedures For Evaluating Leak Detection Methods

Statistical Inventory ReconciliationMethods



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

Final Report

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

June 1990

FOREWORD

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

The Environmental Protection Agency's (EPA's) regulations for underground storage tanks require owners and operators to check for leaks on a routine basis using one of a number of detection methods (40 CFR Part 280, Subpart D). In order to ensure the effectiveness of these methods, EPA set minimum performance standards for equipment used to comply with the regulations. For example, after December 22, 1990, all tank tightness testing methods must be capable of detecting a 0.10 gallon per hour leak rate with a probability of false alarm of no more than 5%. Automatic tank gauging systems must be capable of detecting a leak rate of 0.20 gallon per hour with the same probability.It is up to tank owners and operators to select a method of leak detection that has been shown to meet the relevant performance standard.

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

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

EPA recognizes three distinct ways to prove that a particular method of leak detection 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-partytesting laboratory; or,

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

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

EPA Standard Test Procedures

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

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

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

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

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

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

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

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

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

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

National Consensus Code or Standard

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

Alternative Test Procedures Deemed Equivalent to EPA’s

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

1. The evaluation tests the system both under the no-leak condition and an induced-leak condition with an induced leak rate as close as possible to (or smaller than)the performance standard. In the case of 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.

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

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

ACKNOWLEDGMENTS

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Petroleum Equipment Institute

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

The regulations on underground storage tanks (40 CFR Part 280) specify performance standards for leak detection methods that areinternal to the tank. Test procedures for two types of internal methods, the automatic tank gauging (ATG) systems and the tank tightness testing methods (volumetric and nonvolumetric), have been presented in three separate documents. This document provides test procedures for evaluating statistical inventory reconciliation (SIR)methods.

A statistical inventory reconciliation method is a procedure based on the statistical analysis of a series of daily inventory records taken by the tank owner/operator. The results of the analysis are used to indicate whether the tank is leaking. Other characteristics of the inventory record of interest to the owner/operator may also be included in the analysis. These may include indications of theft or pilferage, average daily throughput, etc.

For this protocol, SIR methods are viewed as services offered commercially to tank owners/operators. Typically these services obtain manual inventory data taken by personnel operating the tanks. The service then analyzes the inventory data and reports the findings and results to the owner/operator. Many of these services are based on proprietary methods or programs to analyze the data. The services vary in the effects that they attempt to detect or control for. This protocol provides a procedure to evaluate the method's ability to detect leaks.Other features or capabilities of SIR methods are not the subject of thisevaluation.

The UST regulations do not specify performance standards for SIR methods *per se*.If an SIR method meets one of the performance standards for internal leak detection methods, it could qualify under those requirements. The purpose of the performance evaluation is to determine the level of performance of an SIR method and compare the estimated performance with the 0.10 gallon per hour or 0.20 gallon per hour detectable leak rate standards.

The performance standards are specified in terms of the probability of a false alarm, P(FA), and the probability of detecting a leak of specified size. A false alarm occurs if the leak detection method mistakenly indicates a leak when the tank is, in fact, tight. Theprobability of detection, P(D), measures the method's ability to detect actual leaks of specified magnitude.

One level of performance for SIR methods is specified as the ability to detect a leak of 0.10 gallon per hour with a probability of (at least) 95%, while operating at a false alarm rate of (no more than) 5%, based on an inventory record of specified length.This would correspond to the performance required of tank tightness testing methods. A second levelof performance required is specified as the ability to detect a leak of 0.20 gallon per hour with a probability of (at least) 95%, while operating at a false alarm rate of (no more than) 5%, based on an inventory record of specified length. This would correspond to the performance requirements for monthly monitoring leak detection methods.

A number of methods based on a statistical analysis of daily inventory records are reaching the market, but little evidence is available on evaluating their performance. Advertising literature for these methods can be confusing. Owners and operators need to be able to determine whether a method meets the EPA performance standards. Vendors of SIR methods need to know how to evaluate their procedures to determine ifthey meet EPA performance standards.

1.2 OBJECTIVE

The objectives of this protocol are twofold. First, it provides a procedure to test statistical inventory reconciliation (SIR) methods in a consistent and rigorous manner. Secondly, it allows the regulated community and regulators to verify compliance with regulations.

This protocol provides a standard method that can be used to estimate the performance of an SIR method. Tank owners and operators are required to demonstrate that the method of leak detection they use meets the EPA performance standards of operating at (no more than) a 5% false alarm rate while having a probability of detection of (at least)95% to detect a leak of 0.10 gallon per hour for an annual test and a leak rate of 0.20 gallon per hour for a monthly test. This demonstration must be made no later than December 22, 1990.The test procedure described in this protocol is one example of how this level of performance can be proven. The test procedure presented here is specific, based on reasonable choices for a number of factors. Information about other ways to prove performance is provided in the Foreword of this document.

It should be noted that this protocol does not address the issue of safety testing of equipment or operating procedure. The vendor is responsible for conducting the testing necessary to ensure that the equipment is safe for use with the type of product being tested. Safety is a concern in the collection of inventory data, but not in the statistical analysis.

1.3 APPROACH

SIR methods are those which are based on daily or periodic inventory measurements and reconciliation to check for loss of product in a tank. The inventory reconciliation is achieved by taking daily dipstick readings of the product level in the tank and reconciling them with the amounts of dispensed and delivered product. The SIR methods then use these daily records to perform a statistical analysis of inventory discrepancies. Various components that might contribute to these discrepancies are generally isolated before a loss rate is estimated. In addition to a loss rate estimate, some SIR methods claim to provide information on a variety of sources of inaccuracies such as dispensing meter error, delivery error, dipstick error, temperature effects, theft, vapor loss, etc. The present protocol is intended to evaluate the SIR method's ability to detect leaks only. It is not intended to evaluatethe performance of statistical methods in all areas, such as theft detection or delivery shortages.

The protocol calls for testing an SIR method by means of a series of data bases of daily inventory records. These data bases will be based on inventory records obtained from operating tanks known to be tight and having a variety of monthly throughputs. The inventory records will be from different months to include the effects of different temperature conditions. Using a small computer program, a number of inventory records of length specified by the vendor of the SIR method will be randomly selected from the data base and modified to include leaks of known rates. The leak rates will be kept blind to the vendors. The vendors of SIR methods will then evaluate the data from each set and submit their results to the evaluating organization.

Two approaches will be taken to the evaluation, depending on the reporting format of the vendor. If the vendor reports the leak rate, the leak rate estimated by the SIR method is compared to the actual leak rate introduced into the data. The differences are summarized and used in the normal probability model for the measurement errors to estimate the performance of the method. If the vendor only reports a pass, fail, or inconclusive result, the proportions of correct responses are used to estimate P(FA) and P(D). The performance evaluation will be based on the length of a standard inventory record with data collection procedures as specified by the vendors.

SECTION 2

SCOPE OF APPLICATION

This document presents a standard protocol for evaluating statistical inventory reconciliation (SIR) methods. The protocol is designed to evaluate SIR methods to determine their performance as leak detection methods. Many of the commercial services also aim to provide other information for the owners/operators, such as identification of probable theft, short deliveries, etc.This protocol does not attempt to evaluate the adequacy of the method for these objectives.

The aim of this protocol is to determine whether a vendor's statistical inventory reconciliation method meets the EPA performance standards for leak detection. The results of the testing are used to estimate the probability of a false alarm, P(FA), and the probability of detection, P(D), for leak rates of 0.10 and 0.20 gallon per hour. This protocol estimates these performance parameters directly from the proportions of correct responses in the data for methods that report only a qualitative result. The protocol analyzes the difference between reported and induced leak rates and uses the variability of these differences together with a normal probability model for the errors to estimate the performance parameters for methods that report a quantified leak rate. The protocol also provides a method to estimate the size of a leak that can be detected by a SIR method that reports a quantified leak rate. It does this by determining the threshold for a 5% false alarmrate and then calculating the corresponding leak rate that is detectable with probability 95%.

Subject to the limitations listed on the Results of U.S. EPAStandard Evaluation form (Appendix B), the results of this evaluation can be used to prove that an SIR method meets the requirements of 40 CFRPart 280. The reporting form lists the testing conditions.

SECTION 3

SUMMARY

The evaluation protocol for SIR methods calls for an evaluating organization to send a set of inventory records to the vendor of an SIR method and for the vendor to perform the statistical analysis and report on each inventory record in the data set. The inventory records will cover tight tanks and tanks with simulated leaks. The records will also cover a range of seasons to represent the conditions during a year. The vendor should report the results of the standard statistical analysis provided by the method, or indicate that the data are not of sufficient quality to be analyzed. The results of the vendor's analysis of the inventory records will be submitted to the evaluating organization, and the results reported by the vendor will be comparedwith the actual tank condition.

