Evaluation Protocol for Vacuum-Wrapped Pressurized Portions of a Fuel Containment and Dispensing System

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PREFACE

This report was prepared by Jairus D. Flora, Jr., Ph.D. with the support of Veeder-Root. This report contains an evaluation protocol for testing the vacuum-wrapped pressurized primary fuel path from tank to dispenser. The purpose of this protocol is to provide a means to certify a new method of leak detection that utilizes secondary containment on piping components of an underground fuel storage and delivery system. The intent of this system is to provide leak detection that exceeds current Federal standards for leak detection on underground tanks and lines defined as: an hourly test of 3 gph (pressurized lines only) and either a monthly test of 0.2 gph or an annual test of 0.1 gph. These current standards are defined as leaks that are to be detected as the product is leaving the primary space and entering either the secondary space or the environment. Additionally, a system passing this protocol can be considered to meet or exceed requirements for Continuous Interstitial Monitoring Methods (Pressure/Vacuum), for example California AB 2481 requirements for continuously monitored vacuum interstitial systems. This protocol is directed at the certification of a system that utilizes a UST system that is completely secondarily contained and the secondary space is continuously monitored with a vacuum such that any product that leaves the primary space will be captured in the secondary space and not allowed to enter the environment; any product captured will either be returned to the primary space or cause product flow to stop.

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CONTENTS

SECTION 1

INTRODUCTION

EPA regulations[1] specify performance standards for leak detection methods for underground storage tanks. Separate performance standards are given for detecting leaks from tanks and from pressurized piping. In particular, leak detection must be capable of detecting a leak of 3 gallons per hour (gph) from pressurized piping within one hour. In addition, on a monthly basis, leak detection systems must be capable of detecting a leak of 0.20 gallon per hour (gph) or 150 gallons per month from pressurized piping with a probability of detection (PD) of at least 95% while operating at a probability of false alarm (PFA) of no more than 5%. On an annual test basis, leak detection systems must be capable of detecting a leak rate of 0.10 gallon per hour. The EPA has provided a series of seven standard evaluation procedures for leak detection methods.[2] Six of these EPA protocols refer to leak detection methods mentioned specifically in the regulations. The other one, for Statistical Inventory Reconciliation (SIR) methods, was developed by EPA for a method that qualifies under the "other method" category mentioned in the regulations. Other protocols, notably one for Continuous In-Tank Leak Detection Methods (CITLDS), have been developed and have been approved by various regulatory agencies.

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

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

1. Evaluate the method using EPA's standard test procedures for leak detection equipment;
2. Evaluate the method using a national voluntary consensus code or standard developed by a nationally recognized association or independent third-party testing laboratory; or,
3. Evaluate the method using a procedure deemed equivalent to an EPA procedure by a nationally recognized association or independent third-part testing laboratory.[3]

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

Alternative Test Procedures Deemed equivalent to EPA's

In some cases, a specific leak detection method may not be adequately covered by EPA standard test procedures or a national voluntary consensus code, or the manufacturer may have

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[1] 40 *CFR* Part 280, Subpart D.
[2] "Standard Test Procedures for Evaluating Leak Detection Methods," EPA/530 UST-90/001-007. Seven different procedures were developed for different leak detection methods and released between March and October 1990.
[3] *Ibid*.
[4] *Ibid*.

access to data that makes it easier to evaluate the system another way. Manufacturers who wish to have their equipment tested according to a different plan (or who have already done so) must have that plan developed or reviewed by a nationally recognized association or independent third-party testing laboratory…. The results should include an accreditation by the association or laboratory that the conditions under which the test was conducted were at least as rigorous as the EPA standard test procedure. In general, this will require the following:

1. The evaluation tests the system both under the no-leak condition and an induced leak condition with an induced leak rate as close as possible to (or smaller than) the performance standard. In the case of volumetric tank tightness testing, for example, this will mean testing under both 0.0 gallon per hour and 0.10 gallon per hour leak rates. In the case of pressurized piping, this will mean testing under the no leak condition and both the 3 gallon per hour (hourly) rate and either the 0.20 gallon per hour (monthly) or the 0.10 gallon per hour (annual) leak rate.
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….
4. The evaluation results must contain the same information and should be reported following the same general format as the EPA standard results sheet.
5. The evaluation of the leak detection method must include physical testing of a full-sized version of the leak detection equipment, and a full disclosure must be made of the experimental conditions under which (1) the evaluation was performed, and (2) the method was recommended for use. An evaluation based solely on theory or calculation is not sufficient.

New technologies currently being brought to the market require development of new protocols.

This document presents an evaluation protocol designed to provide a means to certify a new method of leak detection that utilizes the secondary containment of piping and piping components on an underground fuel storage and delivery system. The intent of this system is to provide leak detection that meets or exceeds current Federal standards for leak detection on underground lines defined as: an hourly test of 3 gph (pressurized lines only) and either a monthly test of 0.2 gph or an annual test of 0.1 gph. These current standards are defined as leaks that are to be detected as the product is leaving the primary space and entering either the secondary space or the environment. Additionally, this system can be considered to meet or exceed requirements for Continuous Interstitial Monitoring Methods (Pressure/Vacuum), for example California AB 2481 requirements for continuously monitored vacuum interstitial systems. This protocol is directed at the certification of a system that utilizes a UST system that is completely secondarily contained and the secondary space is continuously monitored with a vacuum such that any product that leaves the primary space will be captured in the secondary space and not allowed to enter the environment. This protocol does not include testing of the tank's secondary space and is limited to pressurized piping, dispenser liners, and STPs and STP piping sumps. The tank must be isolated from the system and have its own method of interstitial monitoring. Any product captured will either be returned to the primary space or will cause product flow to stop.

SECTION 2

SCOPE OF APPLICATION

This document presents a standard protocol for evaluation of vacuum-wrapped pressurized portions of a fuel containment and dispensing system. It is intended for use on the secondary containment of pressurized piping carrying the product from the tank to the dispenser as well as secondarily contained under-dispenser or in-dispenser containment pans or sumps (UDC or IDC)[5] and a secondarily contained submersible turbine pump (STP). The system to be tested utilizes a UST system that is completely secondarily contained in such a way that the secondary space is continuously monitored with a vacuum. The application is limited to use on interstitial spaces that are sufficiently rigid to withstand the vacuum that will be applied by the monitoring system. This vacuum is such that any product that leaves the primary space will be captured in the secondary space and not allowed to enter the environment. Any product captured will either be returned to the primary space or will cause product flow to stop.

This protocol is based on the fact that as long as a minimum vacuum level is maintained on the secondary space, a leak into the environment cannot occur and the station can safely continue to operate. The focus of this protocol is to verify that the proposed system is capable of maintaining proper secondary containment vacuum levels throughout the entire containment system such that any failure of the secondary vacuum will alarm and be quickly detected, minimizing or preventing loss of product into the environment.

Subject to the limitations listed on the Results of U.S. EPA Alternative Test Procedures form[6] (see Appendix) the results of this evaluation can be used to prove that a Vacuum-Wrapped Fuel Containment and Dispensing System meets the requirements of 40 CFR Part 280, Subpart D. Upon acceptance by the local regulatory agency, the system will be recognized as an approved method for compliance. This test protocol applies to the vacuum-wrapped pressurized portions only of a vacuum-wrapped leak containment system (i.e., pressurized by a submersible turbine pump, not by hydrostatic head from a static fluid as in a tank)**.** For each independent piping configuration (often one per fuel grade), the system may combine multiple secondary vacuum containment zones to protect the entire primary pressurized fuel path from tank to dispenser; this will also include any dispenser containment continuously monitored for integrity (vacuum, brine, or otherwise). If there are multiple zones, each zone will be tested separately. Other parts of a vacuum-wrapped leak containment system, such as a double-walled tank, are covered by pre-existing test protocols.

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[5] For the scope of this protocol, UDC or IDC can be used interchangeably and imply dispenser containment pan or sump.

[6] This follows the language in EPA Standard Test Procedures for Evaluating Leak Detection Methods: Automatic Tank Gauging Systems, page 5.

SECTION 3

SUMMARY

This protocol tests systems that provide a vacuum-wrapped containment system for product dispensing systems. These systems monitor this vacuum-wrapped portion to ensure that the vacuum is maintained to prevent releases or to detect a loss of vacuum that might make possible the release of product. This protocol applies to the entire pressurized primary fuel path from the tank to the dispenser including any dispenser containment continuously monitored for integrity (vacuum, brine, or otherwise).

