

An Evaluation of a Methodology for the Detection of Leaks in Aboveground Storage Tanks

HEALTH AND ENVIRONMENTAL AFFAIRS
API PUBLICATION NUMBER 325
MAY 1994



American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005



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MAY 1994

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ACKNOWLEDGMENTS

We wish to thank the members of the API Storage Tank Task Force, Work Group for AST Monitoring, for their cooperation, their technical support, and their assistance in coordinating the project. We would like to acknowledge the support and encouragement of Mr. James Seebold, the chairperson of the Work Group, and of Ms. Dee Gavora and Andrew Jaques of the Health and Environmental Affairs Department, the API staff members monitoring the program.

We would also like to acknowledge the contributions of the following individuals, companies/individuals: Steve Tostengard, Jerry Engelhardt and Vince Rosero of Santa Fe Pacific Pipeline Partners, Inc., for the use of their company's terminal, and their invaluable assistance in coordinating the field test effort; Robert Brozovich, Gordon Ray and Chuck Hill, also of SFPP, for their efforts in planning and scheduling the experimental work; Bill Matney, Jim Eschberger and Glenn Kauffman for their operational support; Jim Leaird and Dennis Biddle of Physical Acoustics Corporation; and David Waterman and Ralph Nicastro of Rohrback Cosasco System, Inc.

We would also like to acknowledge Gregg Olson and Richard Wise of Vista Research for their assistance in conducting the field test activities, and Monique Seibel and Christine Lawson of Vista Research for their efforts in editing and typesetting this document.

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EXECUTIVE SUMMARY

INTRODUCTION

The American Petroleum Institute has undertaken a significant technical effort to define and advance the state of the art of leak detection in aboveground storage tanks (ASTs). This report presents the results of Phase IV of the API leak detection program. The three research efforts that preceded Phase IV were focused on the assessment of leak detection technology for ASTs and a detailed evaluation of passive acoustic and volumetric measurement methods. Field tests conducted on operational ASTs as part of the Phase III effort demonstrated that accurate leak detection could be accomplished through acoustic and volumetric techniques, and suggested specific changes in system design and test protocol to improve the performance of each technology. Based upon the Phase III results, general recommendations were made regarding further experimental work.

In addition, a methodology was developed which combines multiple AST testing technologies in order to assess the integrity of an AST. The proposed methodology may also include multiple tests with each technology. This methodology is designed to verify the presence of a leak in the case of a detection, and thereby minimize the occurrence of erroneous decisions based on test results which indicate the presence of a leak when none exist (false alarms). Effectively combining independent test methods should result in a very robust leak detection practice. Three leak detection techniques were selected for evaluation in the Phase IV program: passive-acoustics, volumetric methods (including both level-and-temperature and mass measurement systems), and soil-vapor monitoring. Though soil-vapor monitoring was not evaluated in the previous phases of API's research, it was identified as a technology of interest to the industry and was included in this phase. Individually, all three of these technologies are believed to have the potential for reliably detecting small leaks in the floor of an AST. When used together, the reliability of the test results increases.

Other AST leak detection technologies exist, and new technologies and new implementation techniques are being developed. Other technologies may perform equally well in a similar test methodology; however, API has limited the focus of this research to the three technologies mentioned above. The test methodology presented here is one example of a method to improve the reliability of a test decision through the used of multiple testing techniques.

The proposed leak detection methodology was applied to 14 ASTs during an eight-week period between 15 March and 3 May, 1993, at a facility provided by Santa Fe Pacific Pipeline Partners, Inc..

The objectives of the Phase IV study were:

- to assess the applicability of the general features of the three AST leak detection technologies (acoustic, volumetric, and soil-vapor monitoring technologies) over a wide range of tank types, petroleum fuels, and operational conditions
- to assess the applicability of a general leak testing methodology for ASTs which involves multiple tests at multiple product levels in the tanks
- to determine the integrity of 14 ASTs using two or more test methods

CONCLUSIONS

Based on the results of all tests performed, none of the 14 ASTs tested is believed to be leaking. Since there were no indications of a leak, the performance of the proposed test methodology could not be directly evaluated for its effectiveness in reducing false alarms or missed detections. Based on a study of the noise environment for each of the test methods included in the methodology, however, the proposed methodology is believed to have met the requirements for incorporating independent test methods with reasonable probabilities of detection.

The results of passive-acoustic testing performed in this test series indicates that the data collection and analysis approach based on the recommendations from Phase III, and demonstrated in this program, can be employed on a wide range of tanks with a low probability of false alarm. Acoustic leak detection tests differentiate acoustic leak signals from impulsive

noise events primarily on the basis of the estimated spatial origin of the signal and on its duration. A detection is made when a number of acoustic events are located in an area on the tank floor that is consistent with the location accuracy of the acoustic sensor array. The two sources of false hits, which can lead to false detections, are non-leak sources of impulsive acoustic signals generated at the floor of an AST, and the mislocation of impulsive acoustic signals that originate from locations other than the floor of the tank (e.g., the product surface, tank shell, tank roof, etc.). The data collection and analysis approach used in this test series yielded no false events in any of the 14 ASTs tested. This is an extremely important result, because until now implementations of acoustic technology have required that a test decision be made even though there may be many hundreds of false events indicated in the data. The primary noise sources identified in this test series originated at the product surface, and were due to condensate dripping on the product surface and noise associated with the motion of the ASTs' floating roofs. No impulsive noise sources were found to have originated from the tank floor, even though all of the tanks tested had some internal floor-mounted structure. This is also an important result, because noise sources at the floor of an AST could be difficult to distinguish from a leak signal. In the 14 ASTs tested, it was found that all noise sources recorded could be spatially discriminated from any possible leak signal through analysis of digital time series of the acoustic waveform.

