APPENDIX C

DEVELOPMENT OF A TANK TEST METHOD

This appendix is a summary of the report, "Development of a Tank Test Method for a National Survey of Underground Storage Tanks." The work was conducted under EPA Contract No. 68-02-3938, Work Assignment No. 25.[1]

The appendix first summarizes the search for a suitable tightness testing method and the reasons for the final selection. Then the field procedures developed in the pilot test are described. A more detailed description of the field tightness test plan may be found in the test and analysis plan.[2]

I. SELECTING A METHOD

In preparation for the field tightness testing, MRI first searched for a suitable test method. Their objectives were to evaluate potential test methods to be used for the national survey, to conduct a pilot survey using the test method selected, and to develop a test plan for the national survey. The research was conducted in five stages. The first stage consisted of a

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[1] "Development of a Tank Test Method for a National Survey of Underground Storage Tanks," H.K. Wilcox, J.D. Flora, C.L. Haile, M.J. Gabriel, and J.W. Maresca, April 1986.

[2] "Test and Analysis Plan for the Tank Testing Program of the National Survey of Underground Storage Tanks," H.K. Wilcox, J.W. Maresca, Jr., J.D. Flora, C.L. Haile, June 10, 1985.

review of current methodology for detecting leaks in underground tanks. Second, field observations were made of several methods in use. Third, of the several methods observed, five were selected to be evaluated by conducting tests of these methods on a single tank system at a closed service station. Three of these five methods were selected for further evaluation in the fourth stage by testing tank systems at four military installations and at an operating service station. In the final stage, the method chosen for use in the national survey program was tested in a pilot study of 17 tank systems.

II. GENERAL METHOD SELECTION CRITERIA

The main criteria used to select a method for the national program were:

1. Quantitative measurements were desired. However, this did not preclude consideration of other approaches.
2. A detection level of 0.05 gal/h as established by the National Fire Protection Association, Inc., was taken as the target detection limit.
3. Minimal disruption to the station operation was considered to be important.
4. The method and equipment had to be rugged for use on the national survey.
5. The test should be applicable in a wide variety of tank system configurations.
6. The method should allow a reliable assessment of accuracy, precision, and sensitivity.
7. Costs for testing and data analysis had to be within the available budget.
8. Sufficient equipment and manpower to conduct the national survey were required.

The scope of the method selection research and pilot study did not permit exhaustive method evaluation of all available test methods in order to select a procedure with optimum characteristics for all criteria. Hence, some compromise was necessary to proceed expeditiously with the survey.

III. PRELIMINARY REVIEW AND TESTING

The methods reviewed in the first stage are shown in Table 1. Those for which further evaluations were conducted are also indicated. The methods were classified into groups according to their measurement characteristics.

Five methods were selected for further testing at a closed service station in Kansas City. Brief descriptions of each are provided below. A more complete review of tank testing methods can be found in EPA's report.[3]

- The ARCO method utilizes a photo optical sensor to monitor the level of a partially filled tank. If the test conditions are set up properly, the device is self compensating for temperature changes. Only the portion of the tank containing the product is tested.

- The Certi-Tec method uses pressure transducers which are located just below the surface of the liquid to measure level changes. Seven thermistors are used to measure temperature at various levels in the tank during testing. The tank is overfilled during the test by adding an extension to the fill pipe. Both the tank and lines are tested at the same time.

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[3] "Underground Tank Leak Detection Methods: A State of the Art Review," EPA/600/2-86/001, January 1986.

Table 1. Leak Detection Methods Reviewed

Detection method	Literature review	Field site visits	Preliminary testing	Development study	Pilot study
<u>Volumetric</u>					
ARCO tank test	X	X	X	X	
Certi-Tec test	X	X	X		
Ethyl Tank Sentry	X				
Ezy-Chek	X				
Heath Petro-Tite tank and line testing system	X	X	X	X	X
Hydrostatic (standpipe) testing	X				
Lasar interferometry	X				
Leak Lokator test	X	X	X	X	
Mooney tank leak detector	X				
Pald-2 leak detector	X				
Pneumatic testing (air test method)	X				
<u>Non volumetric</u>					
Dye method	X				
Vacutect method	X				
Helium leak detection method	X	X	X		
Tracer Research	X				
<u>Inventory monitoring</u>					
Manual methods	X				
Automated	X	X			
<u>External monitoring</u>					
Pollulert	X				
Remote infrared sensing	X				
Ground water and soil core samples	X	X		X	
Underground radar	X	X			

- o <u>Leak Lokator</u> uses a buoyancy probe to monitor level with a single thermistor located at the midpoint of the tank. The method can be used to test a partially filled tank (with lower sensitivity) or an overfilled tank. Either the tank or the tank and lines can be tested.

- o The <u>Petro-Tite</u> method monitors level visually in an extended fill pipe. The product level is returned to the reference level at 15 minute intervals during the test. The product is stirred continuously during the test to achieve a uniform temperature. Temperature is monitored with a single thermistor located at the inlet to the pump near the top of the tank. The tank and lines are all tested at the same time.

- o The <u>Varian helium</u> leak detection method, a nonvolumetric method, is based on the detection of helium outside a tank which has been slightly pressurized with helium. The tank should be empty during the test if the entire tank is to be tested. It is also helpful to drill a number of small holes in the surface above the tank to assist in the location of the leak. Pressure can be monitored simultaneously to provide a quantitative estimate of the leak rate. The lines are also tested at the same time.