The inventory records submitted for the evaluation will consist of inventory records collected on actual tanks known to be tight. The organization performing the evaluation should have evidence that the tank used for testing is tight, independent of the method currently being tested. The evidence that the tank is tight may consist of any of the following:

1. At least three automatic tank gauging system (ATGS) records within a 3-month period with inventory and test modes indicating a tight tank.
2. A precision tank tightness test in the 6 months preceding or any time after the last date covered by the inventory data that indicates a tight tank.
3. Continuous vapor or liquid monitoring system installed that indicates a tight tank.

Any of the above types of evidence would be acceptable evidence that the test tank is tight. The evidence that the tank is tight should be reported on the data reporting form (Appendix B).

Loss of product representing leaks of certain sizes will be introduced into some of the inventory records. This information will be kept blind to the vendors. Thus, the data records will include inventory records from tight tanks and from "leaking" tanks. The ability of the method to accurately identify leaks of specified sizes will form thebasis for the evaluation.

SECTION 4

SAFETY

The evaluation consists of statistical analysis of inventory data supplied by the evaluating organization. Thus, the work will involve office work and no special safety considerations apply.

The instructions for data collection specified by each vendor of SIR methods should address the safety issues involved in collecting the inventory data. These activities would include taking a stick reading of the tank and reading the meter totalizer. Thus, the safety issues deal with safety around the tanks during the data collection phase, and not with the evaluation of the method or the statistical analysis of the inventory data.

SECTION 5

APPARATUS AND MATERIALS

Since the leak detection method consists of data analysis of inventory records supplied by a client, no special apparatus is necessary.The materials needed consist of a set of test data records to be supplied by the evaluating organization to the vendor for analysis and reporting, together with a code or key that allows the evaluator to identify the actual status of each tank in the test data set. The evaluator will also need access to a personal computer or some other computer facility to perform the data analysis.

SECTION 6

TEST PROCEDURE

The test procedure to evaluate the performance of statistical inventory reconciliation methods consists of eight steps. These steps, to be followed by the evaluating organization, are listed first and are followed by a more detailed explanation of their implementation. The appropriate data analysis methods are presented in Section 7.

6.1 PROCEDURE OVERVIEW

Step 1: Determine whether the type of data reported by the vendor of the SIR method is quantitative (results include a leak rate and an interpretation of the results indicating the tank status as leaking, tight,or inconclusive) or qualitative (results include only the tank status of leaking, tight, or inconclusive). The type of data reported by the vendor affects the evaluationdesign and the data analysis.

Step 2: Determine the data requirements set by the vendor. Obtain the vendor's data reporting form.

Step 3: Obtain inventory records from tanks determined to be tight by evidence as described in Section 3. Arrange with the tank operator for follow-up contacts to answer questions that may arise about the data.

Step 4: Create the data base, adding induced leaks to some records, and coding the data to prevent identification.

Step 5: Submit the data base to the vendor of the SIR method.The design is to be kept blind to the vendor to preventleak status or leak rate identification.

Step 6: Interact with the vendor of the SIR method to discuss questions pertaining to the data. Interact with the tank operator to resolve data questions and relay the information to the vendor of the SIR method.

Step 7: Receive results from the vendor of the SIR method.

Step 8: Analyze the data and report the results to the vendor of the SIR method.

6.2 IMPLEMENTATION OF THE PROCEDURE

The steps above require more explanation in order to carry them out successfully. In particular, the designs for the two types of reporting (quantitative or qualitative) are different and require different amounts of data.

6.2.1 Determine Type of Data--Step 1

Some vendors of SIR methods report an estimated leak rate to the client and interpret for the client whether the measured leak rate indicates that the tank is leaking or whether the measured rate is within the margin of error. Also, a third category of inconclusive results is often reported under a variety of names. Actual reported leak rates are referred to as quantitative data. If the estimated leak rate is thebasis for reporting and judging whether a tank is leaking, then the evaluation can proceed by comparing the leak rate measured by the SIR method to the leak rate induced in the records.The differences between the measured and induced leak rates can be used with a normal probability error model to estimate P(FA) and P(D), the performance parameters of the method.

Other vendors of SIR methods do not report an estimated leak rate to the client. Instead, they report a tight, a leak, or an inconclusive result. The data obtained from reporting only the conclusions are referred to as qualitative data. If the data are qualitative, then the performance measures P(FA) and P(D)are estimated as the proportion of false alarms and the proportion of records correctly identified, respectively. An evaluation based on qualitative data requires a larger number of valid test records than does an evaluation based on quantitativedata. A vendor may be evaluated according to his choice (qualitative or quantitative) if the vendor uses the design for qualitative data. If a qualitative report evaluation is done and the method can estimate leak rates, results based on the quantitative data may be reported as supplemental data calculations.

6.2.2 Determine Vendor’s Data Requirements--Step 2

Each SIR method will have unique data requirements. The evaluating organization will discuss the data requirements with the vendor and obtain a copy of the vendor’s data reporting form. The evaluating organization will then determine exactly what data elements need to beincluded in the inventory data sets. For example, a method may require a copy of the tank chart, daily mean ambient temperatures, or meter calibrations as partofthe inventory record. In addition, the length of the record required is an important consideration. It is suggested that a longer record than the minimum required by the vendor of the SIR be obtained. Establishing the data requirements before data collection begins ensures that the data records to be submitted as the basis for the evaluation accurately reflect the practice of the SIR method.

6.2.3 Obtain Data Base--Step 3

The evaluating organization will obtain a data base of inventory records from actual in-service tanks with evidence that the tanks are tight as described in Section 3. The data will be collected to meet the data requirements defined in Step 2. Data collection efforts will typically involve obtaining inventory records and arranging with the tank operators to be contacted to resolve data questions that the vender ofthe SIR method may have as the statistical analysis proceeds. It mayalso involve some ancillary data collection on the part of the evaluating organization, such as performing a meter calibration test and providing those data to the vendor of the SIR method. The evaluating organization will take care to ensure that the variables recorded and the length of the data record meet the vendor's specifications. The number of records required depends on the data type as described in Step 4.

The inventory data base will provide data collected under a variety of actual tank conditions. In selecting the sites and times for the data collection, the evaluating organization should obtain a wide variety of conditions. Since inventory reconciliation could be applied as a monthly monitoring approach, it is important to ensure that the evaluation dataset include data representative of the different ambient conditionsencountered over the course of a year. Also, since it is possible thatSIR could be conductedonly once during a year, the evaluation must document that the SIR method is valid whenever it might be conducted.

In order to ensure that the data base covers an adequate range of conditions, the inventory records collected should cover the range of seasonal conditions. The ideal way to do this would be to have an equal number of records from each month of the year from geographic areas that experience a large seasonal temperature change (including frost and snow in the winter). In order to make the data collection more practical, while still covering the different conditions, the following requirements have been established. Define as hot months, those months for which the average daily high temperature exceeds the ground temperature (5 ft below the surface,at the typical tank depth) by at least 15°F. Define as cold months those months for which the average daily low temperature is at least 15°F below the ground temperature (5 ft below the surface). All other conditions are defined as mild. Limit the proportion of inventory records from mild months to one-third of the total. The remainingrecords are to be from hot and cold months, with at least 10% from eachcondition. That is, one could set up the data base with a third of theinventory records, from hot, one third from cold, and a third from mild. Another possibility is 30% from mild,10% from cold, and 60% fromhot.

The data should include a variety of tank sizes, preferably concentrating on larger tanks, since those are anticipated to be more difficult to be evaluated by SIR methods. The results of the evaluation will be limited by the tank sizes actually incorporated in the data. The data base should also have a range of throughputs. However since larger throughputs are generally associated with larger tank sizes, no specific requirements on throughput have been incorporated.

The tank inventory records should all be from single tanks. That is, no manifolded tanks should be included.

The usual application for SIR methods would be for tanks that use manual gauging. Consequently, the evaluation data set should concentrate on tanks with manual inventory. No more than 25% of the data records should be collected by automatic tank gauging (ATG)systems unless method is designed for and restricted to tank with ATG systems. If data from tanks with ATG systems are used,the pattern of results should be checked to determine whether the SIR method is achieving better results for the tanks with ATG system records. If so, this indicates that the quality of the stick readings is a limiting factor for that method.