The soil-vapor monitoring test applied in Phase IV used pentane, which was present in the petroleum fuel, as the target vapor. Two types of hydrocarbon sampling systems tuned for the detection of pentane were used: a fiber optic sensor system capable of measuring concentrations of pentane on the order of 5 ppm, and a gas chromatograph capable of measurements to 1 ppm. The results of the pentane injection test performed as part of the series of soil-vapor monitoring tests indicated that pentane propagation through the oiled-sand backfill under the tanks at the test site was too low for a leak to be reliably detected. In order to gain a better understanding of the propagation characteristics of pentane, additional injection tests were performed at another site where the backfill material was sand that had not been oiled and was therefore much more permeable. This second series of injection tests resulted in a much more reliable detection of the injected pentane. While soil-vapor monitoring techniques can potentially be used to detect leaks

in ASTs, it is apparent that the soil conditions at the test site limited the effectiveness of this technique. The effect of soil conditions on test variability could be mitigated through the use of longer test periods and a more stable substance as the target vapor. In order for this technology to be effective operationally, and to achieve a reasonable probability of detection, the spacing of sensor wells and the duration of the monitoring period must be carefully chosen. For best results, these decisions should be based on the propagation characteristics of the target vapor as measured at the test site prior to the conduct of a leak detection test. The other important source of error is the presence of water at the bottom of the AST during a test. Unless water is removed, it will prevent the release of pentane and render the test ineffective. Water was drained from all ASTs prior to the start of the Phase IV test series. While the results of the soil-vapor monitoring tests are believed to be valid, there is insufficient information to assess the effects of any residual amount of water left at the bottom of these ASTs.

The performance of volumetric tests, both those that use level-and-temperature measurements and those that use mass-measurement techniques, was consistent with that achieved during the Phase III experiments. While specific noise mechanisms differ in the two types of volumetric tests, the noise in both cases is driven by ambient temperature changes; in the Phase IV test series, the two types of volumetric test had approximately equivalent levels of performance. As in Phase III, it was found that in order to achieve good performance in both types of tests, accurate temperature compensation and test durations greater than 24 h were required.

Section 1

BACKGROUND

The American Petroleum Institute has undertaken a significant technical effort to define and advance the state of the art of leak detection in aboveground storage tanks (ASTs). This report presents the results of Phase IV of the API leak detection program. The three research efforts that preceded Phase IV were focused on the assessment of leak detection technology for ASTs and a detailed evaluation of two leak detection methods: passive acoustics and volumetric measurement (Vista Research, Inc., 1991; Vista Research, Inc., 1992; Vista Research, Inc., 1993a; Vista Research, Inc., 1993b). Field tests conducted on operational ASTs as part of the Phase III effort demonstrated that accurate leak detection could be accomplished through acoustic and volumetric techniques, and suggested specific changes in system design and test protocol to improve the performance of each technology. Based upon the Phase III results, three general recommendations were made regarding further experimental work. First, perform tests on a wide range of operational ASTs using leak detection systems that incorporate the modifications in data collection and analysis suggested by the Phase III results. Second, develop and test a standard procedure for evaluating the performance of volumetric and acoustic leak detection methods in terms of the probability of detection (P_D) and probability of false alarm (P_{FA}). Finally, areas in which volumetric and acoustic methods could benefit from further technological development were identified. The Phase IV effort is intended to address the first of these recommendations. The series of leak detection tests that comprise the Phase IV study were conducted on 14 operational ASTs provided by an API member company in support of the ongoing effort to advance AST leak detection technology. Field test activities for this program were conducted between 13 March and 3 May, 1993. The objectives of this study are:

- to assess the applicability of the general features of the three AST leak detection technologies (acoustic, volumetric, and soil-vapor monitoring) over a broad range of tank types, petroleum fuels, and operational conditions

- to assess the applicability of a general leak testing methodology for ASTs which involves multiple leak detection tests at multiple product levels
- to determine the integrity of 14 ASTs using two or more test methods

The organization of this report is as follows. Section 2 presents a brief description of the leak testing methodology used during the test series. Section 3 contains the specifications (i.e., tank construction and dimensions, product type, etc.) of each of the ASTs tested. Results of the leak detection tests and a summary of the important findings for each of the test methods are presented in Section 4. The conclusions and recommendations derived from these tests are described in Section 5. The final section of this work includes a summary of the general features of system design and test protocol considered to be important with respect to each of the three leak detection technologies investigated. This section is based upon conclusions drawn from all four phases of the API program. Appendices A and B describe, respectively, the technical findings of the acoustic and volumetric experiments performed in Phase IV.

Section 2

TEST METHODOLOGY/ PROPOSED AST LEAK DETECTION PRACTICE

Each of the three leak detection technologies has the potential for reliably detecting small leaks in the floor of an AST. The three techniques are based upon measurements of different aspects of the leak signal, and the noise encountered in each type of test is also very different. The ability of the detection system to recognize the leak signal against the noise ultimately determines the system performance. Effectively combining any two, or all three, of these independent methods should result in a very robust leak detection practice.

Other technologies or implementations of the three technologies other than those investigated in this program may exist or may be developed which will perform equally well alone or when combined into a similar test methodology. It should be stressed that the implementation of the test methodology presented here is intended only as an example of how to improve the reliability of a test decision through the use of multiple independent testing techniques.

The proposed leak testing methodology is based not only on the use of multiple methods but also of multiple tests with each method and multiple levels of product with certain tests. The multiple test strategy, if properly conducted, can significantly increase the reliability of the overall test decision, i.e., whether the tank is leaking or not. The three-step methodology described below is based upon the present understanding of the performance and operational limitations of each of the three technologies.

Step 1. The first step in the proposed leak detection methodology is to test the AST using a relatively non-intrusive technique. In this program, two technologies were used: passive-acoustics and soil-vapor monitoring. The use of these two methods as an initial assessment of tank integrity is desirable since (a) each method should be capable of detecting small leaks under a variety of test conditions, and (b) the impact of the tests on tank operations is minimal. If, as a result of the initial tests, a leak is suspected, another test should be conducted using the same

method. This procedure reduces the possibility of a false alarm before a decision is made to proceed to Step 2.

Step 2. The second step in the proposed leak detection methodology, which is taken only after at least two tests in Step 1 indicate the possibility of a leak, is to conduct a volumetric leak detection test with the product level lowered to within 3 to 5 ft of the AST floor. The low product level and the presence of strong diurnal sources of noise require that (a) valves connected to the AST be blinded prior to the test, and (b) the test be at least 24 and preferably 48 h in duration. A tank should not be declared leaking unless two or more volumetric tests give similar indications of a leak.

Step 3. The final step in the proposed leak detection methodology is to remove the tank from service and perform an internal tank inspection. A tank inspection is the current petroleum industry standard for verifying the integrity of the AST floor.