A. <u>Experimental Procedures</u>

Each method was tested over a 2- to 3-day period. A leak simulation system was designed and fabricated by MRI and used to draw product from the tank at a known rate. The precision of the leak simulator was at least an order of magnitude better than that of the test methods. In testing the tank, the objective of each test group was to estimate different simulated leak rates. The leak rates measured by each method were compared with the rates used in the simulation.

The data from the quantitative tank tests were analyzed to determine the precision and accuracy of the tests. For these analyses the accuracy of the test (or bias) was estimated by the mean of the (signed) differences between the leak rate reported and the leak rate simulated. A paired t-test was used to test the hypothesis that the method was unbiased; that is, that the mean signed difference was 0. A linear regression of the reported leak rate on the simulated leak rate was calculated. An ideal regression equation in a tight tank would be $y = 0 + 1.0x$. The scatter of the data about the regression line (correlation coefficient, R) was used as an estimate of the precision of the method. The bias and precision were combined to obtain an estimate of the root mean squared (RMS) error.

B. Results

A summary of the statistical analysis for the quantitative methods as a group is presented in Table 2.

1. ARCO Underground

The ARCO method was used for 15 different simulated leak rates, including one zero rate. An average difference of 0.01 gal/h was observed between the rates reported by ARCO and those calculated by MRI. This estimated bias in the results was not significantly different from 0 ($t = 0.21$, 14 degrees of freedom). The intercept did not differ significantly from 0 and the slope did not differ significantly from 1. The R for the regression was 94.3 percent, indicating that most of the variability of the data was explained by the regression. The RMS error estimated for the method under the conditions of the Kansas City test was 0.05 gal/h. The tests averaged just under an hour (55.7 min) in length. In order to reduce the variability estimated with the method, either repeated determinations or a longer test time would be needed.

Table 2. Summary of Statistical Analyses of Quantitative Methods Tested at Kansas City Site

Method	n[a]	Bias	Intercept	Slope	Standard error	RMS	R^2
ARCO	15	0.01	0.005	0.95	0.049	0.050	94.3%
Certi-Tec	12	-0.25	-0.30	0.71	0.166	0.302	38.9%
Leak Lokator	22	-0.01	-0.01	0.94	0.020	0.021	98.9%
Petro-Tite	18	0.05	0.06	1.05	0.101	0.113	75.9%

[a] n = number of simulated leaks.

2. Certi-Tec Method

The Certi-Tec method was used for 12 simulated leak rates, of which two were set at 0 and so represented the normal condition of a tank test. The leak rates reported by the Certi-Tec method took slightly over an hour (average 64.3 min) for each rate. The estimated bias in the results (difference between the reported rate and the simulated leak rate) averaged -0.25 gal/h. This bias was quite large and was significantly different from 0 ($t = -5.23$, 11 degrees of freedom). The intercept differs from 0 at the 5 percent significance level and the slope differs from 1 at the 5 percent significance level as well. The standard error of the regression was 0.167 gal/h. The R of the regression was only 38.9 percent, indicating that slightly less than 40 percent of the variability in the reported leak rates was explained by the simulated leak rates used in the test.

Thus this method, as implemented during this test, appears to have substantial bias and relatively low precision. Even though taking several repeated determinations of the leak rates and averaging them would reduce the random error, the bias would remain a problem.

3. Leak Lokator Method

The Leak Lokator method was used on 22 tests simulating leak rates. Of these, three were zero simulated leak rates and so represented tests of the tank without any simulated leak. Three simulated leaks into the tank were also used. Using the method, the average reported leak rate was 10.8 min.

The bias in the determinations was estimated to be -0.005 gal/h, which was not significantly different from 0 (t = -0.23, 21 degrees of freedom). Although the estimated slope and intercept agree closely with the ideal, both differed from the ideal values significantly at the 5 percent level although not at the 2 percent level.

These data showed a very small scatter about the regression line, resulting in small estimated values for the standard error of the slope, intercept, and regression. These small standard errors led to the borderline significances of the difference between the regression parameters and their theoretical values. In light of the nonsignificance of the other test for the bias and the small magnitude of both the intercept (-0.012 gal/h) and the bias (-0.005 gal/h), these are probably not of major importance.

4. Petro-Tite Method

The Petro-Tite method was tested under 18 simulated leak rates, of which three were zero rates, corresponding to a tight tank situation. While the usual Petro-Tite test takes an average of four leak rates each reported over a 15-min period, only five of these determinations were based on an hour's data. The remaining leak rates reported were each based on a 30-min test.

From all the tests, the bias was estimated at -0.05 gal/h but was smaller (0.040 gal/h) when restricted to the hour-long tests. The bias from the complete set of tests is significantly different from 0 at the 5 percent level but not at the 1 percent level. If attention is restricted to the 1-h tests, the bias is not significantly different from 0. The intercept is not significantly different from 0, suggesting that the bias is not statistically significant. The slope does not differ significantly from the ideal or theoretical value of 1 at the 5 percent significance level. The R for the regression was 75.9 percent and the standard error of the regression was 0.101. This standard error is interpreted as the precision of a single leak rate determination. It should be noted that the normal test with four 15-min rate determinations should be somewhat more precise than what was reported, and that precision could be improved further by testing for a longer period of time and averaging more individual leak rates reported.

5. Helium Detection Method

Two tests were conducted using the helium detection method. In the first test the tank was tested in its original state. Several large leaks were discovered during the first day's testing, which were repaired. The next day's test revealed substantial reduction in helium loss.