6.2.4 Create Evaluation Data Base--Step 4

The experimental design and the numbers of tank records required for the evaluation data base depend on whether the type of data reported by the vendor is qualitative or quantitative.The analysis described in Section 7 also depends on the type of data reported. Since the tank size and throughput can affect the results, the evaluation data base should contain records from a number of large tanks and a variety ofthroughputs. In particular, at least 20% of the tank records should be from tanks as large as the tank size for which the vendor wants to qualify the method.

Experimental Design for Qualitative Data

If the vendor reports only a qualitative result (pass, fail, inconclusive), the following design is used.

1. Obtain at least 80 tank inventory records following the vendor's data requirements. Randomly divide the records into three groups of size 20, 20, and 40 records. Select at random one of the groups of size 20 called Group 1, to be used with no modifications. The other group of size 20, called Group 2, will include induced leak rates. The group of 40, Group 3, will be duplicated and one set used with and the other set used without added induced leak rates.

2. Inspect the data for completeness, transcription errors, etc. If gaps in the data or missed delivery records are found, contact the tank operator to complete the data record.

3. Assign induced leak rates for the three groups of tank records:

    - Group 1 data will be submitted for analysis as is and will constitute part of the set of data from tight tanks.

    - Add an induced leak to the data from Group 2. This leak rate is to be equivalent to either 0.10 gallon per hour or 0.20 gallon per hour, depending on the performance standard for which the vendor of the SIR method seeks to qualify. (Note: Qualification for the 0.10 gallon per hour standard automatically implies qualification for the 0.20 gallon per hour standard, but the reverse is not true.) To introduce the leak rate into the data, determine the appropriate number of gallons per day and subtract it from the physical inventory record. Fractional gallons are handled by subtracting one more gallon on the required fraction of days. For example, an induced leak rate of 0.10 gallon per hour is equivalent to 2.4 gallons per day. To induce a leak rate of 2.4 gallons per day, randomly select two days of each five-day period.On the randomly selected days the data are modified by three gallons; on the other three days the record is modified by two gallons. The Group 2 data will be used only as simulated leak rate data and willbe part of the simulated leak group.

- The Group 3 data will be used both as tight tank data and as data with induced leaks. Retain one copy of the data records without induced leaks. Add induced leak rates as described above for Group 2 to the duplicated set of data records of Group 3 to produce additional inventory data records with the induced leaks.

4. Code the data for the three groups by adding a random constant to the totalizer numbers to prevent identification of the sets of tank records by the vendor. Take any other precautions needed to ensure that the identification of the data sets remains blind to the vendor.

5. Submit the total of 120 tank records to the vendor. Note that there will be 60 from tight tanks, and 60 from tanks with simulated leaks. Of the total, 40 tank inventory records will be submitted both with and without an induced leak. These records serve as their own controls and provide added insurance that the data do not contain inadvertent effects that would invalidate the evaluation.

Experimental Design for Quantitative Data

If the vendor reports data on a quantitative basis, that is, a reported leak rate, use the following design.

1. Obtain tank inventory records from at least 32 tight tanks. Randomly divide the 32 tank records into four groups of 8 records each. Four simulated leak rates (including zero) will be induced in the data. The rates to be used are equivalent to 0 (tight), 0.05 gallon per hour, 0.10 gallon per hour, and 0.20 gallon per hour.

2. Inspect the data sets for completeness, transcription errors, etc. If gaps or errors are found, contact the tank operator for corrections.

3. Assign induced leak rates for the four groups of 8 tank records:

   - Randomly assign each group to one of the four leak rates above. Retain copies of the unaltered data.

- For the three groups with non-zero leak rates, determine a daily loss corresponding to the induced leak rate. Induce the daily loss by subtracting the appropriate amount, in whole gallons, from the physical daily inventory record. When the daily loss is a fraction of a gallon, incorporate the fraction by subtracting an extra gallon on the required proportion of days. For example, an induced leak rate of 0.10 gallon per hour is equivalent to 2.4gallons per day. To induce a leak rate of 2.4 gallons per day, randomly select two days of each five-day period. On the randomly selected days the data are modified by three gallons; on the other three days the record is modified by two gallons.

4. Randomly select three of the eight records in each non-zero leak rate group. Code the totalizer numbers by adding a random constant to prevent identification with the record in the induced leak set. Include the nine original records (that is, without induced leak) for these tanks in the set of zero leak records.

5. Submit the data set to the vendor.

In summary, the resulting data base will include 17 records on tight tanks, and 8 for each of 3 induced leak rates for a total of 41 records.Eight records will appear as tight only, 15 will appear withinduced leaks only,and 9 will appear both as tight and with one of 3 induced leaks. The difference in reported leak rate between two records that have both a zero and an induced leak rate allows the tank to be used as its own control. Thus, if any inadvertent factor should be present in the tank record, a comparison of the results with and without the induced leak should still be valid.

6.2.5 Submit Data Base to Vendor--Step 5

The data base developed in Step 4 above is submitted to the vendor of the SIR method for analysis. To ensure that data are blind to the vendor, so that the vendor does not know which data records have induced leak rates and which data records are from the same tanks, a random number generator was used in Step 4 above to generate a random integer for each tank record. This random constant was added to all the totalizer values for that record.

Identify each inventory record with an arbitrary code. The code should enable the evaluating organization to identify the inventoryrecord for follow-up contacts with the tank operator if needed. The code should also allow the evaluating organization to identify the induced leak in the data record. However, the code should not itself contain any information about the conditions.

6.2.6 Resolve Data Questions--Step 6

Often the vendor of an SIR method may identify inconsistencies in the data such as wrong tank chart used, incorrect tank dimensions given, etc. The vendor of the SIR method should identify such features following their usual procedures and submit the findings to the evaluating organization. The evaluating organization will then contactthe tank operator to attempt to resolve the questions. If a question cannot be resolved after the fact, and if the vendor determines that the discrepancy precludes an adequate SIR analysis of that tank record, thenthe fact that the SIR method identified a problem should be recorded and the record should be excluded from the analysis.

For qualitative data methods, a minimum of 40 usable records is needed for each of the tight and induced leak conditions separately. For quantitative data methods, a minimum of 24 usable records is needed. At least 8 of these must be under the tight tank condition and at least 8 under induced leak conditions.

If data problems reduce the data base below the amounts specified above for each data type, additional inventory records should be collected by the evaluating organization and submitted to the vendor. The best approach is to resolve the data problem with a tank owner and submit an additional data record on the same tank.

6.2.7 Receive Analysis Results From Vendor of SIR Method--Step 7

The vendor will submit a report on each tank record to the evaluating organization. This report will be in the same form as that inwhich the vendor would submit results to a client.It need not include all of the features involving inventory tracking or other services that might be supplied to a commercial client. The report must indicate the results of the leak detection evaluation for each tank. The results may be reported as inconclusive, leak indicated, or tight.

6.2.8 Analyze Data and Report Results to Vendor of SIR Method--Step 8

The evaluating organization will analyze the data as described in Section 7. The results will be reported to the vendor. As part of the reporting process, the EPA forms attached to this report (Appendix B) will be completed as described in Section 8.

SECTION 7

CALCULATIONS

The calculations performed on the results submitted by the vendor of the SIR method depend on the type of data submitted. Section 7.1 describes the data analysis appropriate for qualitative data, whileSection 7.2 describes the analysis appropriate for quantitative data.Supplemental calculations that can be done for quantitative data are presented in Section 7.3. These supplemental calculations are optional. They may be useful to the vendor in identifying areas for improvement of the method, but are not needed to demonstrate that the method meets EPA performance standards.

7.1 ESTIMATION OF THE SIR METHOD'S PERFORMANCE PARAMETERS FOR QUALITATITVE DATA

The first step in the analysis is to tabulate the results as reported by the vendor of the SIR method. Form a two-way table of the results, showing the number of tank records identified by the vendor as tight, leaking, or other category against the tight or induced leak conditions introduced into the tank records by the evaluating organization. Table 1 below summarizes the notation used throughout this section. If any records were not analyzed by the vendor because of unresolvable data problems remove these from the data base before proceeding with the analysis.

Report the proportion of inconclusive records as (X + Y)/N. Also calculate and report the proportion of inconclusive results separately for the tight and induced leak record sets. These proportions are X/N_1 and Y/N_2, respectively.

For qualitative results, the estimates of P(FA) and P(D)must each be based on at least 40 tank records. The design provides for 60 recordsfor each estimate, but some records may be judged inconclusive or have data problems identified by a SIR method.If some records are ruled invalid, the number for estimating P(FA) or P(D) will be less than 60 and might drop below 40. If the number drops below 40, additional records must be submitted and analyzed so that the estimates are always based on at least 40 records.