The proposed standardized testing practice for ASTs has, in addition to the improvements in performance described above, a very sound foundation. It terminates in an inspection of the tank bottom, which is the currently accepted practice for making a final decision about the integrity of a tank. This has a subtle but important implication. Regardless of whether there is a real leak or simply a false alarm, the final step in the protocol is the same: tank inspection. Thus, if a lower threshold is selected for the purpose of increasing the probability of detection, the accompanying rise in the rate of false alarm is tolerable, because the alternative would be Step 3 anyway. (At some point, of course, a high false alarm problem will undermine all efforts to test tanks for leaks.) A higher probability of detection favors the environment. Enough is known about the important ("key") features of the three methods that credible threshold selections can be made even if the exact performance of particular systems that operate on the principles of these methods is not known. The proper balance between the P_D and the P_{FA} can be made once the performance of the methods/systems has been evaluated over the range of ambient conditions anticipated during testing.

Section 3

SITE DESCRIPTION

The group of 14 ASTs tested during the API Phase IV effort were of various sizes and construction, and contained diesel, gasoline, turbine, or jet fuel. Any water in the bottom of the ASTs to be tested was drained during the two weeks prior to the start of this test series. All of the tanks were built on an oiled-sand backfill. The tank terminal was bounded by a freeway and a railroad switching yard. A full description of each tested AST is given in Table 3-1.

Table 3-1. AST Summary

AST No.	Product	Nominal Capacity (bbl)	Dia. x Ht. (ft)	Roof Type
2	ULREG	30,000	73 x 40	Float Roof Double Deck
3	MIDGD	20,000	60 x 40	Float Roof Double Deck
7	DIESEL	27,500	70 x 40	Cone Roof
9	TURBINE	20,000	60 x 40	Cone Roof
14	MIDGD	30,000	67 x 48	Float Roof Double Deck
15	ULREG	30,000	67 x 48	Float Roof Double Deck
16	DIESEL	20,000	60 x 40	Float Roof Pontoon Type
18	MIDGD	20,000	60 x 40	Float Roof Double Deck
19	ULREG	20,000	60 x 40	Float Roof Double Deck
22	DIESEL	20,000	54.5 x 48	Float Roof Pontoon Type
23	ULREG	20,000	54.5 x 48	Float Roof Pontoon Type
24	PRM92	10,000	42.5 x 40	Float Roof Pontoon Type
36	JP-4	28,792	67 x 48	Cone Roof Floating Pan
37	JP-5	28,973	67 x 48	Cone Roof Floating Pan

Section 4

RESULTS

The Phase IV program consisted of a set of tests in which the proposed AST leak detection practice was applied to 13 ASTs whose status was not known (the "leak detection tests") and another set of tests in which the three leak detection techniques were used on a 14th AST whose status was known (the "control tests"). The leak detection tests included options for additional data collection when warranted by previous test results. The three leak detection techniques used in the test program were: (1) passive-acoustic tests following the protocol developed as part of the API Phase III field experiments (Vista Research, Inc., 1993a), (2) soil-vapor monitoring tests using pentane (a substance that occurs naturally in the petroleum product) as the target vapor, and (3) volumetric tests (including both level-and-temperature and mass measurements) following the protocol developed as part of the API Phase III field experiments (Vista Research, Inc., 1993b).

Other leak detection techniques -- ones that deviate from the recommendations of the previous API findings -- were also used during Phase IV, and the results of these tests are also included in Section 4. For example, a commercial AST acoustic emissions vendor conducted acoustic tests using that company's standard test protocol, which does not include the collection of waveform time histories as recommended by previous API work. Other AST testing companies conducted high-product-level mass measurement tests and a short-duration mass-measurement test (approximately 4 h). These tests deviate from previous API recommendations that volumetric tests should be conducted at low product levels and that the test should be at least 24 h long.

Tank 23 was chosen as the control tank because it had recently been inspected and was scheduled to be returned to service at the start of this test program. All three leak detection technologies were used to test this tank. The remaining 13 ASTs were tested by means of both acoustic and soil-vapor monitor techniques as the first step of the test methodology. None of the results of these two high-product-level tests indicated the presence of a leak, and therefore,

according to the test methodology, no further tests of these tanks were required. Given this result, Tank 9 was chosen arbitrarily for the conduct of the second step in the test methodology, a low-product-level volumetric test. Tank 2 was also selected for volumetric testing. Site personnel, however, required that the floating roof on this tank remain on the product surface. Since this condition violates the test protocol for a volumetric leak detection test, a valid test could not be conducted. Data on Tank 2 were collected nevertheless, and these data were analyzed to assess the impact of a floating roof on volumetric test performance. A complete list of the tests performed on each tank is given in Table 4-1.

Table 4-1. Summary of Tank Tests

Tank No.	Acoustic Test as per Phase III Recommendation	Acoustic Test	Soil-Vapor Monitoring	High-Product-Level Mass Measurement	Low-Product-Level Mass Measurement	Short Duration Low-Product-Level Mass Measurement	Low-Product-Level and-Temperature Measurement
2	✓	✓	✓	✓			✓
3	✓	✓	✓				
7	✓	✓	✓				
9	✓	✓	✓		✓	✓	✓
14	✓	✓	✓				
15	✓	✓	✓				
16	✓	✓	✓				
18	✓	✓	✓				
19	✓	✓	✓				
22	✓	✓	✓				
23 ¹	✓	✓	✓	✓	✓		✓
24	✓	✓	✓				
36	✓	✓	✓				
37	✓	✓	✓				

1. Control Test

CONTROL TESTS

The series of control tests was conducted between 14 and 28 March, 1993. The tank had been emptied, cleaned, and inspected prior to the start of testing. The floating roof was resting on its legs at approximately eight feet above the tank floor. On 14 March, three feet of JP-4 fuel was transferred into the tank, and on the following day blinds were installed on all valves connecting pipelines to this tank. Also at this time, four ten-foot sections of pipe (three for soil-vapor monitoring and one for pentane injection) were installed under the AST in a radial pattern at 90° intervals. A 24-h settling period was observed prior to the start of volumetric testing.

Volumetric data were collected over a 72-h period from 16 to 19 March. Level-and-temperature and mass-measurement data were collected concurrently during this period. Measured level-and-temperature data showed an average 1.1 gal/h outflow over the three-day period (Figure 4-1).