While some helium was detected around the tank, the amounts were generally very small and could have come from pipe fittings or the tank bungs. Low levels were, however, encountered in one area. The concrete was removed for inspection purposes to see if a line was located in that area. None was found, but helium levels in the excavation were moderate.

The basic problem encountered using the helium detection method is that helium can escape in measurable quantities through threaded connections which have been poorly coated with sealer. Gasoline will not normally pass through these poorly sealed connections at measurable rates under normal operating conditions. This can lead to results which are hard to interpret. In addition, no quantitative results can be produced.

C. Conclusions

As a result of the preliminary testing in Kansas City, the ARCO, Leak Lokator and Petro-Tite methods were selected for further evaluation. The helium method was dropped because of the decision that a quantitative method presented a better option for the national survey. The Certi-Tec method was dropped because of the prototype state of development and its relatively lower performance.

IV. DEVELOPMENT STUDY TESTING

A. Experimental Procedures

Five facilities were selected by the EPA for tank testing. A total of 13 tanks were tested. The initial plan was for each tank to be tested by all three methods. Difficulties in scheduling and plumbing problems at some sites, however, precluded a complete round of testing.

Two types of tests were conducted at each sites: baseline tests which were conducted in the same manner as if no evaluations were being conducted, and leak simulation tests which consisted of measuring leaks under a variety of simulated leak rates (usually four). The process was nearly identical to that described for the preliminary testing.

Three sets of data from the development study were analyzed: baseline test data; leak simulations; and time series analysis of the ambient volume fluctuations after the simulated leaks were removed.

The baseline data for each method was tabulated and compared for each tank where more than one method was used to test the same tank. Where differing conclusions regarding the tightness of the tank were obtained, the data and conditions of the test were further examined in an effort to resolve the conflict.

The data from the leak simulations were analyzed by fitting a linear regression to the data from each tank and method by regressing the reported leak rate on the simulated leak rate. The intercept of this regression represents an estimate of the leak rate of the tank or tanks system when there is no simulated leak. The difference between the intercept of the regression line and the test result from the baseline test provides an estimate of bias or accuracy of the test. The variability of the data about the regression line provides an estimate of the precision of the test. Combining these two measures yields an estimate of the mean square (or root mean square error) associated with the testing method.

The third analysis consisted of a time series analysis of the ambient volume fluctuations after the simulated leaks were removed.

B. Results

1. ARCO Method

The ARCO method was used to test seven tanks during the development study. Of these seven tanks, one tank had only the baseline test run, one tank test resulted in the baseline test and one simulated leak rate, and the other five tank tests all had the baseline leak rate and several simulated leak rate tests.

The baseline test results for ARCO are summarized in Table 3. The ARCO result disagreed with the conclusion for three tanks. However, it must be noted that the ARCO system tested tanks approximately 75 percent full, under no additional head pressure. Thus, the ARCO system provides a test most representative of the usual operating conditions of the tank. If a tank system has a hole in or near the top or fill pipe, or if there is a leak in the lines, this would not result in product leaking under normal operating conditions. While it may be unlikely that all of the leaks encountered during the study are in the top of the tank, it is a possible explanation.

A summary of the results from the leak simulation tests using the ARCO method are summarized in Table 4. By this method of testing, none of the tanks tested were reported to be leaking. However, other test methods gave different results for some tanks.

The data indicate, however, that the ARCO test method performed well at the Damneck and Pitstop North test locations. If a single data point that appears to be an outlier is removed, the method also does reasonably well at the Langley facility. One of the sites (Scott Tank 18) showed essentially no regression of the reported leak rates on the simulated leak rates. This is disturbing because for that test the method could not quantify leak rates under the simulation. One other test, at Fort Lewis, gave a slope substantially different from 1, which indicates that an (unknown) interfering factor is present.

The ARCO method gave a precise determination of a leak rate under some operating conditions. In other cases, it failed to give valid results for reasons that were not understood. In other cases, it failed to give valid results for reasons that

Table 3. Summary of Baseline Results and Tank Tests Attempted

Facility and tank	ARCO		Leak Lokator		Petro-Tite		MRI conclusion
Damneck	+0.02	C[a]	-0.077	N[b]	+0.003	C	Tight
Pitstop							
1 (south)	+0.02[c]	C	-0.741 (Poor sensitivity)	N	-2.892	N	Leak
2 (north)	0.0	C	-0.012	C	-0.05	C	Tight
Scott							
1 (17)	Out of time		-0.299	N	+0.004	C	Tight[e]
2 (18)	+0.02[c]	C	-0.178 Problem, possibly manifolded	N	-0.812	N	Leak[e]
Ft. Lewis							
1 (8C25 north)	-0.04	C	Leak about gasket-could not test		--		Tight
2 (8C25 south)	0.0[c]	C	-0.027	C	-0.342	N	Leak
3 (4194)	--		-0.172 (Poor sensitivity)	N	-3.0	N	Leak
4 (10E10)	--		-0.191[d]	N	-0.024	C	Tight
Langley							
1 (HS tank 3)	--		-0.448	N	--		Leak
2 (HS tank 5)	Physical problem with tank		-3.0[d]	N	--		Leak
3 (MoGas)	-0.03	C	--		--		Tight
4 (Golf course)	--		--		-2.540	N	Leak

[a]Certifiable.
[b]Noncertifiable.
[c]Test OK, but leak (possibly in upper part or piping) not found.
[d]Test appeared OK, but data are inconsistent.
[e]Interactive effects between Tanks 17 and 18 were observed by Leak Lokator
- (negative sign) indicates leak out.
-- indicates testing was not conducted at that tank by the test company indicated.