There are two sites for testing called for in this protocol: laboratory tests and field tests. The laboratory tests are designed to determine the performance of the system. They involve setting up test conditions that would not be practical in the field. The field tests involve a full-scale demonstration of the operation of the system in the field. The field tests will be used to confirm the performance determined in the laboratory. Limitations on the system in terms of pipe size, line length, or interstitial volume are determined by the larger of the piping systems used in the laboratory or the field tests.

There are several types of tests to be conducted. One series of tests is intended to show that the system can detect a degradation of vacuum to a specified level with at least a 95% probability of detection. This requirement has been interpreted to mean that the probability of detection (PD) estimated from the evaluation tests must be at least 95%. This PD is estimated by dividing the number of correct detections among the evaluation tests by the total number of simulated leak tests. With a sample size of 21, the estimated PD will be at least 0.95 (95%) if at least 20 tests result in correct detection. The number of tests was chosen to be 21 to be consistent with the earlier EPA Protocols[7] and so that the point estimate of PD would be at least 95% even if the system missed one detection during its evaluation tests.

A second type of test is intended to show that the system will have no more than a 5% false alarm rate (chance of alarming under normally occurring variability of vacuum level). The requirement of a probability of false alarm (PFA) of 5% or less has been interpreted to mean that the PFA estimated in the evaluation testing must be 0.05 (5%) or less. The PFA is estimated by dividing the number of false alarms during the testing by the number of tests on a tight system. The number of false alarm tests was again chosen to be 21, consistent with the earlier EPA protocol,[8] and so that the system could have one false alarm during testing and still pass.

A variety of other tests are called for to demonstrate that the system is capable of dealing with a variety of possible conditions, including water ingress, product ingress, physical breach of the secondary containment, etc., while either maintaining a vacuum level that will contain any product, or identifying a fault condition and alarming. Since these are demonstration tests that do not relate to either the false alarm probability or the required detection rate, only a limited number of such tests, generally three, is required along with a single test to demonstrate continuity of the interstitial space. The multiple tests will include the demonstration that a loss of vacuum and water or product incursion can be detected on different types of pipe and sumps. The number 3 was selected to allow for the demonstration that the system performed correctly,

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[7] "Standard Test Procedures for Evaluating Leak Detection Methods: Non-volumetric Tank Tightness Testing Methods," U.S. EPA/530/UST-90-005, March, 1990.
[8] *Ibid*.

while providing replication to ensure against an anomalous result on a single test. Since these tests are designed to demonstrate that the system can operate correctly under a variety of conditions, the system is required to perform correctly on all of the demonstration tests.

Laboratory Tests

Laboratory tests will be conducted on a complete, but (usually) scaled down, system with additional equipment to allow the tests to be performed. The laboratory tests will include several types of tests designed to test the various modes of failure that could occur. Some tests will be conducted by allowing air to ingress into the interstitial space as might occur if the outer wall were breached. Other tests will allow water ingress into the interstitial space. This might occur if the outer wall was breached and the pipe was in fill saturated with water. Both of these types of test will be conducted with the air or water at atmospheric pressure and the interstitial space at the designed vacuum level. A third type of testing will allow product (such as diesel fuel) to ingress into the interstitial space. The product will be at the pipeline operating pressure, about 30 psi relative to the atmosphere, while the interstitial space will again be at its designed vacuum level. This type of failure could occur if there were a breach in the primary wall allowing the product into the interstitial space.

The laboratory tests will determine that the system can maintain a vacuum and prevent release for small leak rates. They will also show that the system can detect when the leak rate is large enough to cause a sufficient loss of vacuum to reduce the protection provided by the vacuum-wrapped interstitial space and issue an alarm or shut down the pump.

Laboratory tests may be conducted with different types of double-walled pipes. The types of double-walled pipes to be used will be those designated by the manufacturer of the system. For example, tests might be conducted on open type double-walled systems, such as 3-inch over 2-inch pipes, or on pipes with restricted interstices, such as flex lines.

Field Tests

Field tests will be conducted on full-scale installed systems. The field tests will include simulating leaks by allowing air ingress into the interstitial space. No tests will be conducted with liquids, either water or product. The reason for this restriction is that allowing liquids into the interstitial space could compromise the system. Three types of demonstration tests are planned. One type will be with a large leak to demonstrate that the system can detect the loss of vacuum and alarm or shut down. A second demonstration test will be conducted with a small leak rate to demonstrate that the system can maintain the vacuum and not give a false alarm when minor changes in the vacuum occur. Finally, a demonstration test will be run to show that the system can detect an excessive replenishment rate and alarm. The rate of replenishment is limited to a maximum of 85 liters per hour or a lesser rate if specified by the manufacturer.

Pipe Types and Limitations

The system must be tested on each type of double-walled pipe for which it is designed to be used; testing on one type of double-walled pipe would qualify the system for use on other models of the same type with similar interstice characteristics. The size of the system and its interstitial characteristics will be used to determine limits on the application of the system in terms of size. Limits will be specified on the total interstitial volume and length of line for open interstices, and on the length of line for restricted interstices. See Section 9 for more details on types of double-walled pipe.

For open interstice pipelines, following the EPA Pipeline protocol, application will be limited to systems up to twice the interstitial volume of the larger of the piping used in the field test or the piping used in the laboratory testing. In this case, the total volume of the interstice of the pipes including all branches becomes the limiting value. A further limitation is that the length between sensors is limited to be no more than twice the longer of the length of the piping used in the field or the piping used in the laboratory testing.

For restricted interstice pipelines, the system is limited to the length used during the laboratory Product Ingress Testing. The length limit applies to the distance between the 2 nearest sensors monitoring a length of pipe. The reason for this is that the restricted interstice restricts the flow of liquid and so affects the response time if liquid comes into the interstitial space. If the system under evaluation has only one pressure sensor in the pipe interstice zone, the length limit applies to the distance from the sensor to the farthest point of any branch in the pipeline.

SECTION 4

SAFETY

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

This section does not attempt to address the safety concerns involved in conducting the testing involved in this protocol. The evaluation involves working with flammable and volatile liquids. Persons conducting this testing should have knowledge of the safety requirements for working with such substances. Evaluators should follow all applicable safety procedures when working with this equipment.

SECTION 5

LABORATORY TESTS

This section provides the detailed test methods and schedule for the laboratory tests. The system relies on maintaining an adequate vacuum in the interstitial space to contain any leaks from the primary pipe. The system must be capable of detecting a loss of vacuum to a level that might allow for a loss of product to the environment and issuing an alarm if such a loss of vacuum occurs. The system must be capable of alarming if the vacuum replenishment rate exceeds 85 liters per hour or a lesser rate if specified by the manufacturer. The system must also be capable of operating normally without alarming when temperature or barometric pressure changes occur.

Equipment

Approximately 40 feet of rigid, open-interstice double-walled piping to be tested should be connected to the submersible turbine pump installed in a suitable tank. This piping should be connected to a dispenser at the other end, with any appropriate double-contained fittings and any dispenser containment pans or sumps that are part of the system. Generally, there will be a return path allowing the liquid to be pumped around a loop and returned to the tank. A low spot should be incorporated in the piping so that a blockage may be simulated. A valve will also be used to allow for part of the interstitial space to be isolated.

The vacuum monitoring and control components will be added to this laboratory set up. This will include the vacuum-producing source, various vacuum or pressure sensors in the interstitial space, and connections to the control module or console.

The evaluator will need to install a valve connected to an airflow controller to allow for letting air into the interstitial space. One or more pressure/vacuum gauges will also be needed. One will be installed near the opening for air ingress. Another independent pressure/vacuum gauge will be installed at each point where the system has a vacuum sensor. At least two air ingress ports will be installed, one near each end of the system. The airflow controller will be needed to measure and control the rate of air ingress in part of the testing.

Once the test system has been set up, conduct an initial test to ensure that the system is tight. This test should be conducted by evacuating the system to a relatively high vacuum and holding the system at that vacuum for period of time. This is intended to show that the test setup is tight. It is also intended to allow for any out gassing of vapors from a new plastic or resin. Testing should not begin until the test setup has been shown to be tight and any out gassing has stabilized at a low enough level so as not to interfere with the testing in the judgment of the evaluator for the particular system being tested. That is, the evaluator has the responsibility and authority to determine when a test apparatus is sufficiently tight so as not to interfere with the testing for the particular system on test.

1. Air Ingress Testing

a. Determine that the system reliably alarms with loss of vacuum ("leak" tests).