Table 1. TABULATION OF EVALUATION RESULTS

Records submitted to the vendor as	Reported by the vendor as			Total analyzed
	Tight	Leaking	Inconclusive or other	
Tight	T_1	L_1	X	N_1
Leaking	T_2	L_2	Y	N_2
Total			(X + Y)	N

The following notation is used:

N = total number of records submitted by the evaluating organization, normally 120

N_1 = number of tight records submitted, normally 60

N_2 = number of induced leak records submitted,normally 60

T_1 = number of results correctly identified as tight by the SIR method

L_1 = number of results incorrectly identified as leaking (false alarms) by the method

T_2 = number of results incorrectly identified as tight (missed leaks) by the method

L_2 = number of results correctly identified as leaking by the method

X = number of tight records determined to be inconclusive

Y = number of induced-leak records determined to be inconclusive

7.1.1 False Alarm Rate, P(FA)

From the results obtained by the vendor and using the above notation, the probability of false alarms is calculated as

Inorder for the method to meet the EPA performance standard, P(FA) must be less than or equal to 5% (or 0.05 as a proportion). It is possible for a method to make no errors (i.e., $L_1 = 0$), thus providing an estimate for P(FA) of zero. This does not mean that the method is perfect. An upper confidence limit for P(FA) is calculated based on the binomial distribution. If the observed number of errors, L_1, is zero, the upper confidence limit for P(FA) is calculated by the formula below and reported on the results form (Appendix B). A confidence coefficient of 95% is recommended. The upper confidence limit, UL, for P(FA)is calculated as where (1 - α)x 100% is the confidence coefficient, and $m_1 = (N_1 - X)$is the number of submitted tight tank records with a conclusive result.

The formula above applies if no errors out of m_1 were made by the method. Table 2 below is provided to calculate approximate limits based on different numbers of errors made. The entries in Table 2 are based on the Poisson approximation to the binomial. Exact binomial confidence limits may be used if they are available.

To use Table 2 to calculate confidence limits for P(FA), find the entries corresponding to the number of errors out of m_1 records on tight tanks. Divide the table entries by the number of tank records, m_1. The two numbers that result arethe lower and upper confidence limits. Thus the point estimate of P(FA) is given by the number of errors on tighttank records divided by the number of tight tank records, m_1, and the 95% confidence limits are determined by taking the appropriate entries from Table 2 and dividing each by the same number.

As a numerical example, suppose a method made a leak status determination on 50 tank records from tight tanks, mistakenly identifying one of these as leaking. The point estimate of P(FA) is 1/50 or 2.0%. From Table 2, the entries corresponding to one error are 0.1 and 5.6. Dividing each of these by 50 and multiplying by 100% gives the confidence limits of 0.2% to 11.2%.

Table 2. VALUES FOR COMPUTING APPROXIMATE 95% CONFIDENCE LIMITS FOR P(FA)AND P(D)

	Values	
Number of errors	Lower	Upper
1	0.1	5.6
2	0.2	7.2
3	0.6	8.8
4	1.0	10.2

7.1.2 Probability of Detecting a Leak, P(D)

The probability of detection, P(D), is calculated from the proportion of records correctly identified by the method as leaking. Thus, P(D) is calculated as

In order for the method to meet the EPA performance standard, P(D) must be at least 95% (or 0.95 as a proportion). Again, it is possible for a method to make no mistakes (i.e., $T_2 = 0$), in which case the estimated P(D) would be 1.00 or 100%.This does not mean that the method is perfect.If the observed P(D) is 100%, a lower confidence limit for P(D) is calculated by the formula below and reported. The suggested confidence coefficient for this calculation is 95%. The formula for the lower confidence limit, LL, of P(D) is

where (1 - α) x 100% is the confidence coefficient and $m_2 = (N_2 - Y)$ is the number of submitted induced leak records with a conclusive result. For one or more errors, the entries in Table 2 can be used.

To use Table 2 for calculating a confidence interval on P(D), lookup the entries for the number of missed detections. Divide these numbersby m_2 and subtract the result from 1. The answers give the 95%confidence limits for P(D).

As a numerical example, suppose that a method made a determination of leak status on 50 tank records with induced leaks, being in error on two of these (mistakenly identifying them as tight). The point estimate of P(D)is 48/50 or 96.0%. From Table 2 the entries for two errors are0.2 and 7.2. Dividing by 50 gives 0.004 and 0.144.Subtract each of these from one, and multiply by 100% to get the 95% confidence interval of 85.6% to 99.6%.

7.1.3 Additional Calculations

If the method meets the EPA performance requirements based on the estimates calculated above, analysis could stop at this point.If the method does not meet the performance requirement, the pattern of responses for the tank records that were used twice should be investigated. There are 40 such pairs of records that were submitted both with and without induced leaks. However, this number could be reduced if the method reports inconclusive results. Excluding inconclusive results, there are four possible patterns for the pairs of results from these records.

Denote the first letter in a pair as the reported result on the record submitted without alteration (i.e., as a tight tank) and the second letter in the pair as the reported result on the record submitted with the induced leak.Then the four result possibilities are (T,T), (T,L),(L,T), and (L,L), of which the pair (T,L)is the only correct answer. Tabulate the pairs by the four possibilities. Of these, the (L,L) pairs represent data that could have some interfering influence. Remove any of these cases from the false alarms, L_1, and recalculate the P(FA)as shown in Section 7.1.1. If this adjustment reduces the P(FA) below 5% and the P(D)is at least 95%, then the method meets the EPA performance standards.

It should be noted that the requirement on the total number of conclusive results in the tight record category has to be at least 40. Using the notation in Table 1, this means that $[N_1 - X - \text{number of } (L,L)] = [T_1 + (L_1 - \text{number of } (L,L))]$ has to be at least 40. Should this notbe the case, then the data base needs to be augmented by appropriate new inventory records.

7.2 ESTIMATION OF THE SIR METHOD'S PERFORMANCE PARAMETERS FOR QUANTITATIVE DATA

In the case where an SIR method reports estimated leak rates for each record submitted, the data base will consist of pairs of induced and reported leak rates for each record. Assume that the SIR method produced conclusive results on n records. Should all results be usable, then a total of 41 pairs of leak rate data would be available for analysis. A minimum number of 24 conclusive results is required, with at least 8 conclusive results in the tight condition category and at least 8 conclusive results in the induced leak category. The estimation of the performance of the SIR method is based on the n pairs with conclusive results.

7.2.1 Basic Statistics

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 method as follows.

Mean Square Error, MSE

where L_i is the estimated leak rate obtained by the SIR method from the ith record at the corresponding induced leak rate, S_i, with i=1,…, n.

Bias, B

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

Variance and Standard Deviation

The variance is obtained as follows:

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

Test for Zero Bias

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

Compute the t-statistic

–

From the t-table in Appendix A, obtain the critical value corresponding to a t with (n-1) degrees of freedom and a two-sided 5% significance level. Denote this value by t_c.

Compare the absolute value of t_B, abs(t_B), to t_c.If abs(t_B)is less than t_c, conclude that the bias is not statistically different fromzero, that is, the bias is negligible.Otherwise, conclude that the bias is statistically significant.

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

7.2.2 False Alarm Rate, P(FA)

The normal probability model is assumed for the errors in the vendor’s estimated leak rates. Using this model, together with the statistics estimated above, allows for the calculation of the predicted false alarm rate and the probability of detection of a leak of 0.10 (or0.20) gallon per hour.

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

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

False Alarm Rate with Negligible Bias

In the case of a nonsignificant bias (Section 7.2.1), compute the t-statistic where SD is the standard deviation calculated above and Cis the method's threshold. Using the notational convention for leak rates, C is positive.P(FA) is then obtained from the t-table, using (n-1) degrees of freedom. P(FA) is the area under the curve to the right of thecalculated value t_1.

In general, t-tables are constructed to give a percentile, t_a, corresponding to a given number of degrees of freedom, df, and a preassigned area, a or alpha, under the curve, to the right of t_a (see Figure 1 below and Table A-1 in Appendix A). For example, with (n-1)=40 degrees of freedom and a = 0.05, t_a = 1.684.