Table 4. Results of Leak Simulation Tests Using ARCO Method

Tank	Baseline rate	Intercept	Bias	Slope	SE	RMS
Damneck	0.02	-0.023	-0.003	1.049	0.022	0.023
Pitstop south	0.02	-	-	-	-	-
north	0.0	-0.092	-0.092	0.809	0.041	0.101
Scott 18	0.02	-0.145	-0.165	-0.044	0.099	0.192
Fort Lewis						
8C25 south[a]	0.0	-0.005	-0.005	1.140	-	-
8C25 north	-0.04	-0.094	-0.054	0.493	0.047	0.072
Langley						
MoGas	-0.03	-0.336	-0.306	0.419	0.367	0.478
	-0.03[b]	-0.027	0.003	1.167	0.118	0.118

Negative = Leak out
Positive = Leak in
Bias = Intercept - base

[a] Two points only.
[b] Outlier removed.

were not understood. It can detect inflow or outflow, but would be defeated if the water table were at a level that approximately balances the hydrostatic pressure of the product. It is also subject to interference from wind and is sensitive to vibration. It has the advantage of not requiring an overfilled tank, but this is counterbalanced by the disadvantage of not being able to detect potential leaks in the upper quarter of the tank.

The ARCO method was not recommended for use on the national survey program for several reasons. The primary reason was the decision to test the entire tank. Secondary reasons were the sensitivity of the method to interference from vibration and the relatively high frequency of tests that did not adequately quantify the simulated leak rates.

2. Leak Lokator Method

The Leak Lokator method was used to test 10 tanks during the development study. Of these, two tanks had only baseline tests and no simulated leak tests conducted. The baseline test results are summarized in Table 5. The Leak Lokator test conclusions agreed with MRI's conclusion in 6 of the 10 tank tests. Of the other four, the Leak Lokator test failed to certify three tanks that had been concluded to be tight based on data from all test methods and certified one tank that had been determined to be leaking.

A summary of the results from the leak simulation tests using the Leak Lokator method is presented in Table 5. The RMS errors ranged from about 0.02 gal/h to 0.44 gal/h. The standard errors ranged from 0.015 to 0.304. Among the tanks judged to be tight, the standard errors ranged from 0.015 to 0.165 and the RMS error ranged from 0.021 to 0.437. The large values for the upper

Table 5. Results of Leak Simulation Tests Using Leak Lokator Method

Tank	Baseline rate	Intercept	Bias	Slope	SE	RMS
Damneck (@ 120")	-0.0775 @ 125 (+0.008 @ 118)	-0.0825 (-0.005)	-0.005 (-0.13)	0.786	0.025	0.0255 (0.028)
Pitstop south	-0.524	-	-	-	0.209	-
north	-0.012	-0.026	-0.014	0.879	0.015	0.021
Scott 17	-0.299	-0.366	-0.067	0.839	0.048	0.082
18[c]	-0.178	-	-	-	0.047	-
Fort Lewis						
8C25 south	-0.027	-0.010	0.017	0.734	0.097	0.099
4194	-0.171	-0.159	0.013	0.749	0.026	0.029
10E10 NTC[a]	-0.191	-0.596	0.405	0.541	0.165	0.437
TC[b]	-0.191	0.069	0.260	0.835	0.098	0.278
Langley						
HS 3	-0.448	-0.641	-0.193	-1.78	0.048	0.199
HS 5	-3 or more	0.126	0.126	2.43	0.304	0.329

Negative = Leak out
Positive = Leak in
Bias = Intercept of their (adjusted for base) regression
Intercept = Bias plus base

[a]NTC - not temperature corrected.
[b]TC - temperature corrected by Leak Lokator.
[c]Leak Lokator observed interactive effects between Tanks #17 and #18 during the testing of #18. The reasons for this are not understood.

end of the range are from a test that had problems. If that data point is excluded, the upper end of the ranges becomes 0.048 and 0.082. With the ability of Leak Lokator to obtain multiple leak rate determinations fairly rapidly (about one every 10 to 15 min), one could presumably reduce these error estimates by making several leak rate determinations at a tank and averaging them.

The Leak Lokator method gave valid estimates of leak rates in most cases. The variability of a single leak rate measurement tends to be somewhat large relative to a 0.05 gal/h criterion, but the ability of the system to obtain leak rate determinations in about 10 min once the test is running would allow multiple determinations and averaging to reduce this variability. The method has the advantage that its level monitoring system can be used at any desired level (head pressure). Thus, if line leaks are a problem, the testing could, in principle, be conducted using a level below the piping to determine the location of the leak.

The hydrostatic pressure from a water table could pose a problem for this test. Testing did not appear to be standardized to any specific product level. Since the leak rate through a given aperture would change with head pressure, testing different tanks at different levels makes leak rate determinations difficult to compare and quantify.

3. Petro-Tite Method

The Petro-Tite method was used to test nine tanks during the development study. The locations of these tank systems and reported leak rates were given in Table 3. Three of the systems tested had leak rates so large (in excess of 5 gal/h) that simulation of additional leak rates on the order of 0.2 gal/h was not feasible. Simulated leak rate testing was performed on five tank systems.

The baseline tests conducted by Petro-Tite agree with the conclusions reached by MRI based on analysis of all the data. It should be noted that in some cases (e.g. Ft. Lewis #1) where other testers experienced difficulties, Petro-Tite would have also had difficulty.