The purpose of these tests is to show that the system will reliably alarm if the vacuum in the interstitial space drops to an inappropriate level. Since these tests must cause the vacuum to drop to near zero (or the pressure to increase to atmospheric) in order to demonstrate that the system detects a loss of vacuum, the vacuum replenishment source will be disabled for these tests. For all other laboratory tests, the system will be left in its operational condition with the vacuum source enabled. Note that in the event that there are multiple sensors, the system must report the results (e.g. alarm) separately for each sensor or the sensors must be isolated and tested separately.

The manufacturer or vendor will specify the level of vacuum that should lead to an alarm by the system. This could be specified as the pressure relative to atmospheric pressure or it could be specified as absolute pressure. Care must be taken to ensure that the correct interpretation of the stated pressures or vacuum is used. The evaluator will install an independent pressure/vacuum gauge to monitor the vacuum level in the interstitial space. The normal operating level of vacuum in the interstitial space will be established. Then the evaluator will allow air to enter the interstitial space until the specified alarm level of vacuum is reached. Once the vacuum has decayed to the specified level, the air inlet will be closed. The evaluator will record the elapsed time from when the system reaches the target pressure until the alarm occurs and the alarm pressure. If the system fails to alarm within one hour, the test will be recorded as a failure to detect. In this case no elapsed time is recorded and the test is not used in calculating a mean response time. If the alarm occurs prior to reaching the specified target pressure, the evaluator will record the pressure at which the alarm occurs and 0 for response time. The vacuum source will be reconnected and the test will be repeated by again establishing the normal operating level of the vacuum in the interstitial space and repeating the process. A minimum of 21 tests is required. The system must alarm in at least 20 of the 21 tests (at least a 95% detection rate).

The evaluator will select the rate at which air is allowed into the system for these tests. The rate to be chosen is a compromise between fast enough to perform the test in a reasonable time, but slow enough to permit the evaluator to measure the alarm pressure and the elapsed times accurately, and slow enough that it is within the system's specified replenishment rate; see (c.) below. A rate of half the specified replenishment flow rate should be acceptable for most interstice volumes; in the case of very small interstice volumes, the evaluator may use lower rates to perform this test in order to achieve the accuracy desired and to avoid any system replenishment rate alarms.

b. Determine that the system does not have excessive false alarms ("no-leak" tests).

The purpose of these tests is to document that the system does not alarm unnecessarily or inappropriately. That is, to document that the system does not issue a false alarm when changes in temperature or barometric pressure induce small changes in the vacuum level in the interstitial space.

It would be possible to introduce temperature changes that affect the vacuum by pumping hot liquid through the primary pipe. However, it is impractical to create external pressure changes to simulate barometric pressure changes. Since the relevant effect of either temperature or barometric pressure changes is to change the vacuum level (that is, to change the relative pressure between the interstitial space and the external atmosphere), altering the pressure in the interstitial space can adequately simulate this effect. The change in the interstitial pressure that might be expected to occur in an extreme case can be calculated from hypothesized temperature and barometric pressure changes. This change in the vacuum level can be introduced and maintained to document that the system does not alarm under conditions where there is only a change in the vacuum level resulting from expected external effects.

The EPA protocol for pipeline leak detection methods uses a maximum temperature difference of 25 degrees F between the product pumped through the line and the ground. The standard EPA protocol does not specify anything about barometric pressure conditions. Barometric pressure changes generally occur slowly and usually do not exceed 2 inches of mercury over a day or so. Calculations show that a change (increase) in the temperature of the interstitial space by 25 degrees F, coupled with a barometric pressure change (decrease) of 2 inches of mercury would produce a change of less than 1.5 psig in the relative pressure between the interstitial space and the external (atmospheric) pressure. In this case the relative pressure of the interstitial space would increase or become closer to the atmospheric pressure, indicating an apparent loss of vacuum. Consequently, for "false alarm" tests, the evaluator will introduce air into the interstitial space to allow the pressure in the interstitial space to increase by 1.5 psi (that is, the vacuum in the interstitial space will be degraded by 1.5 psi). The evaluator is responsible for selecting the rate at which the pressure will be allowed to increase. This rate should be fast enough to give a reasonable test time, but slow enough so that it will not trigger an alarm because of the replenishment rate. The absolute pressure in the interstitial space should be changed by the full 1.5 psi, but not so rapidly as to trigger an alarm because of the replenishment rate. Note that the acceptable rate will be a function of the volume of interstitial space. Very small interstitial volumes will require small rates.

The proposed testing is at least as stringent as the EPA standard pipeline protocol. The standard EPA pipeline test protocol requires testing with the product temperature up to 25° F different from the ground temperature. However most of the specified tests are at less extreme temperature differences. The current protocol tests the effect of the most extreme temperature condition specified in the standard EPA protocol. To this effect, it adds an extreme barometric pressure effect in the same direction. Inducing the combined effect of temperature and barometric pressure is more stringent than ignoring the effect of barometric pressure. Further, inducing the effect of temperature directly is more stringent than circulating hot product, because circulating product would not create as large an effect as is being induced in this protocol.

It is anticipated that the vacuum system will have an acceptable range of pressure in the interstitial space (for example 7±1 psi of vacuum or 7.7 ±1 psi absolute). The test will be started with the (absolute) pressure at the midpoint of this acceptable range. The pressure will be allowed to increase by 1.5 psi and the new pressure (or degraded vacuum) will be maintained for at least twice the anticipated response time (provided by the vendor) and whether or not the system alarms will be recorded. If an alarm occurs, the response time will be recorded.

After the test period, the air ingress will be shut off and the interstitial space will be returned to the normal operating vacuum. Then the false alarm test will be repeated. A total of at least 21 "false alarm" tests will be conducted. The system must not issue a false alarm more than once in the 21 tests (less than a 5% false alarm rate).

Note: The "false alarm" tests of part (b.) and the "leak detection" tests of part (a.) may be conducted in a randomized pattern. If a vendor were operating the system, this randomization should be done, but if the system is operated only by the evaluator or is automatic, this randomized sequence is not necessary.

c. Determine that the system alarms if the allowable vacuum replenishment rate is exceeded.

The vendor will specify a maximum replenishment rate that is allowed by the system. This replenishment rate is limited to a maximum of 85 liters per hour. The manufacturer may specify a smaller limit to the replenishment rate. This rate is expressed in units of airflow, for example, in liters per hour or cubic feet per hour. This rate corresponds to a maximum vacuum decay rate that is allowed by the system. However, for testing and control, the air ingress rate will be measured and controlled. This air ingress rate will depend on the type of double-walled pipe being tested. It will be larger for open interstices, such as 3-inch over 2-inch rigid pipe, and may be quite small for restricted interstices.

To conduct the test, the system is set up and the normal operating conditions are established. Then a valve is opened, allowing air to ingress into the interstitial space through a flow meter at the rate specified by the vendor. This rate should be one that the vendor determines as a rate that would alarm. If the vendor does not specify a rate, the rate of 85 liters per hour may be used, as this is the upper acceptable limit for air ingress and vacuum replenishment. This condition is maintained for at least twice the suggested response time (supplied by the vendor) or until the system alarms and the evaluator will record whether or not an alarm occurs. When an alarm occurs, the pressure (vacuum) level in the interstitial space is recorded, along with the time since starting the airflow.

Small interstices will experience fast vacuum decay at high air ingress rates; if the vacuum control system does not permit constant or frequent replenishment, the interstice may reach the specified unacceptable vacuum threshold and the system would alarm for a no- or low-vacuum condition. For example, if a 1 gal interstice were subjected to an air ingress at a constant rate of 10 gallons per hour, it would see its vacuum decay from –7 psig to 0 psig in approximately 3 minutes. The purpose of these tests is to demonstrate that the system will alarm if there is excessive replenishment. If the system alarms because the vacuum degrades too much, it may be necessary to modify the test apparatus by connecting a vacuum chamber to the interstice. This can be done using a propane tank, for example. This additional vacuum chamber will increase the volume of the interstice so that the excessive replenishment rate can be tested without leading to a no (or low) vacuum alarm. The test is successful if the system alarms due to excessive replenishment within the suggested response time.

Once the alarm has occurred, or the maximum time has been reached without an alarm, the data are recorded. The air ingress is shut off. The system is allowed to return to its normal operating condition, and the test is repeated. A total of at least 3 demonstration "replenishment" tests is required. The system must alarm correctly on all 3 tests.

2. Water Ingress Testing

This series of water-ingress tests is designed to demonstrate that if there is a breach in the outer wall, allowing an excessive amount of water to come into the interstitial space, the system must detect this condition and issue an alarm. These water-ingress tests apply to the interstitial spaces of the pressurized piping below grade level, the submersible turbine pump (STP) and any vacuum monitored UDC.

