SECTION 8

STATISTICAL ANALYSIS OF LEAK DATA AND LEAK STATUS DETERMINATION

Section 6 above described the physical tightness test procedure used in this survey, a modification of a commercially available method. A field test for a single tank system[1] produced raw data which required analysis and interpretation before a determination could be made as to whether the test showed evidence that the tank system was leaking. Section 7 described the initial steps of data reduction which yielded a measured volume change rate and an estimate of the measurement variability of that rate for each tightness test. In that section, results of quality assurance retests were also given.

This section of the report discusses further statistical analyses required to evaluate the total measurement variability, to estimate the actual leak rate and to determine whether a given tank system can be judged to be tight or leaking, based on the tightness test. It also includes three further analyses. One speaks to the issue of whether the leaks measured by the test can be attributed to leaks in distribution lines. The second looks at how full tanks are kept in practice, which sheds some light on the relevance of assessing tank system leaks by filling tanks to capacity. The third discusses the possible impact of the typical filling behaviors reported on the estimates of percent of tank systems that leak in practice.

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[1] Due to the nature of the test, a "tank system leak" means a leak anywhere in the tank vessel, associated fill pipe, vent pipe, distribution lines, fittings, or connections.

I. TOTAL MEASUREMENT ERROR

The quality assurance retest data given in Section 7 offers a means of estimating the size of the error in the physical test measurement that is due to variation from one test occasion to another. It also indicates that the magnitude of this component of measurement error is substantially greater than the error measured for a single test result. In the usual statistical analysis of components of variance, the component measured for a single test result is the within-test variance, the component due to factors varying from test to test is the between-test variance, and their sum is the total variance of a single test result.

In order to estimate the total variance of a given test result, the average between-test variance must be estimated and added to the within-test variance estimated for that test. Two data sets were used to estimate the between-test variance: (a) the complete retest (34 cases) and (b) those test results from tanks which are clearly tight (observed volume change was a flow <u>into</u> the tank system of 0.0 to 0.2 gallons per hour, 133 cases). Data set (a) allows an estimate of total variability because both between-test and within-test components are involved in the test/retest but the underlying tank leak rate would not vary between test times. Data set (b) provides measures of leak which are due to random error alone. No liquid could actually flow into the tank during the test, since product in the tank was under test pressure. Thus, data set (b) also includes both components of variance. An estimate of total variance was computed from the measured volume changes in each data set, and the average within-test variance was estimated from the measured within-test variances for the same data sets. The between-test variance was then estimated by subtraction. Appendix D, Part V describes the estimation of between-test variance in more detail, specifying the model and formulas used.

The two sets of variance components estimates agreed very closely. In order to get a single estimate of between-test variance to use in adjusting the stated within-test variances, the two estimates were combined in a weighted average using the number of cases in the data set as the weights. The final estimate of between-test variance was 0.00199 gallons per hour squared, which in terms of gallons per hour is about 0.04 gallons per hour. (This figure has not been adjusted for test pressure as described below.) The estimated between-test variance was added to the square of each within-test standard error to get an estimated total measurement variance for each test result. The square root of this was then used as the total measurement standard error in the statistical hypothesis test described below.

II. ADJUSTING MEASURED LEAK RATES TO ACCOUNT FOR TEST PRESSURE

This subsection describes how leak rates were adjusted from test pressure to "typical" operating pressure (i.e., a set of standard assumed conditions) for tank systems judged to be leaking under test conditions. In order to conduct the physical test, increased hydrostatic pressure is placed on the tank system. As a consequence of this, any leak or flow through an orifice in the tank system would be increased over what would occur under the (smaller) pressure encountered in operation. Torricelli's form of Bernoulli's Law was used to calculate adjustments to the measured flow rates, under certain assumptions. It should be noted that the basis for the adjustment is the assumption that the measured flow represents a leak through an orifice or hole. Thus, it is not logically consistent to adjust test volume change rates for pressure unless the system, tank, or line was judged to be leaking, even though it would be computationally feasible to do so, and leak rate adjustments were made after the leak status had been determined.