A summary of the results from the leak simulation tests using the Petro-Tite method is presented in Table 6. The RMS errors ranged from 0.036 to 0.193 for tanks judged to be tight. The 0.193 is rather large, but that tank posed special problems, leading to the conclusion that the 0.193 is not representative. Error estimates on tanks judged to be leaking were larger, ranging up to 0.24 gal/h. Larger errors are to be expected for systems with large leaks because large leaks make it difficult to maintain product level and so therefore to obtain an accurate volume. However, the errors remained acceptably low relative to the associated leak rates.

As a result of the more detailed analysis of Petro-Tite data, several suggestions for improving the errors involved in the Petro-Tite method were developed. None of these involve significant procedural changes. Improved algorithms could likely result in better test results.

The Petro-Tite method seems capable of identifying and successfully dealing with many types of interferences in tank testing. Although there are situations that can lead to invalid test results, for the tanks tested in this study all tests but one were believed to be valid. However, difficulties were encountered that increased the error associated with the estimated leak rates beyond that which is desirable. In

Table 6. Results of Leak Simulation Tests Using Petro-Tite Method

Tank	Baseline rate	Intercept	Bias	Slope	SE	RMS
Damneck	+0.003	-0.009	-0.012	1.01	0.052	0.054
Pitstop south	-2.89	-	-	-	0.240	-
north	+0.050	+0.069	+0.019	1.26	0.078	0.075
Scott 17	+0.004	+0.002	-0.002	1.075	0.036	0.036
18	-0.812	-0.774	0.038	0.608	0.109	0.115
Fort Lewis						
8C25 south	-0.342	-	-	-	0.107	-
4194	-3.0	-	(Could not fill tank)		-	-
10E10	-0.024	-0.038	-0.014	1.50	0.193	0.193
Langley golf course	-2.54	-	(Could not keep filled)		-	-

Negative = Leak out
Positive = Leak in
Bias = Intercept - base

difficult cases, the error rates were such that one could not reliably detect leak rates as small as 0.05 gal/h. Most of the situations with large error estimates were cases where a substantial leak was present, and hence the loss in precision did not interfere with the detection of the leak.

4. Time Series Analysis of Ambient Noise Data

Because the data obtained from ARCO was not sufficient, time series analyses were performed only on the Leak Lokator and Petro-Tite data.

a. Description of Ambient Noise Analysis

The second analytical approach was to remove the simulated leaks from the data to produce volume, temperature, and temperature compensated volume time series that were longer than normally used during a tank test. These data were analyzed to determine whether the results obtained during a standard tank test period (i.e., a baseline test) were consistent with longer test times and to determine whether the temperature-estimated volume changes required for compensation adequately accounted for the total volume changes in a non-leaking tank.

Petro-Tite Method

Continuous time series of the change in volume and the change in temperature (converted to volume using the product volume and the coefficient of thermal expansion) for an entire day of Petro-Tite testing were generated from the data collected every 15 min by subtracting the simulated leak volume from the measured volume. The volume change used for this 15-min interval was an average of the volume changes observed before and after this period. Cumulative time series of volume, temperature, and temperature-compensated volume were then generated for analysis. The temperature-compensated time series were generated by subtracting the temperature (expressed in volume) from the measured volume on a point-by-point basis. This is the same method used by Petro-Tite. A least squares line was then fit to each of the three time series to estimate the mean rate of change of volume, temperature, and temperature-compensated volume. The temperature-compensated volume was compared to the baseline test results. The standard Petro-Tite data analysis method was used to estimate the temperature-compensated volume rate for the baseline tests (i.e., sum of the temperature-compensated volume computed for four 15-min periods).

Leak Lokator Method

Time series of the cumulative volume and cumulative temperature were generated for each simulated leak sequence of the Leak Lokator data. Each time series ranged from a total of 40 min to over 100 min and included four to nine of the standard Leak Lokator volume rate measure periods. The simulated leak rate was subtracted from the uncompensated volume rate measurements made by Leak Lokator and converted to volume using the reported measurement time. These volume measurements were then summed to obtain the cumulative volume time series. The mean volume rate for each simulated leak sequence was taken from the Leak Lokator data sheets. A continuous time series of temperature was generated each day of testing from annotated readings of temperature made every 5 to 10 min and placed on the strip chart of temperature by Leak Lokator personnel. Those sections of the temperature time series which bracketed the volume data for each simulated leak sequence were used in the analysis to compensate for temperature. The temperature data was converted to a volume time series and a least squares line was fit to the data to estimate the average rate of change of volume caused by the rate of change of temperature over an hour. A mean temperature-compensated volume rate was then computed for each simulated leak period by subtracting the mean rate of change of temperature from the mean rate of change of volume and compared to the results from the baseline test and the other simulated leak test sequences.

b. Petro-Tite Ambient Noise Analysis Results

A summary of the mean and 95 percent confidence intervals on the mean volume rate, temperature rate, and temperature-compensated volume rate estimated from the long Petro-Tite time series is presented Table 7. The rates were obtained by fitting a least squares line to each time series. The confidence intervals are based on the standard deviation of the ordinate about the regression line. The site, tank number, number of 15 min data points, and the test result using Petro-Tite's 0.05 gal/h detection criterion are also given. For comparison, the baseline test result is added to the table. Agreement between the baseline test results and the long time series results is good, except for Pitstop Tank No. 2. The time series from the Fort Lewis Tank No. 4 indicate that a potential leak began several hours after the test had begun.