Mass measurement data indicated an outflow of 0.8 gal/h (Figure 4-2). In both tests the most likely cause of the measured outflow is incomplete compensation for the thermal influence from steadily decreasing ambient temperature over the three-day period. Another possibility is loss of product through evaporation; however, the character and rate of the decrease in measured volume do not appear to be consistent with evaporative loss (Vista Research, Inc., 1991).

At the completion of volumetric tests, the valve blinds were removed and the product level in the tank was increased to 35 ft. The blinds were then re-installed in preparation for the high-product-level volumetric test.

Acoustic leak detection tests were conducted on the control tank between 22 and 24 March. Each acoustic test was conducted over a six-hour period that included two hours for setup and system calibration and four hours of data collection. Over the course of this test, all impulsive signals recorded were found to have originated at the product surface and to have been caused by either the motion of the floating roof relative to the AST shell or by condensate dripping down an access port located near the center of the floating roof. No impulsive signals were emitted from the AST floor, indicating that the tank was not leaking.

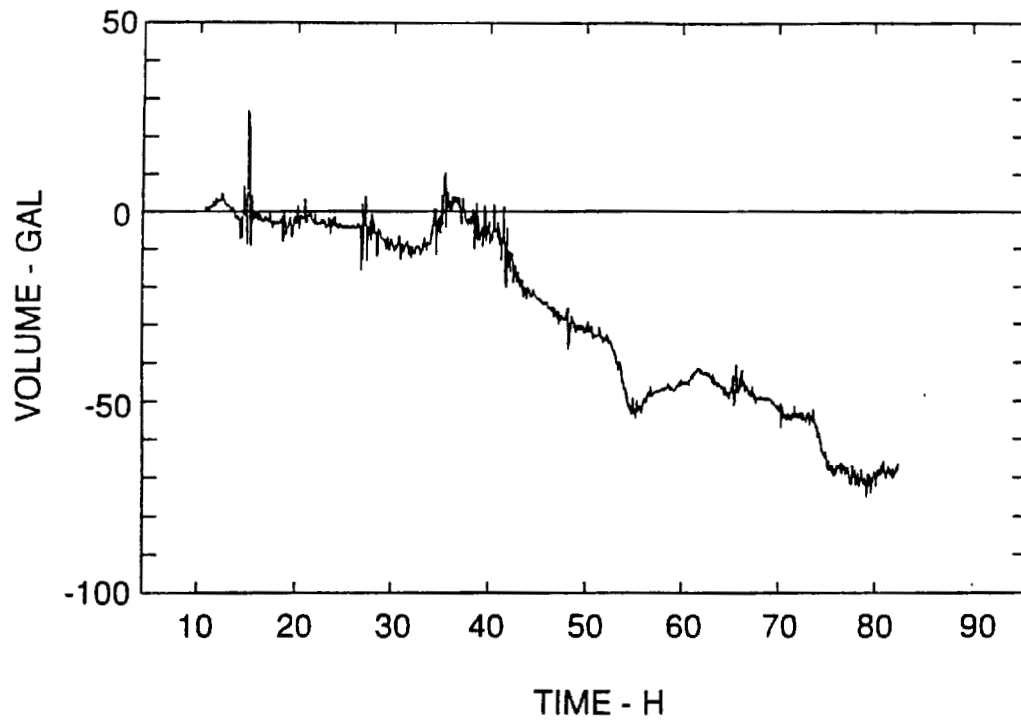


Figure 4-1. Level-and-temperature volumetric data (control tank).

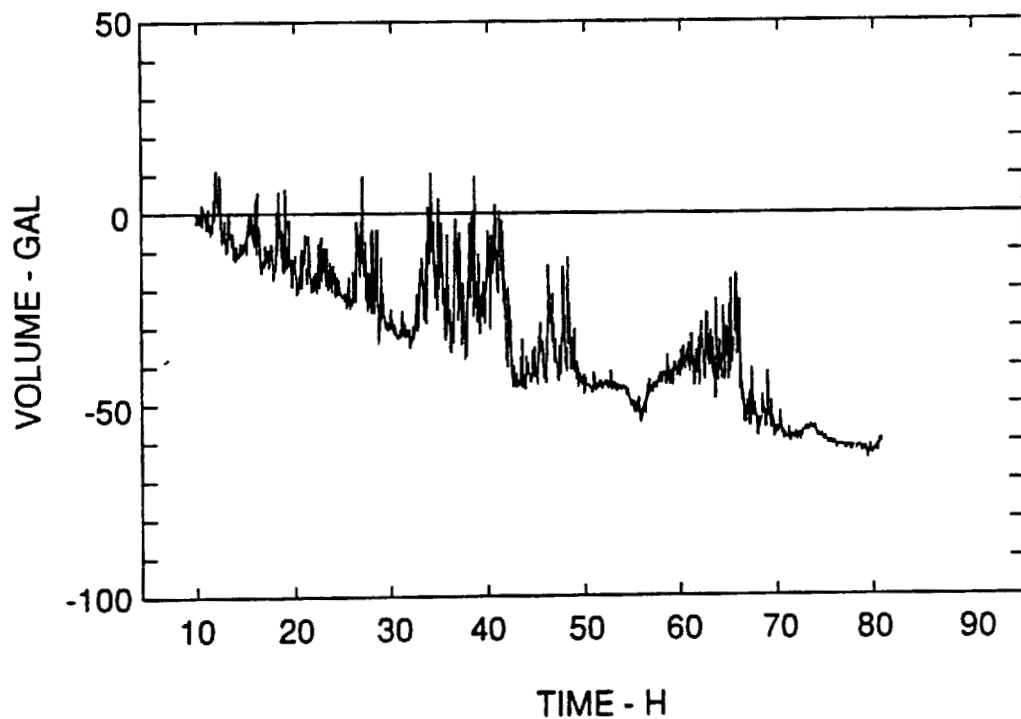


Figure 4-2. Mass-measurement volumetric data (control tank).

Figures 4-3a and 4-3b show, respectively, the location estimates of impulsive events separated into two categories: (1) events which originated from *above* the AST floor and (2) events which originated *on* the AST floor.