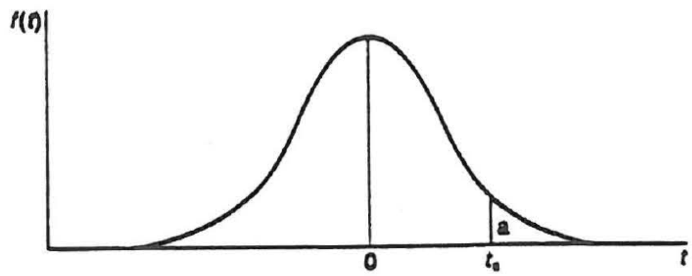


Figure 1.Student's t-distribution function.

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

Suppose that the calculated t_1= 1.70 and has 40 degrees of freedom. From Table A-1, obtain the following percentiles at df = 40:

t_a	a (alpha)
1.684	0.05
1.70	X to be determined
2.021	0.025

Calculate X by linearly interpolating between 1.684 and 2.021 corresponding to 0.05 and 0.025, respectively.

Thus the probability of false alarm corresponding to a t_1 of 1.70 with40 df would be 4.9%.

A more accurate approach would be to use a statistical software package (e.g., SAS or SYSTAT)to calculate the probability.Another method would be to use a nomograph of

Student's t such as the one given by Lloyd S. Nelson in *Technical Aids*, 1986, American Society for Quality Control.

False Alarm Rate with Significant Bias

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

P(FA)is then obtained from the t-table, using (n-1) degrees of freedom.P(FA)is the area under the curve to the right of the calculated value t_2. (Again,recall that C is positive, but the bias could be either positive or negative.)

7.2.3 Probability of Detecting a leak Rate of Specified Size, P(D)

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

P(D) with Negligible Bias

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

Next, using the t-table at (n-1)degrees of freedom, determine the area under the curve to the right of t_3. The resulting number will be P(D).

P(D)with Significant Bias

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

Next, using the t-table at (n-1)degrees of freedom, determine the area under the curve to the right of t_4. The resulting number will be P(D).

The P(D)for a leak rate of 0.20 gallon per hour can be calculated in the same way, replacing 0.10 by 0.20 in the equations above.

A quantitative method will not meet the performance standards if the differences between its measured leak rates and the induced leak ratesare too large. It is possible that despite the evidence required to show that the tanks in the data base are tight, a tank may actually have a leak. The use of some data both with and without induced leak rates provides a check on this possibility. The evaluating organization can compare the differences between the reported leak rates for those tank records with and without induced leaks. Comparison of the differences in reported leak rate with the differences in induced leak rate provides a comparison independent of an actual leak rate.

To make this comparison, consider only those records that were submitted both with a zero and a non-zero leak induced. Let LO_i denote the measured leak rate for the ith such record when a zero induced rate was used, with i from 1 to r (usually r = 12), and let $L1_i$ denote themeasured leak rate for the ith such record with induced leak rate S_i. Form the r differences:

Remove the corresponding differences ($LO_i - S_i$) and ($L1_i - S_i$) from the data set for the (usually 24) records involving tank records used twice. The total remaining data points must be at least 24. (There will be 29 such points if no data records were judged invalid by themethod.) Recalculate the bias, standard deviation, P(FA), and P(D). If these calculations indicate that the method meets the EPA performance standards, conclude that the method meets the EPA performance standards.It would be assumed in this case that the original failure tomeet the EPA performance standards was due to some discrepancies in the data. If the results with this modification do not meet the performance standards, then the method has not demonstrated that it meets the federal EPA performance standards.

Reporting P(FA)and P(D)

In order to meet the EPA performance requirements, the P(FA) must be5% or less. In making this determination, round the calculated P(FA)to the nearest whole percent. Similarly, to meet the EPA performance requirements, the P(D) must be at least 95%, again rounded to the nearest whole percent. Depending on the performance level, the P(D)may be calculated for either a leak rate of 0.10 gallon per hour or 0.20 gallon per hour. If a method meets the requirement for detecting a leak rate of 0.10 gallon per hour, it will meet the requirement for 0.20 gallon perhour. Thus the calculations for a leak rate of 0.20 gallon per hour would normally be required only if the method did not meet the detection requirement for the smaller leak rate.

7.3 SUPPLEMENTAL CALCULATIONS AND DATA ANALYSES(OPTIONAL)

Other information can be obtained from quantitative test results. This information is not required for establishing that the method meets the federal EPA performance requirements, but may be useful to the vendor of the SIR method. The calculations described in this section are therefore optional. They may be performed and reported to the vendor, but are not required and are not reported on the results form (in Appendix

B). These supplemental calculations include determining a minimum threshold and a minimum detectable leak rate. Such information may be particularly useful to the vendor of the SIR method for future improvements of his method. The results of this section are based on the average performance of the method on the data used in the evaluation. These results assume that the bias and precision of the method can be estimated from the evaluation data. Other data sets may exhibit more or less variability, and so the method might do better or worse on individual tank records.

7.3.1 MinimumThreshold

The n pairs of leak rate data can also be used to determine a threshold that would result in a false alarm rate of 5%. This threshold may not be the same as the threshold, C, used by the vendor.The vendor may not use the same threshold for all tank records. Denote by $C_{5\%}$ the threshold corresponding to a P(FA) of 5%. The following demonstrates the approach for computing $C_{5\%}$.

Solve the equation

for $C_{5\%}$. If the bias is not statistically significant (Section 7.2.1), then replace B with 0. From the t-table (Appendix A)with (n-1) degreesof freedom obtain the 5th percentile. Denote this value by $t_{5\%,(n-1)}$. Solving the equation above for $C_{5\%}$ yields

or

In the case of a nonsignificant bias (i.e., B = 0), this would be

7.3.2 Minimum Detectable Leak Rate

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

where$C_{5\%}$ is the threshold corresponding to a P(FA) of 5%, as calculated in Section 7.3.1, and B is the bias estimated for the method.

Solving this equation is equivalent to solving

or

which, after substituting $t_{5\%,(n-1)}$x SD for ($C_{5\%}$-B), is equivalent to

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

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

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

If the bias <u>is not</u> statistically significant:

For a P(FA)of 5% $C_{5\%} = t_{5\%,(n-1)}(SD)$

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

If the bias <u>is</u> statistically significant:

For a P(FA)of 5% $C_{5\%} = t_{5\%,(n-1)}(SD) + Bias$

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

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

The calculated results represent average results obtainable with data of the quality used in the evaluation. In particular, the constant threshold, C, calculated above depends on the variability of the inventory records being approximately constant. These additional calculations may not be useful for all methods.

SECTION 8

INTERPRETATION

The results reported are valid for the factors considered in the evaluation. These were chosen to represent the factors thought to be most important in influencing performance of the method as a leak detection method. Additional factors such as small daily pilferage could lead to an increased false alarm rate. Vendors are encouraged to (and mostdo) report an indication of the variability of the results as well as the estimated leak rates and other factors.

8.1 BASIC PERFORMANCE ESTIMATES

SIR methods can be conducted annually or monthly, depending on the leak detection option.The amount of data needed is determined by eachmethod and is not tied to the frequency of applying the SIR method. The performance standard differs according to the frequency with which the leak detection method is applied.

The relevant performance measures for showing that an SIR method meets EPA standards are the P(FA) and P(D)for a leak rate of 0.10 gallon per hour (annual records)or 0.20 gallon per hour (monthly records).The estimated P(FA) can be compared with the EPA standard of P(FA) not to exceed 5%. In general, a lower P(FA)is preferable, since it impliesthat the chance of mistakenly indicating a leak on a tight tank is less. However, reducing the false alarm rate will generally reduce the chance of detecting a leak. The probability of detection generally increases with the size of the leak. A higher estimated P(D) for a specified leak rate means that there is less chance of missing a leak of that size.

For qualitative data, the discrete nature of the data implies that only a few discrete values of P(FA) or P(D)are allowable if the methodis to meet the EPA standard. With the standard 60 tests for each type of record (tight or leaking tank), the possible values are 0, 1/60, 2/60, etc. Consequently, the reported estimates are only precise to about 2%. The confidence limits reported indicate the range in which the true P(FA) or P(D)is expected to be. For example, a method that achieved zero false alarms out of 60 would not be expected to have a zero false alarm rate. However, its false alarm rate should be less than 4.9% with 95% confidence.

8.2 LIMITATIONS ON RESULTS

As noted before, tank size may influence the results of a statistical inventory analysis. Consequently, to allow for this effect, theextrapolation of the reported results to larger tanks is limited. Specifically,the results may be extended to tanks 50% larger than the 80th percentile of tank sizes used in the evaluation data.

Similarly, throughput may affect the performance of the method. The 25th, 50th, and 75th percentiles of monthly throughput for the records in the evaluation data set are reported as test conditions.