The time series of volume, temperature, and temperature-compensated volume were generated by removing the simulated leaks from the Petro-Tite volume time series. The time series are 3 to 6 times longer than the standard 1 h Petro-Tite test. The first hour of each time series contains the baseline data. Several

Table 7. Summary of the Petro-Tite Analysis

Location	Tank	N	Volume rate (gal/h)		Temperature volume rate (gal/h)		Temperature-compensation volume rate (gal/h)		Baseline test results		Test results
			$\bar{x}$	95% CI	$\bar{x}$	95% CI	$\bar{x}$	95% CI	Test result	Temperature-compensated volume rate (gal/h)	
Damneck	1	20	0.043	0.008	0.064	0.008	-0.021	0.003	Tight	+0.003	Tight
Fort Lewis	2	7	-0.287	0.036	0.084	0.038	-0.371	0.050	Leaking out	-0.0342	Leaking out
Fort Lewis	4	22	-0.025	0.022	0.017	0.025	-0.042	0.027	Tight	-0.024	Tight
	4[a]	9	0.023	0.035	-0.051	0.133	0.074	0.117	Leaking in[c]		
	4[b]	13	-0.104	0.027	-0.006	0.040	-0.098	0.435	Leaking out		
Pitstop	2	19	0.151	0.010	0.013	0.009	0.133	0.011	Leaking in	-0.05	Tight
Scott AFB	1	24	0.184	0.017	0.190	0.014	-0.006	0.005	Tight	0.004	Tight
Pitstop	1	8	-2.493	0.139	0.279	0.061	-2.773	0.089	Leaking out	-2.892	Leaking out
Scott AFB	2	16	-0.714	0.024	0.009	0.005	-0.722	0.028	Leaking out	-0.812	Leaking out

[a] First 2.25 h of the test.
[b] Last 3.5 h of the test.
[c] Direction of flow only; not statistically significant from zero.

observations about the strengths and weaknesses of the method can be made from the data.

First, the time series for Damneck Tank No. 1 and for Scott Air Force Base Tank No. 1, tanks declared to be tight, illustrates the high correlation between the low frequency trends of the temperature and volume data required for temperature compensation. This suggests that the method of temperature compensation, circulation of the product and measurement of the rate of change of temperature with one temperature sensor, is a reasonable approach.

Second, negative, high-frequency correlations were observed between the temperature and temperature-compensated volume rate time series for some of the tests. This suggests that the method is overcompensating for temperature effects. These high-frequency temperature fluctuations are probably caused by inadequate resolution of the Petro-Tite temperature sensor. This increase in the high-frequency fluctuations in the temperature-compensated volume data can be a problem if the test time is too short.

Third, inspection of the temperature-compensated volume rate time series for each test suggests that a one-hour test is too short to reliably detect small leaks. Within a test, fluctuations with period of 30 to 90 min are observed which are sufficiently different from the low frequency trend exhibited by the entire time series.

Fourth, the time series for the tests conducted on Fort Lewis Tank No. 2, Scott Air Force Base Tank No. 2, and Pitstop Tank No. 1 indicate that the tanks are leaking. The measured temperature changes are too small to account for measured volume changes.

c. <u>Leak Lokator Ambient Noise Analysis Results</u>

A summary of the mean and 95 percent confidence intervals on the mean volume rate, temperature rate, and temperature-compensated volume is presented in Table 8. The site, tank number, duration of the test sequence, the number of Leak Lokator volume rate measurementss in the test sequence, and the test result based on Leak Lokator's 0.05 gal/hr criterion are also given. For comparison, the baseline test results are also shown. Several observations about the data presented in Table 8 are noteworthy. First, the test sequence results for each tank tested are internally inconsistent. The results from five of the six tanks tested could be declared tight or leaking depending on which data sequence was used. The results of the other tank test (Ft. Lewis, Tank #3) indicate that the tank is leaking but cannot determine whether the flow is into or out of the tank. Second, temperature, volume, and temperature-compensated volume rate data exhibit a large range of variability compared to 0.05 gal/hr. The high variability in the temperature compensated volume rate suggests that the test time is too short and a single thermistor is not adequate for measuring the mean temperature change in the tank. These conclusions are based on the raw Leak Lokator data and an analysis similar to that used by Leak Lokator except (1) an average of four to nine standard Leak Lokator volume rate measurements were used instead of one and (2) the average rate of changes of temperature over one hour was determined by fitting a least squares line to 5 to 10 temperature values over the hour instead of the two end points. The uncertainty in the Leak Lokator temperature-compensated volume rate results presented in Table 8 is about a factor of five smaller than the uncertainty of a single 10 min volume rate measurement and a two-point temperature rate measurement.