Torricelli's and Bernoulli's Law assumes a flow is through an orifice with neither resistance nor turbulence. In our situation, this is not the case. The flow rates generally will be small enough so that the assumption of no turbulence is reasonable. However, in most cases, leaks will be through corroded sections and will be into soil which may present some resistance. The effect of resistance would be to lower the flow rate. How much the flow rate would be lowered under the different pressures is not known. Consequently, the effect of violation of these assumptions on the adjustment to leak rates is not known, but it is assumed to be negligible. There are some other implicit assumptions. These include that the orifice is constant, that the temperature and density do not change, and that the product is not viscous.

Since the test is conducted at elevated pressure, flow rates through any orifices will be larger under the test conditions than they would be under actual tank operation. The magnitude of the difference depends on a large number of variables. In particular, flow rates would vary by location of the hole in the tank (distance from the bottom), amount of fuel in the tank, and pressure of a water table part way up the tank. The adjustment factors would also vary with diameter of the tank. Since diesel tanks were tested at the same pressure (hence at a lower head-distance) as gasoline tanks, the adjustment also varies with fuel type because of the density difference. The assumed operating conditions used in calculating the adjustment factors (in addition to the basic assumptions of Bernoulli's law) are as follows:

- The water table is assumed to be below the bottom of the tank;
- The tank is assumed to be buried to the depth of three feet from grade to top of tank;
- Three tank diameters are assumed based upon volume, since actual diameter of tanks was not known);
- The average operating level of the tank is assumed to be half full; and
- The orifice or hole is assumed to be in the bottom of the tank.

The table below gives the adjustment factors used to adjust the estimated tank leak rates to these assumed standard operating conditions.

Adjustment factors for tank system leak rates

Tank diameter and associated volume ranges	Fuel type	
	Gasoline	Diesel
48" (0-1,100 gallons)	0.395	0.430
64" (1,101-7,000 gallons)	0.456	0.496
96" (7,001-15,000 gallons)	0.558	0.608

The factors were multiplied by the leak rates estimated by the physical tests to obtain the adjusted leak rates. The adjusted total measurement error is calculated by multiplying the total measurement standard error by the adjustment factor. Leaks measured by the line tests can be similarly adjusted either to the system test pressure or to assumed operating conditions. As is discussed in Section V below, valid distribution line tests could not be conducted on about 60 percent of the tank systems judged to be leaking. Further, distribution line leak rates accounted for very little of the system leak rate. Thus for the major findings in this report, system leak rates were adjusted directly to assumed operating conditions. See Part VII of Appendix D for details.

III. DETERMINATION OF LEAK STATUS

The physical leak measurement technique was described in Section 6. As a result of variability in the instrument readings and temperature adjustment process, the physical test does not produce an absolutely positive determination that a tank system either is leaking or is not leaking.[2] Instead, the test produces an estimated leak rate (or flow rate) along with a measure of uncertainty in the estimate (i.e., standard deviation of the leak rate).[3] The determination that a tank system is "leaking" is, therefore, a statistical judgment. The approach taken to leak status determination in this report is the statistical hypothesis testing model. The condition of "non-leaking" is represented by the hypothesis of a zero leak rate. The condition of leaking can then be stated as "having a measured leak rate that is significantly different from zero (flowing out of the tank system)."

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[2] In common practice, a tank is certified or not based on comparing the observed volume change rate to the NFPA standard of 0.05 gallons per hour.

[3] In some cases, the tank system test produced data that were judged to be unreliable. These are considered inconclusive results, by any decision rule. In other cases, unquantifiably large leaks were encountered. These are judged to be leaks by every decision rule.

The ideal statistical test should have:

- o A low probability of false alarm (i.e., for non-leaking tank systems, have a low probability of falsely calling the tank system leaking. This probability is also known as the significance level); and
- o Have a low probability of failing to detect a real leak. (This probability is one minus the power of the test.)

The probability of failing to detect a real leak depends on three factors: the size of the total measurement error of the tank system test, the size of the "real leak" one wishes to detect, and the probability of false alarm for the statistical test adopted. Recognizing the inherent conflict between objectives (a) and (b), above, we have considered two statistical tests with the attributes shown below:

	Probability of a false alarm for a tight tank system	Probability of failing to detect a leak of 0.10 gallons per hour[1] or more
Test 1	5 percent	5 percent
Test 2	1 percent	16 percent

[1] A true leak (i.e., adjusted for test pressure) of 0.10 gallons per hour would have the stated probability of detection on average, since the average adjusted total standard error is 0.030 gallons per hour.