For this testing, water will be introduced into the interstitial space. The water will be under ambient, that is, atmospheric pressure. Consequently, the pressure difference between the liquid water and the interstitial space will be the vacuum level maintained in the interstitial space.

If the piping has an open interstice, such as a 3-inch over 2-inch FRP pipe, testing may be conducted on a laboratory scale with about 40 feet of pipe. If the piping has a restricted interstice, such as flex pipe, testing should be conducted on a longer section, typically 200 to 500 feet of pipe. The flex pipe can be in a coil and so would not take up an excessive amount of space in the laboratory. The reason for this difference is that the restricted interstice retards the flow of liquid and may respond quite differently from an open interstice.

The normal operating level of the vacuum in the interstitial space will be established. The evaluator will establish the rate of water incursion. The rate should be fast enough for a reasonable duration of the test. It should be slow enough so that it will not trigger a replenishment alarm, and also slow enough so the evaluator can accurately watch and record the vacuum levels. The vacuum will be monitored with an independent vacuum gauge at the same points where the system has its monitoring points.

The interstitial space will be opened to the water source. A total volume of water up to the volume of the interstitial space will be allowed to enter the interstitial space. If an alarm occurs, record the response time, volume of water, and the vacuum level when the alarm occurs. The test is continued until the system issues an alarm, or until the total volume of water has entered the interstitial space. At that point, the test is concluded and the results noted, including whether or not the system alarmed, and the total volume of water that came in to trigger the alarm. Once the test has been completed, the water is removed from the interstitial space and the test is repeated to give a minimum of 3 water ingress tests. The system must alarm correctly on all 3 tests.

Note that the same “no-leak” tests as used before serve as “no-leak” tests for the water incursion tests. Likewise, there is no need for further vacuum-replenishment tests.

3. Product Ingress Testing

This series of tests is designed to demonstrate that the system can protect against a breach of the primary (product-carrying) pipe or alarm if such a breach or leak occurs. As such, the series only applies to interstitial spaces surrounding pressurized, product-carrying primary piping and the secondarily contained STP. The system operates by maintaining a vacuum on the interstitial space and monitoring that vacuum to detect problems. A volatile liquid product leaking into the interstitial space may affect the vacuum differently than a less volatile liquid such as water because the product may evaporate more rapidly. This evaporation could produce a larger change in the vacuum level than that just caused by the incursion of the liquid.

Since the primary pipe containing the product operates at a higher pressure, approximately 30 psig relative to atmospheric pressure, the testing will be done with the product introduced to the interstitial space at about 30 psig relative to atmosphere. Since the interstitial space is under a partial vacuum or reduced pressure relative to the atmosphere, this means that the pressure difference between the product and the interstitial space will be greater than atmospheric pressure. For example, if the interstitial space were under 8 psig of vacuum, the pressure difference between the product and the interstitial space would be 38 psig.

An independent vacuum/pressure gauge should be installed near the vacuum source. Another vacuum/pressure gauge should be installed near the leak source, and a third such gauge should be installed at an intermediate, static point. The leak point will be at the maximum distance from a sensor. For example, if there is a sensor at the STP, but no sensor at the dispenser, the leak source would be near the dispenser. If a system has sensors both at the STP and at the dispenser, the leak source should be approximately halfway between the sensors.

If the piping has an open interstice, such as a 3-inch over 2-inch FRP pipe, testing may be conducted on a laboratory scale with about 40 feet of pipe. If the piping has a restricted interstice, such as flex pipe, testing should be conducted on a longer section, typically 200 to 500 feet of pipe. The flex pipe can be in a coil and so would not take up an excessive amount of space in the laboratory. The reason for this difference is that the restricted interstice retards the flow of liquid and may respond quite differently from an open interstice.

For non-restricted piping, product incursion will behave similarly to that of water in the water ingress tests. For restricted piping where the product cannot move away from the leak source as easily, the vacuum at the leak source will decay and may reach zero. For restricted-interstice piping, tests should be conducted with both gasoline and diesel. The gasoline, being volatile, will demonstrate that the system can respond appropriately to the incursion of a volatile liquid and the possible reduction of vacuum through volatilization as well as volume reduction. The diesel fuel, being more viscous, will move more slowly through the restricted interstitial space. Because of its viscosity, it may cause a localized vacuum loss, which should lead to a system alarm. Use of both gasoline and diesel in the testing will test both potential modes of vacuum loss and will qualify the system for use with volatile products as well as with products with equal or lower viscosities to that of diesel (e.g. kerosene).

The system is required to maintain an adequate vacuum for the duration of the test or to alarm if it cannot maintain an adequate vacuum. If the pressure at the leak source reaches zero, the system must alarm within a specified response time after the vacuum at that point is lost. The vendor may suggest a response time of up to one hour. If the system alarms, the response time from the time when the pressure at the leak source reached zero until the system alarmed is recorded and reported. The system must respond within one hour of the pressure at the leak source reaching zero to be consistent with the response time requirement for automatic line leak detectors as specified in 40 CFR §280.44(a). If the pressure at the leak source does not reach zero (e.g. in non-restricted piping), the test is continued until the system alarms or a total volume of product greater than or equal to one and one-quarter times the volume of the interstitial space has been admitted. This volume of liquid was chosen so that the test could completely fill the interstitial space with liquid (the additional 25% of volume was included to ensure enough liquid was used even if the volume of the interstitial space was somewhat uncertain). If the system alarms, the response time is recorded and reported. If a volume of product of one and one quarter the volume of the interstitial space or more has entered the interstitial space, and the system has been able to maintain the vacuum without alarming, this demonstrates that the system was able to contain the product without any release to the environment.

The product will be introduced into the interstitial space through a calibrated orifice. This orifice will be isolated with a valve, so the flow of product can be turned off and on. The orifice should be calibrated to flow 3 gallons of product per hour at 10 psig. At the conclusion of the test the results are recorded, including the response, whether or not an alarm occurred, and the total amount of product introduced into the interstitial space. The response time is recorded whenever an alarm occurs. Also record the vacuum/pressure at each of the independent sensors.

Once the test is concluded, the product is removed from the interstitial space and the test is repeated for a total of at least 3 tests with each product, gasoline and diesel. (If the vendor specifies a limitation of the system to non-volatile products, then testing with gasoline may be omitted.) The system must perform correctly on all three of these 3 gph tests with each product.

Note that as with the water incursion tests, the previous "no-leak" tests serve as "no-leak" tests here, also. Similarly, there is no need to repeat the replenishment rate tests.

4. Testing of Each Vacuum Zone

The tests described above are to be conducted on each separate vacuum zone that the system monitors from end to end of the primary pressurized fuel containment. Different systems might have different vacuum zones. It is anticipated that a system might have one vacuum zone for the double-walled piping. A second vacuum zone could be a double-walled submersible turbine pump (STP). A third vacuum zone could be a double-walled dispenser containment pan or sump. Each of these three zones is discussed briefly below.

Double-walled Piping Zone

The testing described in number 3 above, is based on the double-walled piping. As such, the air ingress testing, the water ingress testing, and the product ingress testing are all applicable, as is the liquid containment with air ingress test described in number 7, below. Likewise, the blockage test is required.

Submersible Turbine Pump (STP) Zone

The testing appropriate for a double-walled submersible turbine pump includes the air ingress testing described above. It also includes the product ingress testing and water ingress testing. The blockage test and the liquid containment with air ingress test are not required for this zone.

Dispenser Containment (UDC) Zone

The testing required for the UDC includes the air ingress tests. The blockage tests are not required. Since the UDC is not subject to product under pressure, the product tests (with ingress at pump pressure) are not required. The purpose of the UDC is to catch any liquid that leaks from the dispenser, meter, or associated piping. Consequently, any liquid that would be on one side of the double-walled UDC would just be at atmospheric pressure. If liquid accumulates in the UDC, it would be detected by the liquid sensor in the pan or sump (not in the interstice). However, if one wall of the UDC were breached, this liquid could enter the vacuum, so the water ingress tests should be run. If a double-walled UDC that is hydrostatically monitored forms part of the system, this monitoring system must be evaluated according to the evaluation protocol for testing hydrostatically monitored interstices[9] and the results referenced in this report.

Other Zones

If other vacuum-monitored zones were defined by other systems, each zone should be tested, at least with the air-ingress tests. Whether the other types of tests are appropriate would depend on what the zone is and whether it is subject to product under pressure or water-saturated backfill, or both.