Table 8. Summary of Leak Lokator--10-min Weighted Sample Analysis

Location	Tank	Test sequence	Total time (min)	N	Volume rate (gal/h)		Temperature volume rate (gal/h)		Temperature-compensation volume rate (gal/h)		Test result
					$\bar{x}$	95% CI	$\bar{x}$	95% CI	$\bar{x}$	95% CI	
Damneck	2	Baseline	1		-0.077						Leaking out
		1	101	8	-0.051	0.004	-0.011	0.007	-0.040	0.008	Tight
		2	112	9	-0.015	0.007	-0.052	0.011	0.037	0.013	Tight
		3	93	8	0.043	0.027	-0.041	0.005	0.084	0.027	Leaking in
		4	59	5	-0.028	0.010	-0.023	0.011	-0.005	0.015	Tight
Fort Lewis	2	Baseline			-0.027						Tight
		1	44	4	0.017	0.014	0.215	0.059	-0.198	0.061	Leaking out
		2	25	3	-0.044	0.028	0.096	0.096	-0.140	0.100	Leaking out
		3	40	4	0.019	0.020	0.001	0.026	0.018	0.032	Tight
Fort Lewis	3	Baseline			-0.172						Leaking out
		1	37	5	-0.130	0.012	0.043	0.004	-0.173	0.013	Leaking out
		2	35	5	-0.089	0.031	-0.001	0.010	-0.088	0.032	Leaking out
		3	43	7	-0.042	0.020	-0.104	0.041	0.062	0.046	Leaking in
Fort Lewis	4	Baseline			-0.191						Leaking out
		1	56	6	-0.203	0.052	-0.251	0.041	0.048	0.066	Tight
		2	41	6	0.157	0.068	-0.031	0.014	0.188	0.070	Leaking in
		3	41	5	0.158	0.034	-0.003	0.010	0.161	0.036	Leaking in
Pitstop	2	Baseline			-0.012						Tight
		1	48	7	0.096	0.009	0.079	0.033	0.017	0.035	Tight
		2	44	4	0.053	0.005	0.006	0.078	-0.003	0.079	Tight
		3	47	6	0.054	0.007	0.057	0.078	-0.003	0.079	Tight
		4	56	5	0.053	0.005	0.221	0.045	-0.168	0.045	Leaking out
Scott AFB	1	Baseline			-0.299						Leaking out
		1	55	6	-0.323	0.029	-0.262	0.075	-0.061	0.080	Leaking out
		2	44	6	-0.225	0.008	0.032	0.008	-0.193	0.011	Leaking out
		3	56	5	-0.241	0.005	-0.008	0.024	-0.233	0.024	Leaking out
		4	36	5	-0.206	0.0374	0.008	0.014	-0.214	0.040	Leaking out

The time series plots of temperature (converted to volume) and uncompensated volume were generated for each of the 21 sequences of Leak Lokator data. These cumulative time series plots illustrate the reasons for the inconsistent test results and the high variability. The volume and temperature time series, and the least squares line fit to the temperature data are presented in the report, "Development of a Tank Method for a National Survey of Underground Storage Tanks."[4]

Some difficulty is evident in using a two-point analysis approach. Depending on which two points are taken, a positive, nearly zero, or negative slope can be determined because of the large fluctuations in temperature.

C. Recommendations for the National Survey Testing

The findings of the development study have resulted in several recommendations concerning the method of tank testing to be used in the national survey program. These recommendations are summarized below.

- **The tank testing method should include putting a head of pressure on the tank.** There are two reasons for this. First, proper compensation for water table effects are necessary if the proper conclusion is to be reached under high water table conditions. Second, this process enhances the flow of product through small holes, making them more likely to be detected, particularly if they are near the top of the tank.

[4] See Footnote 1.

- **The tank test method should provide frequent temperature measurements with a precise thermistor and adequate temperature compensation. The product should be circulated or mixed during the test.** Adequate temperature compensation is a key to successful interpretation of tank test data. Such data must consist of accurate temperature measurements at frequent intervals. The judgment to mix is a choice of techniques which is associated with the better performance achieved by the single thermistor approach used by Petro-Tite over the single thermistor approach used by Leak Lokator.

- **Data on temperature and level changes must be collected frequently.** This is necessary to minimize aliasing of the high frequency fluctuations (out of the signal band) into the lower frequencies (in the signal band). This conclusion is based large on data analysis performed by Vista Research, Inc.[5]

- **Data collection must continue for an adequate period of time so that sufficient data for a precise analysis can be provided. A minimum of 4 to 6 hours with frequent temperature and tank level change intervals is needed.** While a test length of 4 to 6 hours with frequent temperature and level readings is desirable, the practical considerations of cost and disruption to an establishment are also factors.

- **The test method must incorporate an adequate statistical analysis of the data to draw supportable conclusions about the leak rate.** None of the techniques were found to collect either sufficient test data or to provide adequate analysis algorithms. Improved analysis protocols will be required.

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[5] "Analysis of the Pilot Study Tank Test Data," Vista Research, Inc., July 1985.

V. PILOT STUDY

A. Objectives

The results from the earlier stages led to the recommendation that a test using modified Petro-Tite equipment and procedures be adopted for the national survey. The major objective of this final stage was to modify and evaluate the performance of the Petro-Tite method as it was to be used on the national survey. This process included:

- Determining the best sampling interval for collecting the data; that is, the time interval at which product in the standpipe should be re-leveled and data readings made;
- Determining the best length of the test;
- Developing and testing the analysis algorithm;
- Implementing the procedures operationally in the field to identify operating difficulties and correct them;
- Field testing the entire survey data collection effort including scheduling, data collection, and analysis;
- Estimating the detection performance of the method; and
- Finalizing the test protocol.

B. Overview

A sample of 25 tanks was selected from two primary sampling units (PSUs) on the west coast for use in the pilot study. The owners and operators of these tanks were contacted to arrange for the tanks to be tested and to schedule the tests. Timing of the contacts and arrangements for fuel delivery, payments, and scheduling presented difficulties. Recommendations for mitigating these on the national survey were developed. Notifying owners earlier of the test and giving a longer lead time to arrange and schedule the tests were found to be necessary to expedite testing.