In order to verify that the acoustic system was capable of detecting a leak in the AST floor, a leak simulator was installed in the control tank. The leak simulator, when activated, emits impulsive acoustic signals by allowing product to flow through a small orifice into soil contained in the simulator. The air entrapped in the soil creates bubbles that burst in the product flow stream. The signal produced in this way is consistent with observations of real and simulated leak signals made during Phases II and III of the API work (Vista Research, Inc., 1992; Vista Research, Inc., 1993a). Leak detection tests performed on the control tank while the leak simulator was active resulted in the accurate location of the simulator on the AST floor. Figure 4-4a shows the location estimates for recorded impulsive events that originated from above the AST floor and Figure 4-4b for those that originated on the AST floor.

Soil-vapor monitoring tests were conducted during the same period as the acoustic tests. Two types of hydrocarbon sampling systems tuned for the detection of pentane were used: a fiber optic sensor system capable of measuring concentrations of pentane on the order of 5 ppm, and a gas chromatograph capable of measurements to 1 ppm. No detectable levels of pentane were measured with either system at any of the three monitoring wells (sections of pipe) that had been installed beneath the AST. Two gallons of pentane were then injected into the fourth pipe, and suction was applied to the monitoring well located at a 180° angle from the injection well. Suction was applied only during the first eight hours after injection. Twenty hours after the pentane had been injected, levels of 3 to 4 ppm of pentane were measured at the 180° monitoring well, and levels of 1 to 3 ppm were recorded at the other two monitoring wells. Ten days after the pentane had been injected, pentane levels at all wells were below 2 ppm. All pentane detections were made by the gas chromatograph. Pentane was not detected by the fiber optic sensor.

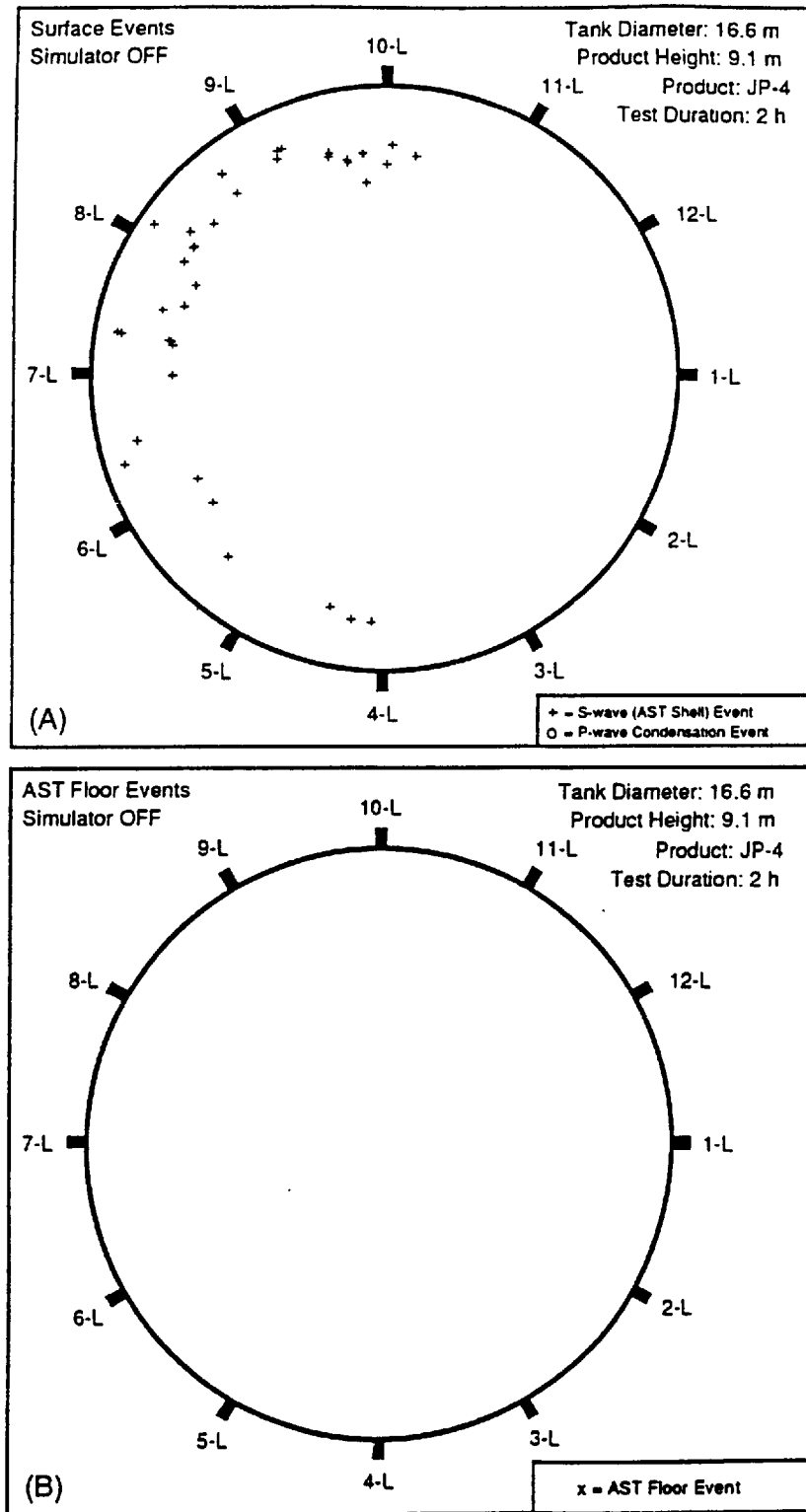


Figure 4-3. Acoustic events: (a) surface events (control tank, simulator OFF); (b) floor events (control tank, simulator OFF).