5. Liquid Sensor Testing

If the system uses a liquid sensor to detect the incursion of liquid into the interstitial space, this liquid sensor should be evaluated according to the evaluation protocol for testing liquid sensors. If the system requires liquid sensors in the dispenser pan or sump (in addition to or instead of the interstice) to detect liquid leaks at the dispenser, they should be also be evaluated according to the evaluation protocol for testing liquid sensors. This testing could be conducted as part of this protocol, or it might already have been conducted. If previous testing is used, reference the testing in this report. If the liquid sensor(s) have not been previously evaluated, they should be evaluated according to the liquid sensor evaluation protocol[10] and the results reported according to that protocol. The liquid sensor evaluation protocol is not repeated here.

6. Blockage Testing

The purpose of this test is to demonstrate that incursion of a small amount of water (or other liquid) will not block the interstitial space and prevent the system from maintaining the vacuum. Alternately, if such a blockage occurs, the system must either overcome it or must identify the problem and alarm. The blockage testing applies only to the pressurized piping and not to other vacuum zones, such as the STP or the UDC

Introduce or simulate a blockage of the interstitial space. This blockage should be simulated two ways. One method is to introduce enough water into the interstitial space to fill a low spot in the piping, forming a liquid trap. This low spot should be a U-shaped section of pipe with the upper part of the low portion of the U just below the bottom of the outside of the main portion of the secondary pipe. This will allow a liquid blockage to be simulated by filling a short section of the interstitial space with liquid. The second method is to install a valve in the system, allowing it to isolate a section of the interstice. Conduct an air-ingress test by allowing the air to ingress on the opposite side of the blockage from the sensor being tested. Determine whether the system detects this condition and issues an alarm (either to denote the blockage or to report the loss of vacuum). Repeat the test allowing air to enter the interstitial space on the opposite side of the blockage. Repeat the test for each sensor by testing with the air ingress on both the near and far side of the blockage.

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[9] "Test Procedure for the Evaluation of Double Wall Pipe with Liquid Filled Interstice for Loss Prevention," Ken Wilcox Associates, May 21, 2004.
[10] "Alternative Test Procedures for Evaluating Leak Detection Methods: Evaluation of Liquid Level Sensors," Ken Wilcox Associates, November 1997.

Since this test is intended to demonstrate that the system can overcome or identify blockage, only one test is needed for each sensor of the vacuum zone. The system must demonstrate that it can either overcome the blockage or identify the blockage and alarm.

7. Liquid Containment with Air Ingress Test

One additional test is required to demonstrate that liquid will not leak out of the interstitial space so long as the appropriate vacuum is maintained. This test will demonstrate that even if there is liquid in the interstitial space and a hole develops in the outer wall, the liquid will not leak out provided that the vacuum is maintained.

To conduct this test, a U-shaped portion of the double-walled pipe will be included in the test apparatus. The distance from the bottom of the pipe at the bottom of the U to the bottom of the horizontal pipe above the U should be at least three times the outer diameter of the pipe. An access port and appropriate fittings should be installed at the low point of the U allowing sight tubes to be installed connecting the interstice at the bottom of the U to the interstices on each of the horizontal sections of pipe above the U so that the liquid level in each side of the U can be monitored. An orifice will be installed below the access port sight tube connections, with a ball valve below it, so it can be closed.

To conduct the test, establish the normal operating level of vacuum in the interstitial space, then allow liquid (water) into the interstice so that the liquid level in the U-shaped part of the pipe is at a level above the bottom of the U at least twice the diameter of the pipe. Open the valve, allowing air to flow into the bottom of the U at a rate slow enough so as not to trigger the replenishment rate alarm, but fast enough so that the test can be run in a reasonable amount of time. The test is continued until two replenishment cycles have been completed or the system alarms due to loss of vacuum. The test is successful if no liquid escapes during the test, or if an alarm occurs within an hour of any liquid escaping.

8. Testing of Additional Pipe Types

Different types of double-walled pipes have quite different interstitial spaces. The results of the testing for an open type of interstice, such as a 3-inch over 2-inch rigid pipe could be quite different from the results if the system were tested with a restricted interstice type of pipe. Consequently, the testing should be done with each type of pipe that the system is intended to be used with.

Once the system has been completely tested with one type of pipe, its ability to detect and alarm in “loss-of-vacuum” situations will have been established. The major difference in applying the system to other types of piping will be in the communication through the interstice, as the volume of the interstice differs substantially among different pipe types. The potential for blockage in a certain segment may also be different. Nevertheless, it is not necessary to conduct a full evaluation with each model of double-walled pipe, since the initial evaluation has established that the system can correctly detect loss of vacuum conditions and alarm. Section 9 describes the procedure for supplementing an evaluation to add a different type of double-walled pipe (e.g. rigid / open interstice; flex / restricted interstice; sand filled interstice; etc.).

SECTION 6

FIELD SITE TESTS

The field tests are conducted after the basic performance estimates have been established during the laboratory tests. The field site tests are intended to demonstrate that the system works in an operational setting. The field site tests also establish the limitations to be reported on size, length, and interstitial volume. These tests will be conducted on an operable installation of the vacuum-wrap system. Consequently, no or very limited modifications of the system will be done.

There are three types of tests to be conducted. One type is a test to demonstrate that the interstice is continuous. The other two test types are “false alarm” or “no-leak” tests and “vacuum-loss” or “leak” tests. Since the laboratory tests will have been run on the same STP and UDC as used in the field, the only vacuum zone tested in the field site tests will be the pressurized piping.

1. Continuity Tests (only needed for pipe zones)

Establish the normal operating vacuum level. Disable or isolate the vacuum source. Introduce an air leak into the interstice at the largest practical distance from the sensor. Confirm that the system identifies and alarms for a loss of vacuum appropriately. Repeat for each sensor. (If the system identifies alarms to each sensor, one test will suffice to show that all sensors alarm.)

Re-establish the normal operating vacuum level. Disable or isolate the vacuum source. Introduce an air leak at the near end of the system to confirm that the system identifies and alarms for a loss of vacuum. One test that demonstrates that the interstitial space is continuous is sufficient. If the interstitial space is not continuous, the piping must be repaired to have a continuous interstitial space or the site is not suitable for testing or for use of this system.

2. Detection of Vacuum-Loss (“Leak”) Tests

This demonstration test is conducted with the vacuum source turned off or isolated from the interstice, once the normal operating vacuum level has been established.

Establish the normal operating vacuum level. Isolate or disable the vacuum source. Introduce a large air leak (one that was determined in the laboratory testing to be detected) and monitor the system until the system alarms or the response time (from the laboratory tests) has been reached. At the alarm or response time, record the results. Since this is a demonstration test, only one (1) such “leak” test must be run. The system must alarm.

3. False Alarm (“No-leak”) Test

This demonstration test is conducted with the vacuum source connected and turned on.

Establish the normal operating vacuum level. Introduce a small air leak into the interstice, allowing the vacuum in the interstice to degrade by 1.5 psi. The rate of air leakage can be chosen by the evaluator to be fast enough for a reasonably short test, yet slow enough so as not to trigger a replenishment alarm. Continue for the response time as identified during the laboratory tests. Record the result (alarm or not), along with the observed vacuum level during the test. Since this is a demonstration test to show that the system works in a field installation, only one (1) such false alarm test is required. The system must not alarm under this demonstration test.

4. Detection of Replenishment Rate ("Leak") Test

Set up a valve with air ingress connected to a flow meter so that the air ingress occurs at the replenishment rate specified by the manufacturer as calling for an alarm. This rate could be less than 85 liters per hour if specified by the manufacturer. If not otherwise specified, the evaluator will select and use a rate just in excess of 85 liters per hour. Establish the normal vacuum operating condition in the interstitial space, leaving the vacuum source connected. Open the valve, allowing the air ingress at the specified rate. Monitor the system until either an alarm occurs or the maximum response time is exceeded. Record the data and results. This is a demonstration to show that the system works in the field installation, so only a single test is required. The system must alarm, demonstrating that it alarms if there is an excessive replenishment rate.

SECTION 7

SUMMARY OF TESTS REQUIRED

The test requirements for each type of testing are summarized in the following tables. Table 1 summarizes the laboratory test requirements. Table 2 summarizes the test requirements for the field site tests. Table 3 summarizes the test requirements for the supplemental tests to add a different type of double-walled pipe. Note that if the system is used with a brine-filled double-walled pan or sump, the brine monitor must have been tested according to the appropriate protocol.