Data were collected at three different time intervals and for three different total time periods. The resulting data were analyzed by various methods to select the most practical and effective data collection interval and test length. A standard data analysis protocol was developed for use when no testing or data problems are identified. Data management procedures for the national survey were developed which included the use of on-site computers to collect data. Data and test review procedures were developed to check each tank test for validity and to ensure that the standard analysis was adequate. A simplified analysis that can be used in the field to visually inspect the data and identify potential testing problems was developed and implemented. The tank test data were analyzed and a data report prepared and submitted to EPA.

C. Data Collection

Data identifying the tank, size, location, product, etc., were entered onto the top of a spreadsheet data file utilizing a portable computer. Then test data are entered as each data point becomes available. This provided a preliminary analysis and estimated volume change rate that can be obtained on the scene.

D. Data Analysis

The data from the pilot study tank tests were analyzed with two objectives. One was to determine the best sampling interval, and the second was to determine the best total test duration. Sampling intervals of 1, 5, 10, and 15 minutes were considered. Data collection at 1-min intervals was found to be impractical for the large scale survey. Both the 5- and 10-minute intervals provided improvements in the precision of the test data, but the 5-minute interval resulted in better precision. Thus, data collection at 5-minute intervals was selected as the standard. This analysis is presented in detail in Vista Research, Inc.'s report.[6]

Selection of the total time of the test was not so clear-cut. Longer test times were desirable from a data quality standpoint, but practical limitations were also considered. A compromise of 2 hours of data at the low level was selected as providing sufficient data while still proving to be practical for the field data collection.

The test protocol used the same equipment as for a standard Petro-Tite test. There were no changes in the test procedures except for the sample interval and length of the test.

The analysis algorithm was modified to include smoothing of the temperature data before applying the temperature correction. A regression line was then fitted to the corrected data to obtain the leak rate.

Seventeen tanks were tested in the pilot study. A summary of the test results is presented in Table 9.

A family of performance curves was generated for the large and small tanks to estimate detection performance for a given leak rate as a function of probability of detection, probability

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[6]Ibid.

Table 9 Summary of Pilot Study Results

Site no.	Tank no.	System leak rate (gal/h)	Standard Error (2 h) (gal/h)	OHM rate (gal/h)	Conclusion	Fuel	Tank size (gal)
1		0.036	0.0074	+0.037	C	UNL	11,907
2	T1	-0.036	0.0098	-0.038	C	UNL	1,034
2	T2	-1.381	0.0490	-1.518	N	D	7,896
2	T3	-0.263	0.0138	-0.367	N	D	7,896
2	T4	0.009	0.0107	+0.015	C	D	10,152
3		-0.012	0.0242	+0.032	C	PUNL	1,036
4		+0.294	0.0601	+0.256	N(I)	UNL	10,152
5	T1	0.026	0.0114	0.042	C	D	10,152
5	T2	-0.107	0.0041	-0.115	N	D	10,152
5	T3	+0.054	0.0047	-0.005	C	UNL	10,152
6		-0.008	0.0137	-0.024	C	UNL	8,000
7	T1	0.036	0.0245	+0.016	C	LR	6,006
7	T2	0.042	0.0307	+0.096	N(I)	LP	6,006
7	T3	0.013	0.0348	+0.031	C	UNL	6,006
8		-0.056	0.0067	-0.029	N	D	10,383
9	T1	-0.010	0.0098	+0.028	C	UNL	1,036
9	T2	-0.015	0.0130	-0.008	C	LR	1,036

C = Certifiable by NFPA standard.
N = Not certifiable (I) Inconclusive test
D = Diesel
UNL = Unleaded
PUNL = Premium unleaded
LR = Leaded regular
LP = Leaded premium

of false alarm, and test time. Detection performance for 0.05 gal/h leaks was unacceptable. A test period of 1 hour or less is too short to achieve reasonable detection performance. For the small tanks, test times of 1, 2, and 3 hours result in the detection of 0.10, 0.075, and 0.05 gallon per hour leak rates with a P_D = 95 percent and a P_{FA} < 5 percent. For the large tanks, test times of 1 and 2 hours result in the detection of 0.25 gal/h leak rates with a P_D = 95 percent and a P_{FA} = 2 percent and 5 percent, respectively.

Of the 17 tanks tested, one resulted in a clearly invalid test. One test was problematical, but the system is probably tight. Three tanks appear to have significant leaks, and the remainder appear to be tight. Due to the fact that the Petro-Tite method places a higher head pressure on the tank than is found in normal operation, the reported rates are overestimates of product loss or leakage in operation.

Since the pilot study data available for analysis was somewhat limited, the determination of the detection limit of the Petro-Tite method could not be established as well as hoped. Further data from the national survey will need to be examined.

VI. RECOMMENDATIONS FOR NATIONAL SURVEY

The recommendations for the national survey are:

1. Use a modified Petro-Tite test method;
2. Data should be collected at 5-minute intervals for 2 hours at each tank; and

3. Data analysis should use improved algorithms to fit data which exhibit curvilinearity in the test results.

The final proposed equipment configurations and data collection, environmental measurement, and data analysis procedures which resulted from the development and pilot studies were specified in a separate document.[7] The actual procedures and methods which were followed in the field are documented in Sections 6 and 7 and Appendix D of this report.

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[7] "National Survey of Underground Storage Tanks: Draft Test and Analysis Plan," Midwest Research Institute, June 10, 1985.