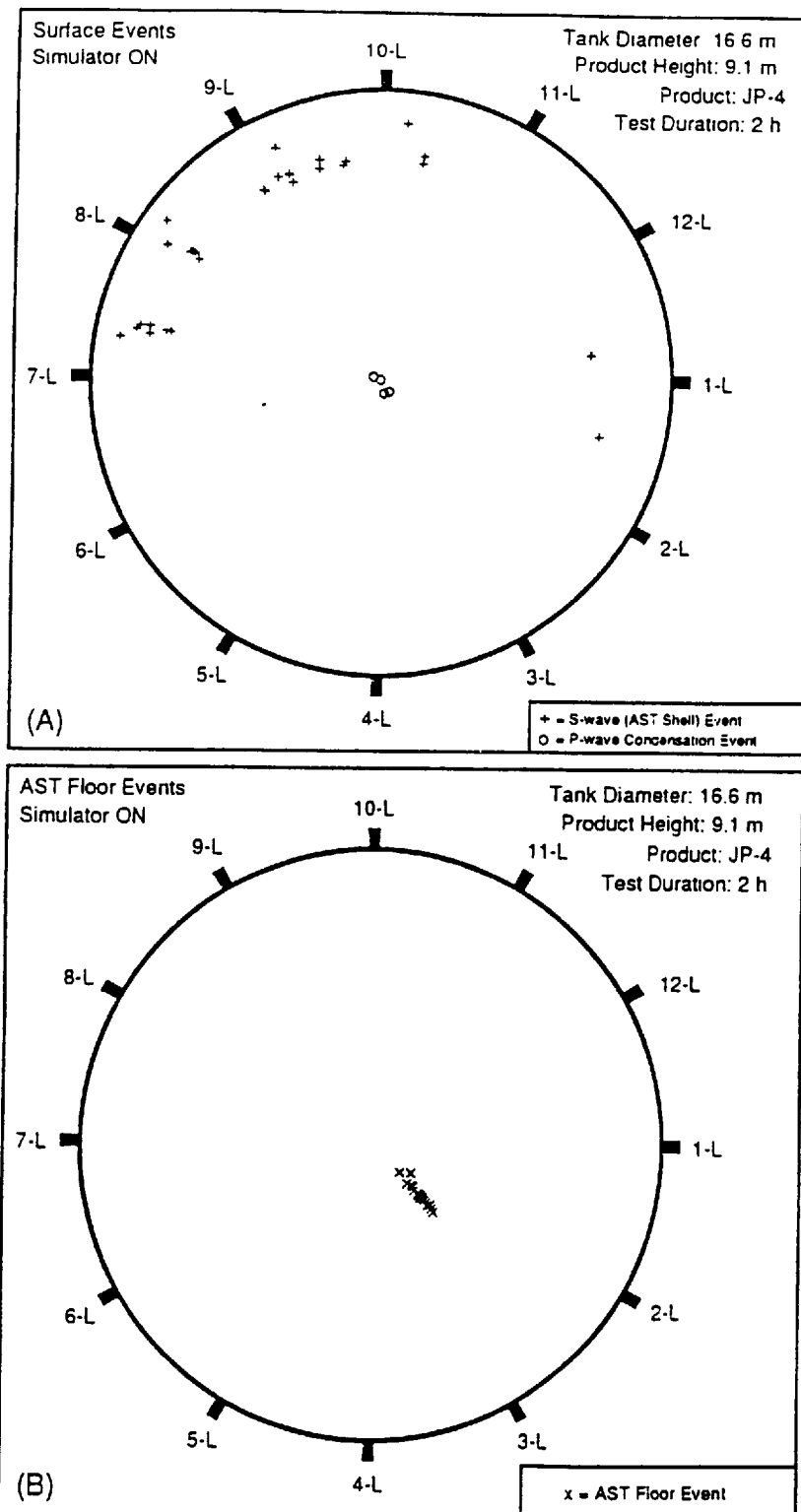


Figure 4-4. Acoustic events: (a) surface events (control tank, simulator ON); (b) floor events (control tank, simulator ON).

After the soil vapor tests had been completed, a high-product-level mass-measurement test was conducted. The results of this test were inconclusive due to the effect of floating-roof motion, which is discussed in Appendix B of this report.

LEAK DETECTION TESTS

Leak detection tests using the proposed methodology were conducted on the remaining 13 ASTs between 7 April and 3 May 1993. Acoustic and soil-vapor monitoring tests were conducted on all 13 tanks. The results of these tests are given in Table 4-2.

Table 4-2. Summary of Leak Detection Tests

Tank No.	No. of Wells	SOIL VAPOR MONITORING		PASSIVE ACOUSTIC			
		Result	Test Duration (h)	Total Number of Hits	Floor Hits	Hits Due to Condensation	Hits Due to Roof Motion
36	2	No measurable hydrocarbons	4	534	0	1	402
37	2	No measurable hydrocarbons	10	1136	0	0	762
22	3	No measurable hydrocarbons	10	866	0	3	802
2	2	No measurable hydrocarbons	6	743	0	262	368
9	2	No measurable hydrocarbons	6	564	0	17	265
7	2	No measurable hydrocarbons	6	100	0	33	44
3	2	No measurable hydrocarbons	5	532	0	81	338
24	2	No measurable hydrocarbons	4	580	0	70	437
18	2	No measurable hydrocarbons	4	599	0	0	474
19	2	No measurable hydrocarbons	4	653	0	0	449
15	2	No measurable hydrocarbons	4	1418	0	26	1260
14	2	No measurable hydrocarbons	5	1120	0	68	732
16	2	Less than 2 ppm pentane measured at both wells. No other hydrocarbon detected.	4	350	0	31	310

Six hours was allotted for the conduct of acoustic tests, two hours for setup and calibration and four hours for data collection. The period set aside for data collection was extended when additional time

was available. Up to two tanks were tested each day. Product levels were at 80 to 90 percent of tank capacity. Acoustic testing was completed on schedule and, as mentioned earlier, did not in any case indicate the presence of a leak.

In the soil-vapor monitoring tests, where pentane was the tracer element, a gas chromatograph was used to sample the air beneath each of the tanks. Under most of the tanks, two monitoring wells each consisting of a ten-foot section of pipe were positioned at a 180° angle to one another. Under Tank 22, three monitoring wells were positioned radially at intervals of 120°. Unlike the control tests, no suction was applied to any of the monitoring wells. Under 12 of the 13 tanks, no pentane was detected; at the two monitoring wells under Tank 16, less than 2 ppm of pentane was detected. The presence of pentane under Tank 16, however, is not believed to have been caused by a leak. If product had been leaking into the backfill, several other constituents of that product would have been detected by the gas chromatograph. The detection of pentane is thought to have been caused by contamination of either the test sample or the equipment.