Table 1. Summary of Lab Test Requirements

Vacuum Zone	Type of Test	Number of Tests
Double-walled pipe	Vacuum Loss (Leak)[1]	21
	False Alarm (ambient changes)[2]	21
	Replenishment Rate (Leak)[3]	3
	Water Ingress[3]	3
	Product Ingress[3]	3 each gas and diesel
	Blockage (1 valve and 1 liquid)[3]	2 per sensor
	Liquid Containment with Air Ingress[3]	1
STP	Vacuum Loss (Leak)[3]	3
	False Alarm (ambient changes)[3]	3
	Replenishment Rate (Leak)[3]	3
	Product Ingress[3]	3 each gas and diesel
	Water Ingress[3]	3
UDC	Vacuum Loss (Leak)[3]	3
	False Alarm (ambient changes)[3]	3
	Replenishment Rate (Leak)[3]	3
	Water Ingress[3]	3

[1] These tests are used to estimate the probability of detection.
[2] These tests are used to estimate the probability of false alarm.
[3] The system must perform correctly on all of these demonstration tests.

Table 2. Summary of Field Test Requirements

Vacuum Zone	Type of Test	Number of Tests
Double-walled pipe	Vacuum Loss (Leak)[3]	1
	False Alarm (ambient changes)[3]	1
	Replenishment Rate (Leak)[3]	1
	Continuity[3]	1

[3] The system must perform correctly on all of these demonstration tests.

Note: When reporting the results of the field tests, also include the date(s) and location of the field tests.

Table 3. Summary of Supplemental Test Requirements (to add Pipe Type)

Vacuum Zone	Type of Test	Number of Tests
Double-walled pipe	Vacuum Loss (Leak) [1]	6
	False Alarm (ambient changes) [1]	6
	Replenishment Rate (Leak) [2]	3
	Water Ingress[2]	3
	Product Ingress[2]	3 each gas and diesel
	Blockage (1 valve and 1 liquid) [2]	2 per sensor
	Liquid Containment with Air Ingress[2]	1
STP (assumes same as for original system)	Vacuum Loss (Leak)	0
	False Alarm (ambient changes)	0
	Replenishment Rate (Leak)	0
	Product Ingress	0
UDC (assumes same as for original system)	Vacuum Loss (Leak)	0
	False Alarm (ambient changes)	0
	Replenishment Rate (Leak)	0
	Water Ingress	0
Field Tests / Vacuum Zone		
Double-walled pipe	Vacuum Loss (Leak) [2]	1
	False Alarm (ambient changes) [2]	1
	Replenishment Rate (Leak) [2]	1
	Continuity[2]	1

[1] The system must perform correctly on all 6 of these tests or the full series of 21 tests must be run.
[2] The system must perform correctly on all of these demonstration tests.

SECTION 8

DATA ANALYSIS

Most of the data from the testing will be qualitative in nature. That is, each test will result in an alarm or no alarm. If the test is one where a leak is being simulated, an "alarm" would be a correct detection. If no leak is being simulated an "alarm" would be a false alarm. For the qualitative data, the data analysis consists of tabulating the tests and their results and using these data to estimate the probability of a false alarm and the probability of detection. These PD and PFA rates are used to define the performance. Several variables are continuous, such as response times, flow rates, and vacuum/pressure levels. The arithmetic mean and standard deviation should be calculated and reported for the continuous variables.

The data can be tabulated as illustrated in Table 4.

Table 4. SUMMARY OF RESULTS

Actual Status	Reported Results		
	Pass	Fail	Total
Tight	T_1	L_1	N_1
Induced Leak	T_2	L_2	N_2

The numbers in Table 4 are used to directly estimate the probability of false alarm (PFA) and probability of detection (PD). The number of tight tests incorrectly identified as leaking, divided by the total number of tight tests estimates the PFA. The PFA can be estimated using the formula:

$$PFA = L_1 / N_1$$

Similarly, the PD can be estimated by the number of induced leak tests that were correctly identified. The PD can be estimated using the formula

$$PD = L_2 / N_2$$

In order for the system to meet the EPA performance standard, the PFA must be less than or equal to 5% (0.05) and the PD must be at least 95% (0.95). This has been interpreted to mean that the PFA and PD estimated from the data developed in the evaluation testing must meet the stated criteria. A minimum of 21 tests of each type (false alarm and leak detection) is required. This requirement is consistent with established EPA protocols (see footnote 6) and allows for a maximum of one error of each type during testing for a system to pass. For those tests where 21 replications are being done, this means that the system must be correct on at least 20 of them. It is possible that no errors will be recorded in the tests. In this case, the estimate of the PFA would be zero and the estimate of the PD would be 100%. No system is expected to be 100% reliable in all cases, so it is important to calculate a confidence interval for the discrete proportion of false alarms or detections to give an indication of what range might be expected for the PFA or PD in practice.

If no errors occurred in the tests, the upper confidence limit for PFA is found from

$$UL = 1 - a^{1/N_1},$$

where (1 – a) is the confidence coefficient, generally set at 0.95, making a 0.05. For one or more errors, the confidence limits are calculated from confidence limits for the parameter of a binomial distribution. These can be found in *CRC Handbook of Tables for Probability and Statistics*,[11] for example.

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

$$LL = a^{1/N_2},$$

where again (1 – a) is the confidence coefficient, usually set at 0.95 or 95%, making a equal to 0.05. For one or more errors in detecting leaks, the confidence limits for the binomial are used.[12]

In cases where a continuous variable is recorded, such as response time, actual vacuum (or pressure) level, or flow rate, the arithmetic mean over a series of tests will be calculated. If the individual values are denoted by d_i, then the average of n such observations is given by D_n found by the formula below:

$$D_n = \sum_{i=1}^{n} \frac{d_n}{n}$$

Likewise, a measure of variability of the observations should be computed and reported. The variance is given by: (where the “D-bar” is the arithmetic mean calculated above).

$$Var = \sum_{i=1}^{n} \frac{(d_i - \overline{D})^2}{n-1}$$

The standard deviation, SD, is the square root of the variance, Var, and is also reported as it is on the same scale as the observations.

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

12 *Ibid*.

SECTION 9

PROCEDURE FOR AUGMENTING EVALUATION (ADDITIONAL DOUBLE-WALLED PIPE TYPES)

Since different types of double-walled pipes have substantially different interstitial space characteristics, the system should be demonstrated to work with each type of double-walled pipe intended for use. The UDC and the STP double-walled portions of the system would not change when a different type of pipe is used, so it is only necessary to test the piping itself, not the double-walled UDC or the double-walled STP.

For the purposes of this protocol, there are two general types of double-walled pipe: pipes with an open interstice and pipes with a restricted interstice. These are commonly called rigid and flexible pipes, but the nature of the interstice—open or restricted—is the most important feature relative to testing systems based on vacuum-wrapped piping.

Pipes with an open interstice have a small resistance to flow of fluid (either liquid or gas) through the interstice. As an example, a "3 over 2-inch" pipe would have an open interstice. For this purpose, we define as an open interstice double-walled pipes for which the inner diameter of the outer pipe is at least 0.25 inch larger than the outer diameter of the inner pipe and the interstice is open and unrestricted. That is, the interstice cannot be filled with sand, polymers, or other material that would restrict flow. This would provide an eighth of an inch (0.125 inch) space open all the way around the inner pipe between the inner and outer pipes. Pipes whose interstitial space does not meet this definition are denoted restricted interstice pipes.

Testing a single model of open-interstice double-walled pipe is sufficient to show that the system can be used on open-interstice pipes, subject to size limitations based on the volume of the interstitial.

For restricted interstice pipes, the key parameter is the resistance to flow in the interstitial space. Models of restricted interstice piping that have substantially greater resistance to flow in the interstitial space would have to be tested separately. To make this specific, if the pressure drop across the same length of pipe is at least 25% greater in a new model of double-walled pipe than in the model already tested, then the new model must be tested under this protocol. In determining this, a liquid flow rate of at least 3 gallons per hour should be used.

Set up the additional type of double-walled pipe with the system as was done for the initial evaluation. Conduct an initial test by creating and holding a vacuum to demonstrate that the test setup is tight and to allow for any out gassing from new plastics or resins. Repeat the air ingress tests as described in Section 5.1. However, since the system has already been shown to alarm reliably when the vacuum degrades sufficiently, only six (6) tests are required of each type (vacuum degradation detection and false alarm tests) instead of the 21 called for in the initial testing. However, no errors, either false alarms or missed detections, are allowed among the six tests. If an error occurs, the entire set of 21 tests must be run.

Conduct the water ingress testing as in Section 5.2. Again, only 3 tests need to be conducted for the supplemental evaluation.

Conduct the product ingress testing as described in Section 5.3. Only 3 tests are needed for the supplement.

Report the results of the liquid sensor testing if done previously as described in Section 5.5. If the system uses liquid sensors, and those have not previously been tested, conduct the testing according to the liquid sensor protocol and report the results.

Conduct the blockage testing as described in Section 5.6.