The performance results are limited to single tanks. That is, the results may not be extended to tanks that are manifolded together and have only a single inventory record for two or more tanks.

Any limiting conditions specified by the vendor for the use of the SIR method should also be included as limitations on the results form.

SECTION 9

REPORTING OF RESULTS

Appendix B is designed to be the framework for a standard report by an evaluating organization. There are three parts to Appendix B, each of which is preceded by instructions for completion. The first part is the Results of U.S. EPA Standard Evaluation form. This is basically an executive summary of the findings. It is designed to be provided to each tank owner/operator that uses this method of leak detection, as documentation that the method meets the EPA standards.Consequently, it isquite succinct. The report should be structured so that this results form can be easily reproduced for wide distribution.

The second part of thestandard report consists of the Description of the Statistical Inventory Reconciliation Method. A description form is included in Appendix B and should be completed by the evaluating organization with the assistance of the vendor.

The third part of the standard report contains a Reporting Form for Test Results, also described in Appendix B. This table summarizes the test results obtained from the method and indicates the induced leak rates added to each inventory record.

If the optional calculations described in Section 7.3 are performed, they should be reported to the vendor. It is suggested that these results be reported in a separate section of the report, distinct from the standard report. This would allow a user to identify the parts of the standard report quickly while still having the supplemental information available if needed.

The limitations on the results of the evaluation are to be reportedon the Results of U.S. EPA Standard Evaluation form. The intent is to document that the results are valid under conditions represented by thetest conditions. Section 8.2 describes the summary of the test conditions that should be reported as limitations on the results form.

APPENDIX A

DEFINITIONS AND NOTATIONAL CONVENTIONS

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

The performance of a leak detection method is expressed in terms of the false alarm rate, P(FA), and the probability of detecting a leak of specified size, P(D(R)), where R is the leak rate. In order to understand these concepts, some explanation is helpful. Generally, the statistical inventory reconciliation method calculates a leak rate from daily inventory discrepancies after accounting for sources of errors other than a leak. This calculated rate is compared to a criterion or threshold, C. If the calculated rate is in excess of the criterion, the tank is declared to be leaking, otherwise, the tank is called tight.

Figure A-1 represents the process of determining whether a tank is leaking. The curve on the left represents the inherent variability of the leak rate on a tight tank (with zero leak rate). If the calculated leak rate exceeds C, the tank is declared to leak, a false alarm.The chance that this happens is represented by the shaded area under the curve to the right of C, denoted α (alpha).

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

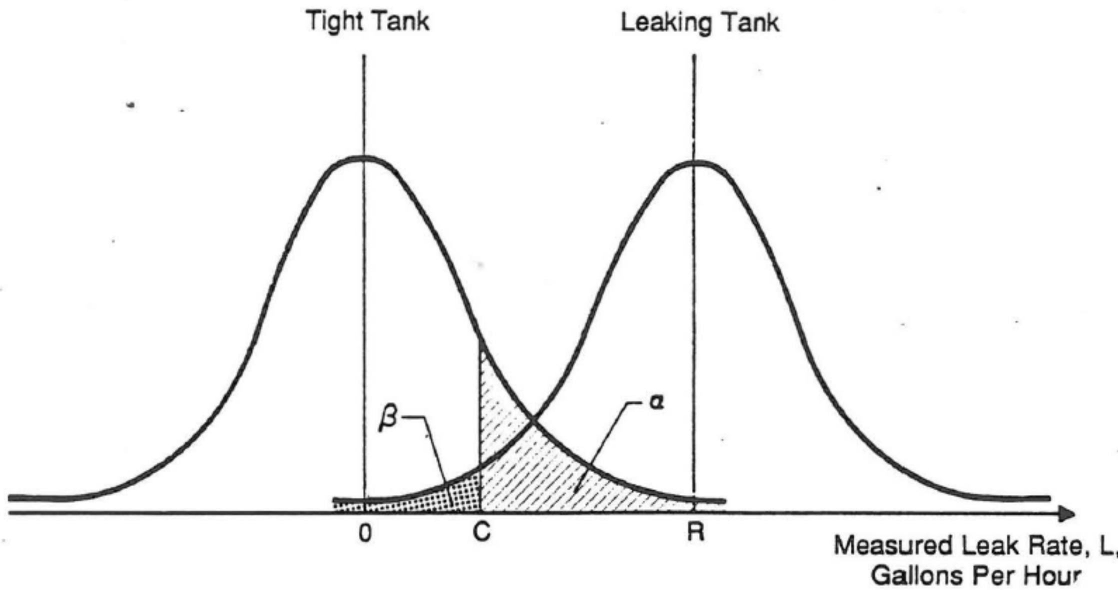
Changing the criterion, C, changes both α and β for a fixed leak rate, R. If the leak rate R is increased, the curve on the right will shift further to the right, decreasing βand increasing the probability of detection for a fixed criterion, C. If the precision of a method is increased, the curve becomes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

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

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

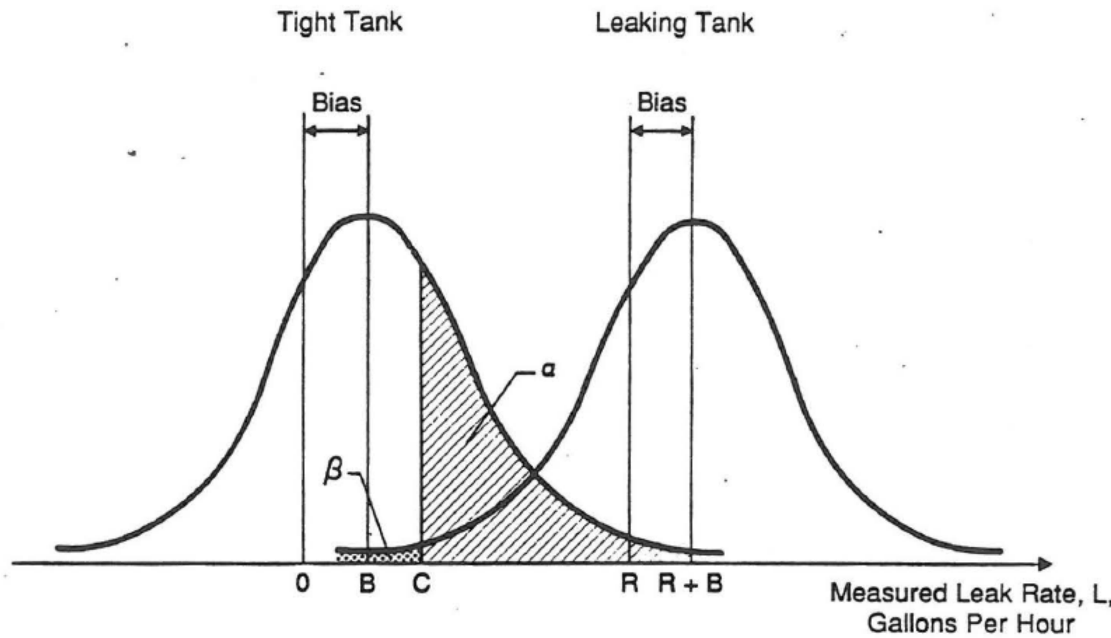
Calculated Leak Rate, R:	A positive number, in gallons per hour, estimated by the statistical inventory reconciliation method and indicating the amount of product leaking out of the tank. A negative leak rate could result from water leaking into the tank, miscalibration, or other causes.
Induced Leak Rate,S:	The actual leak rate, in gallons per hour, introduced in the evaluation data sets, against which the results from a given method will be compared.
Critical Level, C:	The leak rate above which a method declares a leak. It is also called the threshold of the method.
False Alarm:	Declaring that a tank is leaking when in fact it is tight.
Probability of False Alarm, P(FA):	The probability of declaring a tank leaking when it is tight. In statistical terms, this is also called the Type I error, and is denoted by alpha (α). It is usually expressed in percent, say, 5%.
Probability of Detection, P(D(R)):	The probability of detecting a leak rate of a given size, R gallon per hour.In statistical terms, it is the power of the test method and is calculated as one minus beta (β), where beta is the probability of not detecting (missing) a leak rate R. Commonly the power of a test is expressed in percent, say, 95%.
Method Bias, B:	The average difference between calculated and induced leak rates. It is an indication of whether the SIR method consistently overestimates (positive bias) or underestimates (negative bias) the actual leak rate.
Mean Squared Error, MSE:	An estimate of the overall performance of a test method.
Root Mean Squared Error, RMSE:	The positive square root of the mean squared error.
Precision:	A measure of the test method's ability in producing similar results (i.e., in close agreement) under identical conditions. Statistically, the precision is expressed as the standard deviation of these measurements.
Accuracy:	The degree to which the calculated leak rate agrees with the induced leak rate on the average. If a method is accurate, it has a very small or zero bias.