Volumetric tests performed on Tank 9 were 48 h in duration and were conducted with product level at 3 ft. As in the control test, level-and-temperature and mass-measurement data were collected concurrently from 20 to 22 April. Level-and-temperature measurements indicated an average outflow of 0.38 gal/h over the 48-h period, while mass measurements indicated a 1.5 gal/h inflow during the same period. The discrepancy between these two results is believed to be caused by uncompensated thermal effects on the mass-measurement test equipment. Level-and-temperature and mass-measurement data are shown in Figures 4-5 and 4-6, respectively. Four-hour mass balancing tests were conducted a number of times during the two days of testing on Tank 9. A large number of data sets were contaminated by the effects of direct solar heating of the differential pressure gauge. The data provided for analysis were collected between 0450h and 0835h on 22 April. During this period, two identical measurement systems were operating concurrently. Flow rates measured by the two systems during this period were -0.96 and +2.7 gal/h, respectively. The discrepancy between these two measurements cannot be explained on the basis of the available data. The two systems were mounted on the tank at different times and

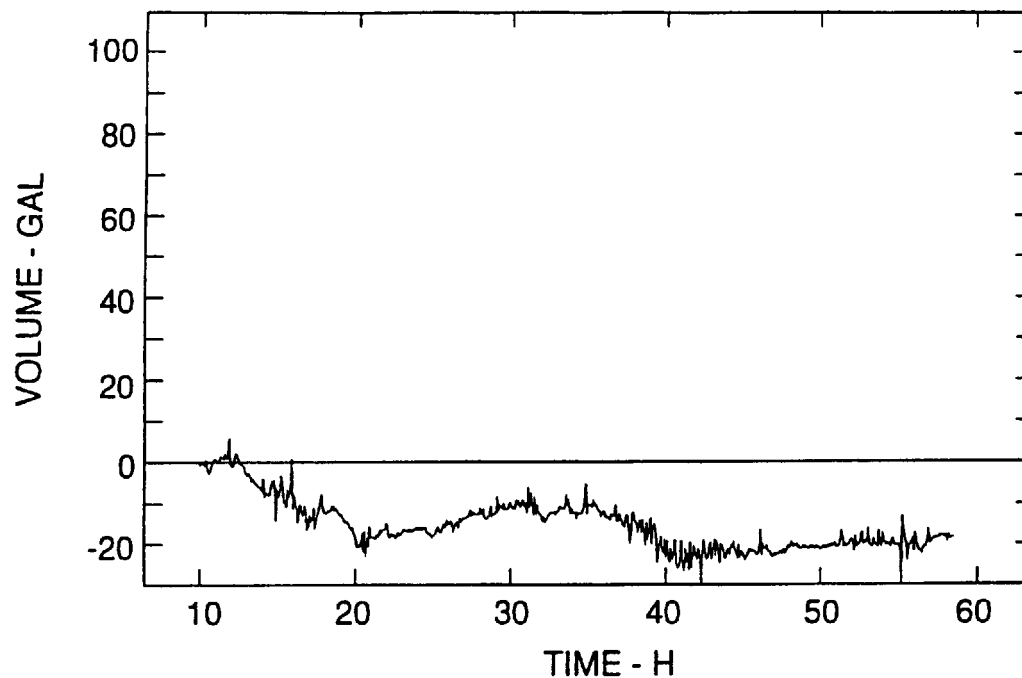


Figure 4-5. Level-and-temperature volumetric data (Tank 9).

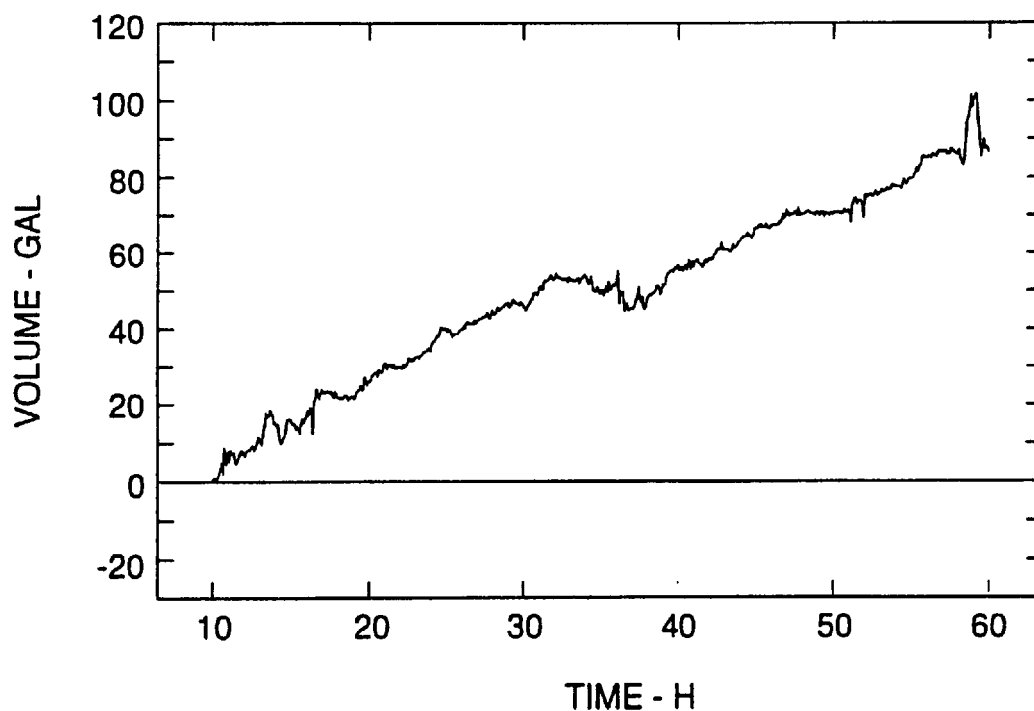


Figure 4-6. Mass-measurement volumetric data (Tank 9).

were therefore subject to different heating environments prior to the time that the measurements were made. The magnitude of the measured flow rates is consistent with known thermal effects on differential-pressure-measurement instrumentation.

Level-and-temperature data from Tank 2 were collected over a 48-h period from 1 to 3 May. During this time the roof of Tank 2 was floating on the product surface. High-product-level mass measurement tests were also conducted on this tank. These data were analyzed to assess the impact of the floating roof on test performance. The results of these analyses are given in Appendix B.

Section 5

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this test series, a number of conclusions can be drawn regarding the performance of each of the three technologies and of the overall test methodology. These conclusions are described below, with recommendations for future study in each area.