Conduct the liquid containment with air ingress test as described in Section 5.7.

Conduct a full-scale field site test as in Section 6.

Report the results of the supplemental testing as an addition to the original evaluation report. That is, the test results should be appended to the original report, noting that the system is now qualified for use on this additional type of double-walled pipe.

For open interstice pipelines, following the EPA Pipeline protocol, application will be limited to systems up to twice the interstitial volume of the larger of the piping used in the field test or the piping used in the laboratory testing. In this case, the total volume of the interstice of the pipes including all branches becomes the limiting value. An additional restriction is that the pipelines are limited in length between sensors to twice the longer of the length of the piping in the laboratory testing or the length of the piping in the field testing.

For restricted interstice pipelines, the system is limited to the length used during the laboratory Product Ingress Testing. The length limit applies to the distance between the 2 nearest sensors monitoring a length of pipe. The reason for this is that the restricted interstice restricts the flow of liquid and so affects the response time if liquid comes into the interstitial space. If the system under evaluation has only one pressure sensor in the pipe interstice zone, the length limit applies to the distance from the sensor to the farthest point of any branch in the pipeline.

SECTION 10

REPORTING

The test results should be reported in tables of the form described and illustrated below. The tables should contain enough rows for the number of tests conducted. Since different aspects of the evaluation call for different numbers of tests, only general forms of the tables are presented. The evaluator is responsible for creating a table of the appropriate form with the requisite number of rows. Note that separate tables should be used for the laboratory tests and the field tests, where applicable. For each table, indicate the type of pipe, the length, and the approximate interstitial volume.

For each of the air-ingress tests, data may be recorded in a table of the form as Table 5.

Table 5. Air Ingress Test Results

Test No.	Start Vacuum	End Vacuum	Response Time* S1, S2, S3	Alarm (Y/N) S1, S2, S3	Did any sensor Alarm? (Y/N)	Alarm vacuum S1, S2, S3
1						
N						
Summary	Ave. Start Vacuum	Ave. End Vacuum	Ave. Times	No. of Alarms	No. of tests with Alarm	Average alarm vacuums

* The response time is relative to reaching the end vacuum. It is recorded if an alarm occurs after the end vacuum is reached.

In Table 5, list the test number, the starting vacuum the ending vacuum, and the time to alarm for each sensor, along with whether each sensor alarmed. Also give the vacuum at each sensor when the alarm occurs. At the bottom of the table, summarize the results by reporting the average starting vacuum level, the average ending vacuum level, the average time to alarm for each sensor, and the number of alarms for each sensor. If a sensor fails to alarm during a test, use the maximum test time as the duration for that sensor. In Table 5, three sensors are indicated. The number of sensors will depend on the specific system. Results for each sensor must be reported. Use an additional table if the table gets too large to accommodate the results for all sensors.

Table 5 is appropriate for the vacuum loss (leak) tests and the false alarm (ambient changes) tests for the double-walled pipe zone, the STP zone, and the UDC zone in the laboratory testing. The number of tests would be the number required as shown in Tables 1-3. The data for the leak and false alarm air ingress tests for each zone of the system should be reported in a table of the form of Table 5. An appropriate title should be used and a letter may be added to the number (e.g. Table 5a) indicate the different test results. If any sensor issues an alarm during a test, this is regarded as an alarm for that test. The total number of leak simulation tests with alarms is compared to the total number of such tests to estimate the probability of detection. Similarly, the total number of ambient condition tests with alarms is compared to the total number of such tests to estimate the probability of a false alarm.

The arithmetic mean and the standard deviation should be calculated and reported for numerical variables whenever multiple tests were conducted (obviously they are not called for when a single demonstration test was run). Report the statistics for the starting and ending vacuum levels and for the vacuum at alarm at each sensor. In addition, report the mean and standard deviation for the response time for each sensor. If one or more sensor has both "positive" and "negative" response times, calculate and report the mean and standard deviation separately for these. Indicate whether the response time is "positive" meaning that it is the time from the vacuum reaching the alarm level until the alarm occurs, or "negative" meaning that the alarm occurred before the vacuum reached the set level.

For each sensor, the evaluator will take the average vacuum level at alarm for each sensor and calculate the maximum vertical distance from that sensor to the low point of the vacuum zone. This distance is calculated so that if water had come into the zone, a vacuum (inward pressure) at the bottom of the zone would still be at least 0.25 psi. even offset by the head pressure of any water column. That is, at the vacuum level when the alarm occurred, any liquid or vapors would still be contained by a vacuum, provided the distance from the sensor to the low point is no more than the calculated distance. This distance is calculated by taking the vacuum level in psi, subtracting 0.25 psi. to get the amount that the vacuum exceeds 0.25 psi., and dividing the result by 0.036. For example, if the vacuum level at alarm were 4.5 psi. (an inward pressure of 4.5 psi.), the calculated height would be found by subtracting 0.25 psi. from 4.5 to get a difference of 4.25 psi. that could be offset by the head pressure of a given height of water, then dividing the result by 0.036 to get the height of a water column that would still leave a vacuum or inward pressure of 0.25 psi. The result is 118.1 inches. The results should be reported in a table such as Table 6.

Table 6. Maximum Height for Sensor Above Zone Low Point

Sensor	Alarm Vacuum (average in psi)	Maximum Height (inches) (alarm vacuum - 0.25)/0.036
S1		
S2		
S3		

Table 7. Replenishment Rate Test Results

Test No.	Start Vacuum	End Vacuum	Air Flow Rate	Response Time S1, S2, S3	Alarm (Y/N) S1, S2, S3	Did any Sensor Alarm (Y/N)
1						
N						
Summary	Ave. Start Vacuum	Ave. End Vacuum	Ave. Air Flow	Ave. Times	No. of Alarms	No. of Alarms

Table 7 is to be used for the replenishment rate tests. Report the fact of an alarm or no alarm for each sensor, along with the response time until each sensor alarms. If no alarm occurs, record the maximum test duration as the response time.

At the bottom of Table 7 report the average starting vacuum level, the average ending vacuum level, the average air flow for the tests, the average response time for each sensor, and the number of alarms for each sensor. The number of tests should be the number called for in Tables 1 to 3. Also calculate and report the standard deviation each of these variables. Report "positive" and "negative" response times separately. Indicate whether the response time is "positive" meaning that it is the time from the vacuum reaching the alarm level until the alarm occurs, or "negative" meaning that the alarm occurred before the vacuum reached the set level.

Table 8 gives the format for a table to report the results of the water ingress tests. Each line should report the indicated values for the given test. The time is the time to response for the system. If a particular sensor did not alarm on a given test, enter the maximum test time for the response time.

At the bottom of Table 8, enter a summary of the results. Calculate the average starting vacuum, the average ending vacuum, the average volume for the water, and the average response time. Also give the number of alarms.

Table 8. Water Ingress Test Results

Test No.	Start Vacuum	End Vacuum	Water Volume	Response Time	Alarm (Y/N) S1, S2, S3	Vac Pressure S1, S2, S3,	Did any Sensor Alarm (Y/N)
1							
N							
Summary	Ave. Start Vacuum	Ave. End Vacuum	Ave. Water Volume	Average Time	No. of Alarms	Ave. Pressure S1, S2, S3	No. of Alarms

Report the results of the water ingress tests separately for each zone. Calculate and report the standard deviation of each continuous variable as well as the mean whenever multiple tests are conducted.

Table 9 is to be used to report the results of the 3 gph product ingress tests. A separate table should be used to report the results for each applicable zone. Report the same quantities as for the water ingress tests and the same summary at the bottom of the table. Calculate and report the standard deviation for these variables as well whenever multiple tests are conducted.

Table 9. Product Ingress Test Results

Test No.	Start Vacuum	End Vacuum	Product Volume	Response Time	Alarm (Y/N) S1, S2, S3	Vac/Pressure S1, S2, S3	Did any Sensor Alarm (Y/N)
1							
N							
Summary	Ave. Start Vacuum	Ave. End Vacuum	Ave. Product Volume	Ave. Times	No. of Alarms	Ave. Pressure S1, S2, S3	No. of Alarms

Table 10 is a form to be used for reporting the results of the liquid containment with air ingress test. Only a single test is required, but each test conducted should be reported.

Table 10. Liquid Containment with Air Ingress Test Results

Start Vacuum	End Vacuum	Test Duration	Liquid Loss (Y/N)	Alarm (Y/N) S1, S2, S3

Attach a copy of the results form for the liquid sensor evaluations if liquid sensors are used. Attach a copy of the results form for the brine sensor evaluations if brine sensors are used.