We have selected Test 1 as the approach used in this study because it provides a low probability of a false alarm and provides an equally low chance of failing to detect a leak of 0.10 gallons per hour when one really exists. The null hypothesis was that the true leak rate is zero, and the alternative hypothesis was that there is a leak out of the tank. The test statistic was the observed volume change rate divided by its standard error. The null hypothesis was tested at a 5 percent significance level by comparing the test statistic to 1.645. If the test statistic was greater than this value, which is taken from the normal distribution, the tank was judged to be leaking. Table 8-1 shows the resulting estimates for percentage of tank systems leaking in the United States (35 percent using Test 1; 32 percent using Test 2). Note that the leak status determination is made before adjusting the leak rate to operating conditions for tank systems judged to be leaking by the statistical test.

Although the probability of failing to detect a leak of a given size (one minus the power) is reported on average for the statistical test used in the report, it is not guaranteed for each tank system tested. One way of specifying this probability as well as the probability of false alarm (significance level) is to run a second test which declares a tank system not leaking only if its measured flow rate is significantly greater than would be consistent with a stated actual leak rate. The final decision for a given tank system test would be inconclusive if the two statistical tests disagreed. Applying this approach with a five percent (or less) probability of failing to detect a leak of 0.10 gallons per hour (on an adjusted basis) or more does not noticeably change the results. The same tank systems are judged to be leaking as were under Test 1 above, and a few of the tank systems judged not leaking by Test 1 become inconclusive after applying the second rule (six cases in the raw data). The percent judged leaking calculated from this slightly reduced base remains 35 percent when rounded to the nearest percent. Thus the stated probability of failing to detect a fairly large leak does hold for most actual tests.

Table 8-1. Estimated percentage of underground motor fuel storage tank systems judged to be leaking under test conditions in the U.S., business and government sectors, using statistical tests

Leak status of tank system[1]	Test 1 (P_1 = .05 P_2 = .05)[2]	Test 2 (P_1 = .01 P_2 = .16)[2]
Percent judged to be leaking under test conditions[3]	35%	32%
Percent judged to be not leaking under test conditions	65%	68%

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[1] Under both tests, 5.5 percent of tanks tested had an inconclusive result. This includes cases where the data were judged unreliable and cases with a statistically significant measured inflow, indicating a vapor pocket or other problem with the test. They are not included in the base on which the percentages are figured.

[2] P_1 = Probability of a false alarm (i.e., falsely declaring a tight tank as leaking) on any one test.

P_2 = Probability of failing to detect a leak of 0.10 gallons per hour when one exists, using a value of 0.03 as the standard deviation of leak rate (the average adjusted total standard deviation)

[3] Includes cases with unquantifiably large leaks as well as with statistically significant leaks.

As a final comparison, we have looked at the estimate of percentage of leaking tank systems that would have resulted if we had used the 0.05 gallons per hour National Fire Protection Association criterion[4] (or "cut-off") as the critical value to distinguish tight or certifiable tank systems from not certifiable (leaking) tank systems. Although this is not a statistical test for detecting non-zero leak rates, it is included for comparison since many commercial tank testing companies apply this criterion, although they use various field test equipment and procedures. Results of applying this criterion are shown in Table 8-2. Applying the .05 gallons per hour cut-off to the estimated leak rates at test conditions results in an estimate of 42 percent of tank systems leaking. Adjusting the leak rates for these tank systems downwards to compensate for the pressure used in the test, as described in Section 8-II above, and applying the .05 gallons per hour cut-off to the adjusted leak rates results in 33 percent of tank systems leaking (because 21 percent of the leak rates initially greater than 0.05 gallons per hour were reduced to less than 0.05 gallons per hour as a result of the pressure adjustment).

These results are given solely as illustrative of what might be found if a national certification program were conducted. Each testing company conducts its tests under different pressures and with different sensitivities. The cut-off is then applied to the observed volume change rate without any pressure adjustment. The results using the NFPA criterion show a large fraction of the underground motor fuel storage tank systems in the United States to be leaking, even though the NFPA test ignores leaks below the

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[4] ANSI/NFPA 329, "Recommended Practices for Handling Leakage of Flammable and Combustible Liquids," Section 4-3.10.1, 1983.