Variance: A measure of the variability of measurements. It is the square of the standard deviation.



C	=	Criterion or Threshold for declaring a leak (a leak is declared if the measured rate exceeds C)
α	=	Probability of False Alarm, P(FA)
β	=	Probability of not detecting a leak rate R
I - β	=	Probability of detecting a leak rate R, P(D(R))
R	=	Leak Rate

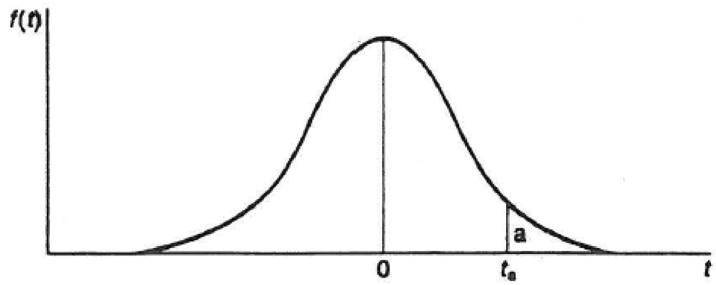
Figure A-1. Distribution of measurement error on a tight and leaking tank.



C	=	Criterion or Threshold for declaring a leak (a leak is declared if the measured rate exceeds C)
α	=	Probability of False Alarm, P(FA)
β	=	Probability of not detecting a leak rate R
I - β	=	Probability of detecting a leak rate R, P(D(R))
R	=	Leak Rate
B	=	Bias

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

Table A-1. PERCENTAGE POINTS OFSTUDENT'S t-DISTRIBUTION



df	a = .10	a = .05	a = .025	a = .010	a = .005
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.333	2.132	2.776	3.747	4.604
5	1.476	2.015	2.571	3.365	4.032
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.499
8	1.397	1.860	2.306	2.896	3.355
9	1.383	1.833	2.262	2.821	3.250
10	1.372	1.812	2.228	2.764	3.169
11	1.363	1.796	2.201	2.718	3.106
12	1.356	1.782	2.179	2.681	3.055
13	1.350	1.771	2.160	2.650	3.012
14	1.345	1.761	2.145	2.624	2.977
15	1.341	1.753	2.131	2.602	2.947
16	1.337	1.746	2.120	2.583	2.921
17	1.333	1.740	2.110	2.567	2.898
18	1.330	1.734	2.101	2.552	2.878
19	1.328	1.729	2.093	2.539	2.861
20	1.325	1.725	2.086	2.528	2.845
21	1.323	1.721	2.080	2.518	2.831
22	1.321	1.717	2.074	2.508	2.819
23	1.319	1.714	2.069	2.500	2.807
24	1.318	1.711	2.064	2.492	2.797
25	1.316	1.708	2.060	2.485	2.787
26	1.315	1.706	2.056	2.479	2.779
27	1.314	1.703	2.052	2.473	2.771
28	1.313	1.701	2.048	2.467	2.763
29	1.311	1.699	2.045	2.462	2.756
30	1.310	1.697	2.042	2.457	2.750
40	1.303	1.684	2.021	2.423	2.704
60	1.296	1.671	2.000	2.390	2.660
120	1.289	1.658	1.980	2.358	2.617
inf.	1.282	1.645	1.960	2.326	2.576

APPENDIX B

REPORTING FORMS

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

1. **Results of U.S.EPA Standard Evaluation--Statistical Inventory Reconciliation Method** (three pages)

2. **Description--Statistical Inventory Reconciliation Method** (three pages)

3. **Reporting Form for Test Results--Statistical Inventory Reconciliation Method** (three pages)

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

Who is responsible for filling out which form?

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

2. **Description of Statistical Inventory Reconciliation Method.** The **evaluating organization** assisted by the **vendor** will complete this form by the end of the evaluation.

3. **Reporting Form for Test Results.** This form is to be completed by the **evaluating organization**. In general, the statistician analyzing the data will complete this form. A blank form can be developed on a personal computer, the data base for a given evaluation generated, and the two merged on the computer. The form can also be filled out manually. The input for that form will be provided by the evaluating organization and the vendor's test results.

At the completion of the evaluation, the evaluating organization will collate all the forms into a single **Standard Report** in the order listed above. In those cases where the evaluating organization performed additional, optional calculations (see Section 7.3 of the protocol), these results can be attached to the standard report. There is no reporting requirement for these calculations, however.

Distribution of the Evaluation Test Results

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

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

The optional part of the calculations (Section 7.3), if done, would be reported by the evaluating organization to the vendor of the SIR method. This is intended primarily for the vendor's use in understanding the details of the performance and perhaps suggesting how to improve the method. It is left to the vendor whether to distribute this form, and if so, to whom.

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

Results of U.S. EPA Standard Evaluation
Statistical Inventory Reconciliation Method

Instructions for completing the form

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

This form consists of five main parts. These are:

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

Method Description

Indicate the commercial name of the statistical inventory reconciliation method, the version, and the name, address, and telephone number of the vendor. Since the method is based on software programs that may be updated, the date reported on the last page is considered the date of the version. If the vendor is not the party who developed and uses the method, then indicate the home office name and address to contact for updates.

Evaluation Results

The criterion for declaring a tank to be leaking is supplied by the vendor. Indicate the leak rate or other criterion in the space provided. Indicate whether the method is quantitative (reports a leak rate)or qualitative (reports only whether the tank is leaking).

The SIR method may not be able to make a determination of the leak status on some of the inventory records. This may be due to inadequacies in the data or to marginal results that are difficult to interpret.Summarize the reported results by filling in each of the boxes of the table on page 1 of the form with the number of inventory records in each category. Calculate and report the indicated totals. The category “inconclusive” is for records that were analyzed but did not give a conclusive result. Vendors may refer to these cases under a variety of terms. The category “not analyzed” is for records that the method identified a data problem with and that were consequently judged unacceptable for analysis. These are removed from the evaluation data base.

The percentages of records that were inconclusive (that is, could not be determined to be tight or leaking by the method) are to be calculated and reported separately among the records from tight tanks, among those with induced leaks, and among all tanks.

P(FA) is the probability of false alarm as calculated in Section 7.1.1 for qualitative methods or in Section 7.2.2 for quantitative methods. If the method is qualitative, calculate and report the 95% confidence limits as described in Section 7.1.3.

P(D)is the probability of detecting a leak ofspecified size as calculated in Section 7.1.2 for qualitative methods or in Section 7.2.3 for quantitative methods. If the qualitative method of Section 7.1.2 is used for P(D), also calculate the 95% confidence interval and reportit. Indicate which leak rate (0.10 or 0.20 gallon per hour) was used in calculating the P(D).

If the P(FA) is 5% or less and if the P(D)is 95% or greater, then check the “does” box. Otherwise, check the “does not” box. Cross out the leak rate for which the performance estimates do not apply.

Test Conditions During Evaluation

The conditions of the data base are summarized here. Report the distribution of tank sizes in the categories indicated by inserting the number of records for each size class of tank.

Report the distribution of throughputs for the tank records in the data base. Calculate the 25th, 50th, and 75th percentiles of the monthly throughputs in the evaluation data base and enter the results on the form.

Report the distribution of the data records by season of year as indicated.

Limitations on the Results

The size (gallons) of the largest tank to which these results can be applied is calculated as 1.50 times the 80th percentile of the tank sizes used in the data for the evaluation.

The minimum record length needed by the method to achieve the performance results reported here is reported as a limitation on the minimum amount of data. This is the average number of usable days of inventory records in the evaluation data base.

The results are limited to single tanks with an inventory record. That is, extension to manifolded tanks with a single inventory record is not allowed.

Certification of Results

Here the person who directed the work of the evaluation provides his/her name and signature, and the name, address, and telephone number of the organization performing the evaluation.

Results of U.S. EPA Standard Evaluation
Statistical Inventory Reconciliation Method

This form tells whether the statistical inventory reconciliation (SIR) method described below complies with requirements of the federal underground storage tank regulation. The evaluation was conducted by the vendor of the SIR method or a consultant to the vendor according to the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods:Statistical Inventory Reconciliation Methods."The full evaluation report also includes a form describing the method and a form summarizing the test data.

Tank owners using this leak detection method should keep this form on file to prove compliance with the federal regulations. Tank owners should check with State and local agencies to make sure this form satisfies their requirements.