Report the type, size, and characteristics of the piping used in the laboratory testing evaluation (for restricted interstices include a measurement of the pressure drop at a flow rate of 3 gal/hr or more for a specified length of pipe):

Laboratory Tests

Type of double-walled pipe: ____
Diameter of double-walled pipe: _____________________________________
Length of pipe: ____
Volume of interstitial space (approximate): ____________________________
Pressure drop at _____gal/hr flow and _____feet:_______psi (not applicable for open interstices)
Under Dispenser Pan or Sump type and size (if used): __________________
In-Dispenser Pan or Sump type and size (if used): ______________________
Model of STP (indicate if double-contained): _________________________
Other equipment in system (list): _____________________________________

Report the type and size of the piping used in the field tests (if the installation has more than one type of pipe, give the type, diameter and approximate length of each type:

Field Tests

Type(s) of double-walled pipe: ____
Diameter of double-walled pipe: _____________________________________
Length of pipe: ____
Volume of interstitial space (approximate): ____________________________
Under Dispenser Pan or Sump type and size (if used): ____________________
In-Dispenser Pan or Sump type and size (if used): _______________________
Model of STP (indicate if double-contained): ____________________________
Other equipment in system (list): _____________________________________

If the interstitial space is open (e.g. 3-inch over 2-inch), the application of the system is limited to pipes with no more than twice the volume of the interstitial space for the larger of the piping in the field tests or the laboratory tests. An additional restriction is that the length between sensors is limited to twice the longer of the length of piping in the laboratory testing or the length of piping in field tests.

If the interstitial space is restricted (e.g. flex) the application of the system is limited to piping installations with the pipe length no larger than the laboratory test piping. The length limit applies to the distance between the 2 nearest sensors monitoring a length of pipe.

APPENDIX

REPORT FORMS

Results of U.S. EPA Alternative Test Procedures
Vacuum-Wrapped Pressurized Portions of a Fuel Containment and Dispensing System Leak Detection Method

This form describes the performance of the leak detection method described below. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the test protocol for vacuum-wrapped pressurized portions of a fuel containment and dispensing system. The full evaluation report also includes a form describing the method and a form summarizing the test data.

Systems evaluated by this protocol provide leak detection that meets or exceeds current Federal standards for leak detection on pressurized underground lines defined as: an hourly test of 3 gph and either a monthly test of 0.2 gph or an annual test of 0.1 gph. These current standards are defined as leaks that are to be detected as the product is leaving the primary space and entering either the secondary space or the environment. Additionally, this system can be considered to meet or exceed requirements for Continuous Interstitial Monitoring Methods (Pressure/Vacuum), for example California AB 2481 requirements for continuous monitored vacuum interstitial systems. Fueling system owners using this leak detection system should keep this form on file to provide compliance with the federal regulations. Fueling system owners should check with State and local agencies to make sure this form satisfies their requirements.

Leak Detection Method Description

Name ____

Version number ____

Vendor ____

____
(street address)

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

Evaluation Results

This Leak Detection Method declares an interstitial space to be leaking when the measured vacuum level degrades to a threshold of ______ psi (or give alternative criterion here:____) Based on _____ alarms out of ______normal operation tests, the system's estimated probability of false alarm (PFA) was _______%. (Must be 5% or less.)

Based on ______detections out of _______ leak simulation (air ingress causing loss of vacuum) tests, the system's estimated probability of detection (PD) was _______%. (Must be 95% or greater.)

The system has demonstrated that it can maintain an adequate vacuum or correctly detect a loss of vacuum under other conditions as indicated below.

Double-walled Pipe Demonstration Tests (must all be correct for the system to pass):

The system detected ____ out of ____ water ingress tests.
The system detected ____ out of ____ product ingress tests at 3 gph.
The system detected ____ out of ____ excessive replenishment rate tests at _____ L/hr (85 L/hr unless a lower rate is specified by the vendor).
The system responded correctly to ___ out of ____ blockage tests.
The system retained the liquid in the interstitial space or alarmed correctly for the liquid containment with air ingress test. (Y or N) ________.

The system responded correctly on all the field tests (Y or N) ____.
The field continuity test showed that the interstice was continuous (Y or N) ______.
(The interstice must be continuous in order for the site to be suitable for use.)

Liquid Sensor Results (if applicable)

	Product		
Parameter	Gasoline	Water	Diesel
Threshold (inches)	_______	_______	_______
Precision (inches)	_______	_______	_______
Detection time (hh:mm:ss)	_______	_______	_______
Fall Time (hh:mm:ss)	_______	_______	_______

Reference for the liquid sensor evaluation: ___________________________
Brine Sensor Evaluation Results (if applicable)

The capacity of the liquid reservoir is approximately _____ gallon
The sensor spacing used to measure the reservoir level alarms is ______ inches
The sensor operating principle is: ____
The approximate volume change to produce an alarm was calculated to be ______ ml when the float is initially at the midpoint of the reservoir.
For a level change of ______ inches (half the distance between the high and low level alarm set points) the volume change is ______ gallons.

Reference for the brine sensor evaluation: ______________________________

Test Conditions During Evaluation

The evaluation testing was conducted using double-walled piping of the type ____________ ______________. The length of the piping was _____ feet. (Indicate each type if more than one.)
For restricted interstice piping, the pressure drop at _____gal/hr (specify) flow and _____feet (specify) was:_______psi (not applicable for open interstices). Application is limited to piping with no more than a 25% greater pressure drop or _____ psi.

The field tests were conducted on a field installation with _____ feet of _____________ (pipe type) of double-walled pipe (indicate for each type of double-walled pipe).

Limitations on the Results

The performance estimates above are only valid when:

- The method has not been substantially changed.
- The vendor's instructions for installing and operating the Leak Detection Method are followed.
- For open interstices the total volume of the interstitial space is no more than _____ gallons (twice the volume of the larger of the laboratory or field test sites).
- For open interstices, the length between sensors is not longer than _____ feet (twice the longer of the length in the laboratory or field testing).
- For restricted interstices, the length limit applies to the distance between the 2 nearest sensors monitoring a length of pipe. This length is no more than _____feet.
- Other limitations specified by the vendor or determined by the evaluator during testing:

Other Information

Are liquid sensors utilized by this method? ( ) Yes ( ) No

If so, please summarize the results or attach a copy of the Results Forms to this document.

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

Certification of Results

I certify that the Leak Detection Method was installed and operated according to the vendor's instructions and that the results presented on this form are those obtained during the evaluation.

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

Description

Vacuum-Wrapped Pressurized Portions of a Fuel Containment and Dispensing System Leak Detection Method

This section describes briefly the important aspects of the vacuum-wrapped fuel containment and dispensing system leak detection method. It is not intended to provide a thorough description of the principles behind the system or how the equipment works.

Method Name and Version

Principle of Operation

What techniques are used to detect leaks in the vacuum-wrapped containment system?

(Check all that apply.)

( ) directly measure the vacuum change

( ) observe a loss of vacuum to a specified level

( ) observe an excessive replenishment rate for the vacuum

( ) observe an excessive frequency of vacuum replenishment

( ) acoustical signal characteristics of a leak
( ) observe liquid in the interstitial space

( ) identification of a tracer chemical in the containment system

( ) other (describe briefly) ____

Data Acquisition

How are the test data acquired and recorded?

( ) manually

( ) by strip chart

( ) by computer

Procedure information

> Waiting times

What is the required waiting period between establishing a vacuum and the beginning of a test. ______ Hours ____ Minutes

Additional Comments: ____

> Test duration

What is the required time for collecting data?

______ Hours ___ Minutes

Additional Comments: ____

What is the sampling frequency for the measurements?

( ) more than once per second

( ) at least once per minute

( ) every 1-15 minutes

( ) at the beginning and end of the test

( ) variable (explain) ____

> Identifying and correcting for interfering factors

How does the Method correct for interference due to the change in temperature or barometric pressure?

( ) no action

( ) system measures temperature and compensates

( ) system measures barometric pressure and compensates

( ) other (describe briefly) _______________________________________

> Interpreting test results

What threshold value(s) is(are) used to declare that a vacuum containment system is leaking and might not provide product containment?

Describe ____

Additional Comments: ____

Under what conditions are test results considered inconclusive?

Describe briefly____

Exceptions

Are there any conditions under which a test should not be conducted?

( ) extremely high or low ambient temperature

( ) extremely rapid barometric pressure changes

( ) other (describe briefly) ____

What are acceptable deviations from the standard testing protocol?

( ) none

( ) other (describe briefly) ____

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

( ) no

( ) yes (describe briefly) ____

Does the system use liquid level sensors as part of its operation?

( ) no

( ) yes