TEST METHODOLOGY

A testing methodology that uses multiple technologies will provide a robust test result. In order for such a methodology to be effective in improving the reliability of a test decision, two criteria must be met. First, the technologies included in the methodology must have acceptable performance in terms of probability of detection and probability of false alarm, and second, each of the technologies must be independent. If noise affects each technology in a different way, the performance of the *multiple-technology methodology* is enhanced. In this test series, independence was achieved in that sources of noise that affected the performance of one technology did not affect the others.

Because this test series did not result in any detections, the performance of the methodology cannot be evaluated directly. The performance of a methodology such as the one used in this program should be evaluated under circumstances in which one or more technologies indicate the presence of a leak. This can be accomplished in one of two ways: tests can be conducted on tanks that are suspected of leaking, or enough tests can be conducted on a tight tank that false alarms occur.

PASSIVE-ACOUSTIC TECHNOLOGY

The results of this test series indicate that passive-acoustic technology, as demonstrated in this program, can be employed on a wide range of tanks and still maintain a low probability of false alarm. Leak detection tests that use this technology differentiate acoustic signals from impulsive noise events primarily on the basis of the origin of the signal, i.e., its location. A detection is

made when a number of acoustic events are located in an area on the tank floor that is consistent with the location accuracy of the acoustic sensor array. There are two sources of illusory events that can lead to false detections. One consists of acoustic signals that seem to originate on the AST floor but in reality do not. The other consists of impulsive acoustic signals that are generated at the AST floor but that are due to factors other than a leak. It was shown during the acoustic tests that the collection and analysis of digital time series reduced the number of false events due to the mislocation of impulsive acoustic noise. Acoustic tests performed in accordance with the methodology prescribed in Phase III of this program indicated *no false events in any of the tanks tested*. This is an extremely important finding given that false events can lead to erroneous test results. Erroneous results can occur in two ways: a concentration of false events in a pattern consistent with the location accuracy of the acoustic sensor array will be incorrectly identified as a leak (false alarm); a large number of false events can mask a grouping of true leak signals, so that a leaking tank will be incorrectly declared intact (missed detection). In addition, there were *no non-leak sources of impulsive acoustic signals originating from the floor* in any of the tanks tested. All of the tanks had internal, floor-mounted structures such as roof drains, pivoted float arms, or roof supports. It was thought that such structures might generate acoustic signals originating at the floor and thus be a source of false events. In none of the 14 tanks tested, however, were impulsive signals found to have originated from the tank floor.

Acoustic tests in which digital time series data were not used showed a large number of false events. Although these did not cause any false alarms, a concentration of false events in one tank indicated the need for a retest. These false events are believed to have been caused by the mislocation of impulsive noise generated at the product surface by the motion of the floating roof.

The two primary noise sources identified in this test series both originated at the product surface: condensate dripping onto the product surface and the motion of the floating roof. Acoustic noise sources were found to propagate through the product as pressure waves and through the tank shell as shear waves. Correct identification of the propagation mode for each signal

received was critical to correctly locating all noise sources. It was found that incorrect identification of the propagation mode can lead to a grouping of false events which can be misidentified as a leak. As identified in Phase III, another potential source of false events caused by mislocation is the multipath reflections of acoustic signals within the tank (Vista Research, Inc., 1993a). These reflections, which were frequently larger than the direct-path signal, can cause a source of impulsive noise at the product surface to be mistakenly identified as a leak. The test and analysis approach demonstrated in Phase III, which involves the collection and analysis of time series data, was shown to be very effective in correctly identifying signal propagation and reflection characteristics; use of this approach resulted no false events over the course of the test series.

Persistent, non-impulsive noise from a nearby freeway and railroad yard was effectively reduced through analog filtering. Persistent noise can adversely affect acoustic leak detection tests by increasing the root mean square (rms) noise level against which the impulsive leak signal must be detected. Noise levels measured after analog filtering were sufficiently low to allow the reliable detection of leak signals of a magnitude consistent with those measured in Phase III.

Over the course of this program, many of the issues involved in passive-acoustic leak detection have been studied and are now better understood. A number of sources of impulsive, acoustic noise have been identified and characterized. The data collection and analysis approach implemented here has been shown to correctly differentiate these noise sources from the leak signal. The result is a test that has a low probability of false alarm and is applicable to a wide variety of tank configurations. Data collected during Phase III, on a tank with controlled leaks of known size and rate, indicate that the approach implemented here should also have a high probability of detection (Vista Research, Inc., 1993a). The remaining issue is the persistence of the impulsive leak signal under actual conditions. Further tests should be conducted on tanks with known or suspected leaks for the purpose of determining the characteristics of the impulsive leak signal and evaluating the detection performance of the passive-acoustic test method.

SOIL-VAPOR MONITORING TECHNOLOGY

During the control tests in which pentane was injected into a section of pipe under the AST, the rate of propagation of this gas through the oiled-sand backfill at the test site was too low for either the fiber-optic sensor or the gas chromatograph to detect a leak. In the interest of better understanding the propagation characteristics of pentane, additional injection tests were conducted at another site where the backfill material was sand that had not been oiled and was therefore much more porous. In this second series of tests, the injected pentane was reliably detected.

Soil-vapor monitoring techniques have potential for detecting leaks in ASTs; it is clear that in these tests, however, the effectiveness of the technology was severely limited by the low permeability of the oiled-sand backfill at the test site. The effect of a low-permeability backfill material in slowing the propagation of the target vapor can be mitigated through the use of a more stable substance as the target vapor and through the use of longer test durations. In order for this technology to achieve a reasonable probability of detection, the propagation characteristics of the target vapor through the backfill under a given tank must be well understood. Only then can the spacing of monitoring wells and the duration of the monitoring period be properly determined. The predictive capabilities required for reliable application of this technology must be developed and verified through additional work.

The existence of a layer of water at the bottom of the tank, although not experimentally investigated in this program, is known to prevent the release of product and therefore of pentane. Prior to this series of tests, water was drained from all tanks. No measurement of water level was made immediately before a leak detection test, however. Any water in the bottom of an AST can be a source of missed detections for pentane soil-vapor monitoring, and unevenness in the tank floor can make characterizing the thickness of any water layer very difficult. If a reasonable probability of detection is to be ensured, this issue must be addressed prior to conducting any test based on pentane soil-vapor monitoring.