Method Description

Name ____

Version ____

Vendor ____

____

(street address)

____

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

Evaluation Results

If applicable, vendor's threshold = _______________ gallon per hour
or vendor's criterion: ____________________________________

This statistical inventory reconciliation method reports results on the following basis (check one):

☐quantitative results (leak rate reported)

☐qualitative results (pass, fail, inconclusive)

Test results are:

		Reported Results				
		Tight	**Leak**	**Inconclusive**	**Total Analyzed**	**Not Analyzed**
	Tight					
Actual	**Induced Leak**					
	Total					

SIR Method ____

Version ____

Evaluation Results (continued)

The proportions of inventory records reported inconclusive are:

___________% among tight tanks

___________% among leaking tanks

___________% among all tanks

The probability of false alarms, P(FA), based on the vendor's threshold, is ___________%.

For qualitative methods, a 95% confidence interval for P(FA) is from

___________to__________%.

The probability of detection, P(D), is ______%. This is valid for a leak rate of (check one):

☐ 0.10 gallon per hour

☐ 0.20 gallon per hour

For qualitative methods, a 95% confidence interval for P(D) is from

___________to__________%.

Based on these results, the method☐ does☐ does not meet the **federal** performance standards established by the U.S. Environmental Protection Agency of 0.10 gallon per hour [or 0.20 gallon per hour] at P(D) of 95% and P(FA) of 5%.

Test Conditions During Evaluation

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

Tank Size (gallons)	<5,000	5,000-10,000	10,000-15,000	>15,000	**Total # of Records**
NumberofRecords					

The tanks had various monthly throughputs.

Percentile of Records	25	50 (median)	75	
Monthly throughput(gallons)				

The data included ____________records during hot weather months.

__________records during mild weather months.

__________records during cold weather months.

SIR Method ____

Version ____

Limitations on the Results

The performance estimates above are only valid when:

- The method has not been substantially changed.
- The vendor's instructions for using the method are followed.
- The tank is no larger than ________ gallons.
- The data records cover__________days or more.
- The method is based on a single (non-manifolded) tank.
- Other limitations specified by the vendor or determined during testing:

  ____

  ____

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

Certification of Results

I certify that the statistical inventory reconciliation method was applied according to the vendor's instructions. I also certify that the evaluation was performed according to the standard EPA test procedure for statistical inventory reconciliation and that the results presented above are those obtained during the evaluation.

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

Description of Statistical Inventory Reconciliation Method

Instructions for completing the form

This three-page form is to be filled out by the evaluating organization with assistance from the vendor upon completion of the method's evaluation. This form provides supporting information on the data requirements and approach of the statistical inventory method.

To minimize the time needed to complete this form, the most frequently expected answers to the questions have been provided.For any questions that require additional information, please provide explanations in the area adjacent to the question. Use the answer that applies most often or in "typical" cases.

There are five parts to this form. These are:

1. General Information
2. Data Requirements
3. Identification of Causes for Discrepancies
4. Reporting of Leak Status
5. Exceptions

In the first part provide the commercial name and other identifying information. Since software is often updated, give the version and date that applies to the method as used in the evaluation.

For the four remaining parts, check all appropriate boxes.Check more than one box per question if it applies. If a box "Other" is checked, please explain or specify. Use additional white space for any otherexplanation you think necessary.

Description
Statistical Inventory Reconciliation Method

This section describes briefly the important aspects of the statistical inventory reconciliation (SIR) method. It is not intended to provide a complete description of the principles behind the SIR method and associated computer software.

General Information

Method Name ____

If applicable:

Version and revision number ____

Date ______________________________________

Vendor ____________________________________

Vendor address and phone number, including area code:

____

____

Contact ____

Data Requirements

Does the method require use of a specified data form provided by the vendor?

- ☐yes
- ☐no

How are the inventory data recorded?

- ☐ manually, on provided forms
- ☐manually, no forms provided
- ☐ hand-entered into a computer
- ☐direct entry from ATGS
- ☐other____

____

What is the required number of usable daily inventory records necessary to detect the indicated leak rate (gallon per hour) with 95% confidence?

If the leak rate is 0.10, the number of daily readings is________________.

If the leak rate is 0.20, the number of daily readings is________________.

Data Requirements (continued)

What is the vendor's *recommended* number of daily records?

☐ 60 daily records

☐ 90 daily records

☐ other, specify ____

Does the method allow for closure of the station on one or more consecutive days of the week?

☐yes

☐no

Does the method require meter calibration?

☐ yes; specify how frequently ____

☐no

Identification of Causes for Discrepancies

Which of the following factors does the method consider? Check the appropriate categories.

	Identify Only	Compensate	Not Considered
dispensing meter errors			
calibration errors			
conversion chart miscalibration			
vapor loss			
thermal effects			
others (list)			

Which of the following effects does the method identify and quantify?

	Identify Only	Quantify	Not Considered
leak rate			
delivery errors			
unexplained losses or gains			
water inflow			
water outflow			
dipstick errors			
others (list)			

Reporting of Leak Status

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 criterion does the method use to declare that a tank is leaking?

☐average daily discrepancy exceeds threshold of _______gal/h

☐daily discrepancy relative to variability exceeds threshold of _________gal/hr

☐water level change exceeds threshold of ______inch

☐statistically significant continuous loss at the _________level of significance.

☐other (specify) ____

Exceptions

Are there any conditions under which the statistical inventory method is inadequate?

☐insufficient number of usable records

☐irregular time intervals between dipstick readings

☐unacceptable daily variability of inventory records

☐other (describe briefly) ____

What elements in the record keeping are left to the discretion of the personnel on site?

☐length of record keeping if beyond minimum requested

☐others (describe briefly) ____

☐none

If applicable, attach a copy of the inventory data collection form(s) as provided to the user by the vendor.

Reporting Form for Test Results
Volumetric Tank Tightness Testing Method

Instructions for completing the form

This form is to be filled out by the evaluating organization upon completion of the evaluation of the method. A single sheet provides for 40 test results. Use as many pages as necessary to summarize all of the tests attempted.

Indicate the commercial name and the version of the SIR method.

In general, the statistician analyzing the data will complete this form. A blank form can be developed on a personal computer, the data base for a given evaluation generated, and the two merged on the computer. The form can also be filled out manually. The input for the form will be provided bythe evaluating organization and the vendor's test results.

The table consists of 6 columns. One line is provided for each inventory record used in the evaluation of the method. If a test was inconclusive, this should be noted and explained.

The **Code Number** in the first column refers to the code assigned by the evaluating organization to each record for decoding purposes during the evaluation process.

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

Column No.	Input	Source
1	Record code number	Evaluating organization
2	Induced leak rate (gallon per hour)	Evaluating organization
3	If quantitative results, estimated leak rate (gallon per hour)	Vendor's reporting form
4	Estimated minus induced leak rate (gallon per hour)	By subtraction
5	If qualitative, estimated leak status	Vendor's reporting form
6	Vendor's comments	Vendor's reporting form

Reporting Form for Test Results

Statistical Inventory Reconciliation Method

Method Name and Version: ____________________

Date: ____________________

	Submitted	Results Reported by Vendor			
		If Quantitative		If Qualitative	
Record Code No.	Induced Leak Rate (gal/h)	Estimated Leak Rate (gal/h)	Est.-Ind. Leak Rate (gal/h)	Tank Tight? (Yes, No, or Inconclusive)	Vendor's Comments
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
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35					
36					
37					
38					
39					
40					

Reporting Form for Test Results

Statistical Inventory Reconciliation Method

Method Name and Version: ______________________________

Date: ____________________

	Submitted	Results Reported by Vendor			
		If Quantitative		If Qualitative	
Record Code No.	Induced Leak Rate (gal/h)	Estimated Leak Rate (gal/h)	Est.-Ind. Leak Rate (gal/h)	Tank Tight? (Yes, No, or Inconclusive)	Vendor's Comments
41					
42					
43					
44					
45					
46					
47					
48					
49					
50					
51					
52					
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79					
80					

Reporting Form for Test Results

Statistical Inventory Reconciliation Method

Method Name and Version: ______________________________

Date: ______________________________

	Submitted	Results Reported by Vendor			
		If Quantitative		If Qualitative	
Record Code No.	Induced Leak Rate (gal/h)	Estimated Leak Rate (gal/h)	Est.-Ind. Leak Rate (gal/h)	Tank Tight? (Yes, No, or Inconclusive)	Vendor's Comments
81					
82					
83					
84					
85					
86					
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